School of Psychology

The Relationship between Visual and Auditory Attention Networks, Phonological Processing and Reading in Typically Developing and Disordered Reading Populations

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Declaration

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

The research presented and reported in this thesis was conducted in accordance with the National Health and Medical Research Council National Statement on Ethical Conduct in Human Research (2007) – updated July, 2018. The proposed research study received human research ethics approval from the Curtin University Human Research Ethics Committee, Approval Number HR04/2016. The research study received human research ethics approval from Western Australia Department of Education, Approval Number D16/0277635.

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Abstract

Both phonological processing and more central cognitive functions, including attention network functioning, are associated with the accuracy and speed of decoding words, critical to the process of reading. Attention network functions include alerting (modulating vigilance), orienting (locating information), and executive control (inhibiting distractions). The role of attention, and its possible interaction with phonological processing in influencing typically developing and disordered reading patterns is not well understood. To address this gap, this research, through a series of pilot, cross-sectional, longitudinal, and quasi-experimental studies, examined whether phonological processing skills mediate the role of attention in reading among primary school aged-students, including those with dyslexia.

A series of pilot studies developed and tested an auditory version of the visual attention network test (Rueda et al., 2004) to enable attention processes in the visual and auditory modalities to be compared. The findings from these pilot studies suggest that auditory attention network efficiency is most suitably assessed using a sound localisation rather than a pitch discrimination approach. The newly developed auditory attention test was then used in the cross-sectional, longitudinal, and quasi-experimental studies, in addition to the previously developed visual attention network test, and standardised tests of phonological processing, and reading accuracy. A reading speed task was also developed specifically for the current research to enable the assessment of exception word and non-word reading speed.

Study 1 hypothesised that the configuration of the mediation would differ based on the stage of reading. That is, for early stage readers, there would be a relationship between attention and reading mediated by phonological processing. In contrast, a direct, unmediated route between attention and reading was predicted for later stage readers. Therefore, a cross-sectional approach that included 72 early stage (aged 6 years to 7 years) and 70 later stage (aged 9 years to 10 years) readers was used to test for mediation effects to confirm the interactive view, based on stage of reading. Following up the children from Study 1, Study 2 focused on examining the stability of the mediation hypothesis using a longitudinal approach to determine the role of attention and phonological processing at Time 1 (T1) upon reading at Time 2

(T2), in 64 early stage readers (aged 7 years to 8 years) and 62 later stage readers (aged 10 years to 11 years).

Together, Study 1 (cross-sectional) and Study 2 (longitudinal) supported the hypothesis for early stage readers, and partially supported the hypothesis for later stage readers. That is, in early stage readers, auditory orienting was related to reading accuracy (Studies 1 and 2) and reading speed (Study 2) through phonological processing. There was some evidence that visual orienting might also be important for reading accuracy in early stage readers, but this effect was not as statistically robust compared to auditory orienting. In contrast, for later stage readers visual orienting was related to reading accuracy (Studies 1 and 2) and reading speed (Study 2) through phonological processing. At more advanced stages of reading, visual executive attention was meaningfully related to reading accuracy through phonological processing (Study 2). However, in addition to this indirect route, auditory orienting directly predicted reading accuracy at more advanced stages of reading for later stage readers (Study 2). This suggests that later stage readers eventually adopt both a mediated and unmediated route to reading accuracy, which differ based on attention modality.

Study 3 employed a quasi-experimental approach to examine group differences between children with developmental dyslexia (DD, 50 children aged 9 years to 10 years) and typically developing reading aged (RA, 50 children aged 6 years to 7 years) and chronological aged (CA, 50 children aged 9 years to 10 years) matched controls, in the pattern of relationship between the visual and auditory attention networks, phonological processing, and reading (accuracy and speed). RA and CA matched controls were drawn from a subset of the early and later stage readers, respectively, in Study 1. The hypothesis remained the same as Study 1 for the matched control groups. However, in line with the developmental deficit view of DD (e.g.,Valdois, Bosse, & Tainturier, 2004), it was predicted that although children with DD would exhibit a similar pattern of mediation as their RA matched controls, they would perform less efficiently on measures of attention, and more poorly on measures of phonological processing and reading. This hypothesis was partially supported. Moreover, in addition to the significant role of auditory orienting attention in predicting reading accuracy via phonological processing, as identified in the RA matched control group, children with DD rely upon at least four attention networks, including auditory executive control, to accomplish reading accuracy.The primary outcomes of this research include (a) a child auditory attention network test, which can be used to assess the efficiency of auditory alerting, orienting, and executive attention within a single 15-minute task, and (b) a more comprehensive understanding of how the interaction between visual and auditory attention networks, phonological processing, and reading operates based on reading stage and reading ability.

Theoretically, for typically developing reading, the findings from these series of studies show reading acquisition is not a purely automatic or implicit learning process, instead, reading involves the reliance upon attention resources as a child continues to develop proficiency, and the manner in which attention influences reading, particularly in relation to phonological processing, operates differently based on stage of reading development. Moreover, the results show that even in more proficient readers (later stage readers), at least some aspects of the influence of attention upon reading are still mediated by phonological processing. This is inconsistent with views that support a purely visual access to word recognition that is independent of phonological processing. Instead, the findings align with views that advocate for a fundamental role of phonological skill in reading. Regarding DD, the findings have provided support for a developmental deficit view of dyslexia, rather than the developmental lag hypothesis. In addition to this, the findings support the idea that children with DD have an overactive visual and auditory attention network, involving within and across modality interactions in all three attention networks – alerting, orienting, and executive attention – that are not observed in typically developing readers. These findings have supported a proposal for an attention network model of reading, which distinguishes between reading pathways based on reading ability and attention modality.

Practically, the findings will assist in informing remediation programmes of better approaches to improve and strengthen reading performance, for both typically developing children and children with DD. Moreover, determining the extent to which the attentional inefficiencies of children with DD is supramodal or modality specific will help advise the creation of learning strategies that are more individualised.

Glossary of Abbreviations

ANOVA	Analysis of Variance
ANT	Attention Network Test
BRIEF	The Behaviour Rating Inventory of Executive Function
CA	Chronological Age
cAANT-SL	Child Auditory Attention Network Test-Spatial Localisation
CC2	Castles and Coltheart Reading Test 2
cd	Difference Test Scaling Correction
CFA	Confirmatory Factor Analysis
CFI	Comparative Fit Index
CR	Composite Reliability
c0	Scaling Correction Factor for the Nested Model
c1	Scaling Correction Factor for the Comparison Model
CTOPP	The Comprehensive Test of Phonological Processing
cVANT	Child Visual Attention Network Test
DD	Developmental Dyslexia
df	Degrees of Freedom
d0	Degrees of Freedom in the Nested Model
d1	Degrees of Freedom in the Comparison Model
EMG	Electromyography
fMRI	Functional Magnetic Resonance Imaging
ISI	Inter-stimulus Interval
IQ	Intelligence Quotient
MIs	Modification Indices
ms	Millisecond (s)
PC	Passage Comprehension
RA	Reading Age
RAN	Rapid Automatised Naming
RMSEA	Root Mean Square Error of Approximation
RT	Reaction Time
T1 & T0	Chi-square Values for Nested and Comparison Model, respectively.
T1	Time 1

T2	Time 2
TLI	Tucker-Lewis Index
TONI- 4	Test of Non-Verbal Intelligence, Fourth Edition
TRd	Satorra-Bentler Scaled Chi-Square Difference Test
SEM	Structural Equation Modelling
SRMR	Standardised Root Mean Square Residual
WI	Word Identification
WRMT-III	The Woodcock Reading Mastery Tests, Third Edition

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Chapter 1 : Introduction

"It [reading] encompasses awareness of the most basic speech units of a language – phonemes ... The "awareness" component of the term is as important to the definition as the "phonological" component, for the skill is proposed to involve, not simply unconsciously discriminating speech sounds … but explicitly and deliberately processing and acting upon them." (Castles & Coltheart, 2004, p. 78)

Background

Reading, and learning to read, are cognitively demanding tasks. They require the reader to coordinate multiple tasks, including word recognition, blending different word parts, noting word order, and maintaining strategies for text comprehension (Adams, 1990). To be a skilled reader, one must be able to accurately and efficiently manage all these different components (Cartwright, 2012). So complex is the process of reading, that approximately 10% of children are classified as having DD, a difficulty with reading that is not explained by poor instruction or poor intelligence (Elliott & Grigorenko, 2014; Shaywitz & Shaywitz, 2008). Generally, models of learning to read are consistent with the idea that oral language functions, including semantics, grammar, and processing of phonological information, are critical to reading. To attain reading accuracy and proficiency, children must learn the mapping between printed words and their phonological codes, and in an alphabetic script, this often involves learning regular letter to sound rules to assist in learning this mapping relationship (Perry, Ziegler, & Zorzi, 2007). Although poor phonological processing skills have been identified as a primary deficit in people with DD, recent evidence indicates that more central cognitive functions, specifically, attention, may also be critical to reading acquisition (LaBerge & Samuels, 1974; Posner & Rothbart, 2007; Walcott, Scheemaker, & Bielski, 2010; Wlotko, Federmeier, & Kutas, 2012).

Attention involves the process by which information is coordinated in an efficient manner. It provides the tools that help readers to appropriately engage and disengage, as well as to ignore irrelevant information, while learning how to read as well as during the process of reading. An efficient attention system is especially important as reading requires cognitive resources that are provided by this system (LaBerge & Samuels, 1974; Petersen & Posner, 2012). The attention system is responsible for the regulation of processing of incoming stimuli for goal-oriented responding, involving mechanisms of (a) selective attention, the ability to appropriately choose relevant stimuli; (b) focusing attention, the ability to sustain attention to stimuli and appropriately disengage; and (c) modulating attention, which determines the extent to which selected stimuli will be processed (Alvarez & Emory, 2006; Johnson, 2002).

More recently, the influence of attention on the development of phonological processing skills has been examined (Dally, 2006; Dice & Schwanenflugel, 2012; Dittman, 2013; van de Sande, Segers, & Verhoeven, 2013). Generally, these studies have identified a pathway between attention and reading that is mediated through phonological processing in beginning readers. However, less is known about if, and how, such pathways operate among more skilled readers and readers with reading difficulties, such as DD. Moreover, the literature has focused predominantly on visual attention, and, to current knowledge, no study has comprehensively examined the indirect influence of attention upon reading via phonological processing in the auditory modality. Therefore, the current study focuses on advancing our knowledge of attention, in vision and audition, and its relation to phonological processing skills in both younger (early stage readers) and more fluent (later stage readers) typically developing children, as well as children with DD. An understanding of the pathways to reading is imperative, as this determines the most effective ways of teaching children how to read, as well as how DD might be diagnosed.

Research Aims

In both typically developing children and children with DD, research on the unique contribution of attention and phonological processing to reading has been well-documented (Hulme, Snowling, Caravolas, & Carroll, 2005; Nicolson & Fawcett, 2006; Vidyasagar & Pammer, 2010). Despite advances within reading research, as well as research examining reading difficulties, our current understanding of how attention mechanisms and phonological processing interact to influence reading is limited, and the details of this relationship remain controversial (Elliott & Grigorenko, 2014).

Consequently, the present doctoral programme of research aimed to employ the model of attention networks as proposed by Posner and Petersen (1990), in both the visual and auditory modalities, to explain the relationship between visual and auditory attention networks and phonological processing in reading, and to further examine this relationship among readers with DD. Therefore, the current study aimed to:

a) Develop a child-friendly auditory version of the attention network test (ANT) developed by Fan, McCandliss, Sommer, Raz, and Posner (2002) that is designed to assess the alerting, orienting, and executive component processes of attention.

b) Examine, using a cross-sectional design, the predictive relationship between the visual and auditory attention networks and reading, and whether this is mediated via phonological processing, across early versus later stages of reading acquisition.

c) Determine, longitudinally, the stability of the relationship between the visual and auditory attention networks and reading via phonological processing across early versus later stages of reading acquisition.

d) Examine, quasi-experimentally, group differences between typically developing and disordered reading populations (children with DD) in the relationship between the visual and auditory attention networks, phonological processing, and reading.

Overview of Thesis Chapters

The following provides an overview of the remaining chapters that comprise this thesis.

Chapter 2 reviews the literature that supports this research. Attention, phonological processing, and reading are examined, as well as other cognitive skills, including executive functions, predicted to be related to reading accuracy and reading speed.

Chapter 3 presents the methodology, including a description of the participants, the timeline of data collection, the design of the tasks employed, and procedures.

Chapter 4 presents the results of the cross-sectional study (Study 1), which examined the predictive relationship between the visual and auditory attention networks and reading, and whether this is mediated via phonological processing, across early versus later stages of reading acquisition.

Chapter 5 presents the results of the longitudinal study (Study 2), which examined the stability of the relationship between the visual and auditory attention networks and reading via phonological processing across early versus later stages of reading acquisition.

Chapter 6 presents the results of the quasi-experimental study (Study 3), which examined the group differences between typically developing and disordered reading populations (children with DD) in the relationship between the visual and auditory attention networks, phonological processing, and reading.

In Chapter 7, the results of all three studies are combined in a general discussion, referencing previous literature, including theories of reading and attention. The theoretical and clinical implications are discussed. Finally, the strengths and limitations of the research, and recommendations for future research are provided, followed by an overall conclusion to this programme of research.

Chapter 2 : Literature Review

Chapter Overview

This review is organised into five sections covering (a) a discussion of current reading models and the role that phonological processing skills play in the development of reading, (b) an overview of theories of the structure and function of the attention system, (c) current views of how attention contributes to reading, both uniquely and interactively with phonological processing skills in typically developing populations, (d) an overview of current views of DD, highlighting the possible role of attention deficits in causing DD, and (e) the significance of the current programme of research.

Models of Reading

Reading has long been viewed as a complex skill that involves multiple higher order processes (Cain & Parrila, 2014; Huey, 1908). A clear understanding of the pathways involved in reading are vital for improving reading outcomes (Panel, Health, & Development, 2000). Becoming a competent reader involves the transition from a process that is attention demanding to more efficient and fluent reading (Bryce, Whitebread, & Szűcs, 2015; Christopher et al., 2012; Speelman & Kirsner, 2005). Following the early work of Fries (1963), Hoover and Gough (1990), while acknowledging the complexity associated with reading, advanced the “simple view of reading”. This view posits that reading is the result of decoding and linguistic comprehension, and that *both* dimensions are a pre-requisite to achieve skilled reading. Decoding is said to involve the ability to use the phonological system for accurate and rapid conversion of printed words into phonological representations, thus providing access to accurate pronunciations and word meanings (Hoover & Gough, 1990). Conversely, linguistic comprehension involves using lexical information to understand the dynamics of the phonological system, as well as to understand word and sentence meaning (Hoover & Gough, 1990). Evidence suggests that both the decoding and comprehension processes can be separate, although, the correlation between the two might depend on stage of reading, with low correlations during the beginning stages, and higher correlations during later, more fluent stages (Chua, 2013; Stanovich, Cunningham, & Feeman, 1984).

Two key models of reading have dominated the literature: (a) the connectionist view (Harm & Seidenberg, 1999; Seidenberg, 2005) and, (b) the dual route model (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001). Both focus primarily on the learning of the alphabetic principle, involving the translation of graphemes (letters) to phonemes (sounds), that is, decoding in the Simple View.

Connectionist view of reading. The connectionist view of reading (Figure 2.1) proposes the existence of a trainable, interconnected network of orthographic and phonological units. The model predicts that over time, the orthographic input of trained words gradually become strongly connected with their phonological units, thus facilitating fluent word identification. Within connectionist models, information is cascaded along one route and all familiar and non-familiar (e.g., pronounceable non-words) words are read through this route, suggesting that there are no discrete pathways to reading (Harm & Seidenberg, 1999; Plaut, McClelland, Seidenberg, & Patterson, 1996). Subsequent exploration of a division between the orthographic and phonological pathways in activating word meaning has been investigated (Harm & Seidenberg, 2004). A comparison was conducted between a model that included a pathway from orthography to phonology to semantics, and a model with a direct pathway from orthography to semantics (Figure 2.1). Although the latter model improved in accuracy of word recognition with training, there was a comparable accuracy improvement in the first model that included phonology, implying that phonological processing contributed to this increase. This was interpreted as evidence of the importance of phonological processing to reading, even with training. More importantly, these findings were thought to confirm the proposed hypothesis that the activation of semantics is jointly determined both by orthographic and phonological information. Moreover, recent functional magnetic resonance imaging (fMRI) data suggest that a visual analysis of orthography is not simply added later in reading development; it is also important during the early stages of reading (Wise Younger, Tucker-Drob, & Booth, 2017).

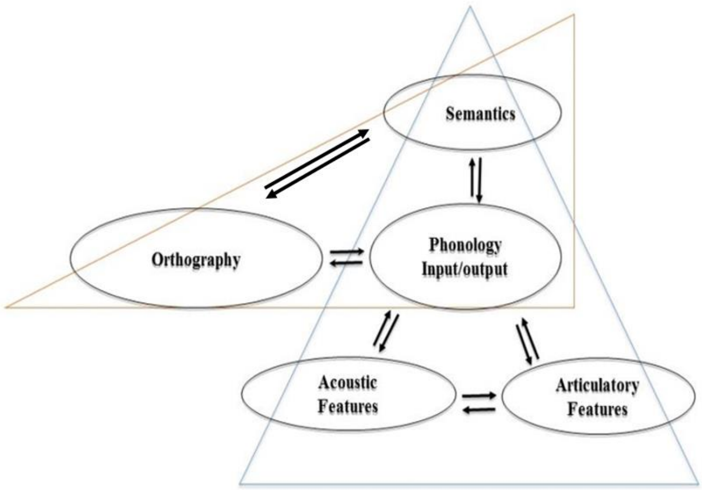


Figure 2.1. Connectionist models showing domains of mapping in speech (blue triangle) and reading (orange triangle) development after Plaut and Kello (1999) and Seidenberg and McClelland (1989).

The connectionist view suggests that the successful development of the relationship between orthography and phonology is dependent upon efficient visual attentional resources in the initial stages of reading. For example, the rapid parsing of graphemes during the segmentation process is likely to depend on visuo-spatial attention (Facoetti et al., 2006), and a pre-processing stage is proposed within which graphemes are sorted into slots (Plaut et al., 1996; Zorzi, Houghton, & Butterworth, 1998). It therefore seems reasonable to speculate that the assembly of phonological, as well as orthographic, information is dependent upon efficient attention processes that enable relevant reading to be efficiently executed (Raye, Johnson, Mitchell, Greene, & Johnson, 2007). This further suggests that weak or compromised phonological processing skills may have an adverse impact on reading (Garlock, Walley, & Metsala, 2001). The discussion of connectionism highlights the important role of attention, particularly in the earlier stages of reading development. While the connectionist view of reading has provided an important insight into reading, it has primarily advanced only one pathway to reading, regardless of developmental stage or skill level. In contrast to connectionist models, the dual-route model of reading proposes distinct differences in the structure of reading sub-skills for early and later stage readers.

Dual route-models of reading. The dual-route model of reading describes two routes to reading – sub-lexical and lexical (Jackson & Coltheart, 2001; Pritchard, Coltheart, Palethorpe, & Castles, 2012). The sub-lexical pathway relies upon developing grapheme to phoneme correspondence (GPC) rules, that are principally used to read (e.g., decoding into phonological form and mapping to lexical orthographic representations) new or unfamiliar words with regular pronunciations (e.g., FLANNEL) and pronounceable non-words (e.g., BLEANER) (Castles et al., 2009). In assessing the ability of a reader to use the sub-lexical route, tasks are given to ensure that the reader is only able to use this pathway (through the reading aloud of novel letter-strings in isolated non-words).

A second pathway, the lexical route, involves a more direct, unmediated access to a mental database of previously stored units of each word's orthographic pattern and their pronunciations, which in turn facilitates more fluent reading (Coltheart et al., 2001). This pathway is therefore used to accurately read familiar words, including exception words (e.g., 'CHOIR' and 'COUGH'), where the pronunciation is irregular. It has been further emphasised that associating a printed word (orthography) with its given pronunciation (phonology) is heavily dependent upon the initial development of visual (orthographic representations) and phonetic (phonological representations) forms, as well as the efficiency of the processes that facilitate the correct link between these two different representations (Hulme, Goetz, Gooch, Adams, & Snowling, 2007). Further refinements to the dual-route model generated evidence showing that, in addition to phonological mechanisms, visuo-spatial attention also plays a significant role in the process of grapheme-parsing. This involves dividing letter strings into their distinct graphemes (Perry et al., 2007). In assessing the ability of a reader to use the lexical route, tasks are given to ensure that the reader relies predominantly on this pathway, through the reading aloud of exception or irregular words.

Reading Routes and Stages of Reading Development

Beginning readers. The sub-lexical route (i.e., a phonologically mediated route), is generally used by beginning readers for establishing a mental lexicon, which supports the development of more competent and efficient reading (Aitchison, 2012; Maris & de Graaff Stoffers, 2009; Taft, 2013). This argument has been supported by observations of phonological recoding in beginning readers, as they sound out written symbols while reading (Dice & Schwanenflugel, 2012; Russell, Ukoumunne, Ryder, Golding, & Norwich, 2016; van de Sande et al., 2013). Evidence for this phonological recoding hypothesis has been demonstrated by varying the impact of different phonological variables (e.g., pronounceability, rhyme) on the nature of the recognition patterns of visually presented words (Leinenger, 2014; Rubenstein, Lewis, & Rubenstein, 1971). In line with this view, the activation-verification model of reading emphasises that a word’s phonological representations are the principal pathway to both locating and activating information from the mental lexicon (Jared & O’Donnell, 2017; Lukatela & Turvey, 1991; Van Orden, 1987).

However, the view that phonological recoding is necessary for reading has been refuted by evidence that people with congenital deafness, for example, present with typically developing reading abilities, even though they are unable to perform or have immense difficulty with grapheme to phoneme conversion (Baron, 2014; Goolkasian, 2012; Huie, 2010). Nevertheless, the general view is that while children very early in reading might identify particular words on the basis of some key visual features (e.g., the two parallel lines in the middle of "yellow"), further advancement in the capacity to read printed words involves going through a stage of learning letter to sound relationships (Ehri, 2013). In turn, recoding the letters into verbal (phonological) form to read aloud helps to access the meaning of the text. While the sounding out of words via the sub-lexical route is useful during the initial stages of reading, using this route is quite slow, and demanding on cognitive resources including attention; this route also does not ensure that words are read strategically and efficiently (Farrington-Flint, Coyne, Stiller, & Heath, 2008). To access a more direct route that enables more fluent reading, beginning readers must be consistently exposed to both the written word and its pronunciation concurrently, before acquiring direct lexical access (Henderson, 2018; Rayner, Pollatsek, Ashby, & Clifton Jr, 2012).

Fluent readers. Much of the debate about how reading is achieved has focused on whether reading at more fluent stages relies on a phonological or visually mediated access (Goswami, Ziegler, Dalton, & Schneider, 2001; Grainger, Lété, Bertand, Dufau, & Ziegler, 2012; Jared & O'Donnell, 2017; Sandak, Mencl, Frost, & Pugh, 2004). Over time, with reading practice, knowledge of the orthographic patterns of words (stored as orthographic recognition units) develops, and so the child can access the meaning of the word directly via visual analysis of the print and activation of the correct lexical orthographic units (Ehri, 2014; Henderson, 2018). Therefore, as children become more fluent, reading is considered to progress from print to meaning by way of minimal mediated access of phonological information (LaBerge & Samuels, 1974; Perfetti, 2013).

This visually mediated position (i.e., using the lexical route) suggests that any internal representation is unlikely to be phonological, and such representations are formed primarily based on visual information (Dehaene & Cohen, 2011; McCandliss, Cohen, & Dehaene, 2003). For example, Baron (1973) presented three conditions in which homophones were differentially presented in specific phrases. In the first condition, there was orthographic and phonological congruence between the homophones (MY NEW CAR, I KNEW HIM). In the second condition, there was phonological congruence, but orthographic incongruence for the homophone (MY KNEW CAR, I NEW HIM). In the third condition, there was both orthographic and phonological incongruence for the phrase (OUR NO CAR, KNEW I CAN'T). Participants were required to determine if the semantics of the phrase was legitimate. No significant differences were found between rejection time latencies for the second and third conditions. If phonological representations mediated the relationship between visual input and word recognition, Baron (1973) hypothesised that participants would access incongruent homophones via a route containing their correct spelling, then reject this information given the mismatch. A subsequent increase in the rejection times for the incongruent homophones would be expected. However, since this was not the case, Baron concluded that phonological mediation is not required for access to lexical information. Similarly, studies using lexical decision tasks showed that German readers, aged 8 years and 9 years, were more likely to indicate that pseudo-words (e.g., POAST) were real words, relative to control non-words (e.g., LOAST). However, there were no significant differences in accuracy rates between word types for English participants, suggesting that English children use orthographic familiarity to complete the task. In contrast, German children activate phonological information (Goswami et al., 2001). Likewise, French children across Grades 1 to 5 were more likely to classify pseudo-homophones as words, compared with control non-words, but the difference in how accurately each word type was read decreased as reading age increased. These findings suggest that the language of the reader influences the extent to which children rely on the phonological recoding strategy (Grainger et al., 2012).

However, Baron’s (1973) conclusion that phonological mediation is not necessary for reading might be flawed in more than one way. Firstly, although the reaction time (RT) latencies in Baron’s (1973) second and third conditions were not significantly different, there were more errors made in the phonological congruent/orthographic incongruent condition (MY KNEW CAR, I NEW HIM), compared to the condition where both phonological and orthographic were incongruent (OUR NO CAR, KNEW I CAN’T). The error data from Baron’s study can, in fact, be interpreted to illustrate that phonological recoding plays a role in lexical access because it is likely to reflect an interference of previous phonological knowledge, such that the word “NEW” was still interpreted as “KNEW” given the same pronunciation of both words. Simply put, participants would not have made more errors in the phonological congruent/orthographic incongruent conditions if they were not activating phonological information. Furthermore, participants were exposed to the words prior to the experiment and 16 times during the experiment. These repeated exposures might have increased their familiarity with the test items, which were then stored in memory, therefore leading to less reliance upon activating phonological information. This implies that reading experience is an important factor in determining if a phonologically mediated route to reading is adopted (Ehri, 2017; LaBerge & Samuels, 1974; Speelman & Kirsner, 2005).

Secondly, there is evidence that graphemic judgments themselves might be influenced by phonology. For example, although the findings of Kleiman (1975) support the claim that phonological mediation is not required to access lexical information, it is possible that the graphemic judgment task used in their study was influenced by phonology. Participants were presented, visually, with pairs of words and asked to judge whether they were phonologically similar (TICKLE-PICKLE) or phonologically dissimilar (HEARD-BEARD) (Kleiman, 1975). An advantage was observed, for the phonologically similar pairs. While both pairs looked the same, this finding can be interpreted as providing evidence that the influence of phonology helped with the grapheme judgement task.

In a subsequent study (Barron & Baron, 1977), participants, aged 6 years to 13 years, had to indicate whether or not a picture rhymed with a visually presented word, for example, a picture of a car with the written word “bar”. The researchers hypothesised that this task would encourage younger children to sound out words (i.e., using the sub-lexical route), and that there would be a significantly slower decoding speed for younger compared with older children. However, decoding times remained constant across each grade, suggesting no developmental shift from using phonological mediation to a visually mediated access. The authors concluded that the use of a visually-mediated access did not seem to depend on practice (experience), which later readers are thought to possess. However, an alternative view could be that the children comprising the sample were not young enough to identify any significant differences, or that the difficulty level of the words did not require that level of processing.

Other researchers have argued that in more fluent readers, the phonological loop that transforms visual information to auditory information does not disappear; however, reading involves less reliance on sound based transformation, and thus on the phonological loop (Rayner et al., 2012). Electromyography (EMG) feedback shows that during the reading process, more fluent readers still engage in sub-vocalisation even though there is no overt behaviour of such actions (Church, Coalson, Lugar, Petersen, & Schlaggar, 2008; Edfeldt, 1960; Sokolov, 1972; Turkeltaub, Gareau, Flowers, Zeffiro, & Eden, 2003). In a more recent study using a masked priming paradigm with children in Grade 1 to 5, pseudohomophone primes or non-word control primes preceded French words (Ziegler, Perry, & Zorzi, 2014). Participants produced faster lexical decisions for words preceded by pseudohomophone primes, a finding that did not significantly differ across grades (Ziegler et al., 2014). This was interpreted as evidence that phonology plays a fundamental role in reading, not only among early stage readers, but also at more fluent stages of reading. In contrast, findings from priming studies in English conflict with this conclusion. For example, in earlier studies using a similar experimental design to Ziegler et al. (2014), the pseudohomophone priming effect was not observed in English readers in Grade 3 to 5 (Booth, Perfetti, & MacWhinney, 1999; Davis, 1998).

Overall, the evidence for the view that word recognition relies solely upon either a phonological mediation or a visually mediated pathway is equivocal, in particular for English readers. The equivocal evidence for English readers could reflect variations in how English speaking children are taught the correspondence between spelling and sound. Alternatively, the conflicting findings might also indicate differences in reading ability and word familiarity. Subsequently, a reconcilist position has emerged where researchers have argued for a word recognition model comprising dual access to both the sub-lexical and lexical pathways, with readers drawing more heavily on phonological or visual mediation as required by their reading stage, orthography, word type, or task demand (see Castles, Rastle, & Nation, 2018 for an extensive review on the transition from early to novice reading).

Phonological Processing Skills: A Common Denominator in Reading Models

The role of phonological processing skills underpinning the development of reading is common to most models of reading development (Pritchard et al., 2012). Phonological processing includes an awareness of sounds (phonological awareness), the ability to retain sounds in memory (phonological memory), and the ability to rapidly retrieve sounds (rapid automatised naming or RAN), all of which contribute to the development of phonological representations of words in the lexicon (Biemiller, 2006; Furnes & Samuelsson, 2011; Spira, Bracken, & Fischel, 2005). Each skill has been found to contribute to children's developing word and non-word reading, comprising bivariate correlations within the range of .66 to .82 (Dally, 2006; Hulme & Snowling, 2009; Wagner, Torgesen, & Rashotte, 1994; Wagner & Torgesen, 1987). Moreover, each skill is classified as either an explicit (conscious) or implicit (automatic) focus on word sounds that can in turn either constrain or facilitate the development of skilled reading (Brunswick, Martin, & Rippon, 2012; Hulme & Snowling, 2009; Melby-Lervåg, Lyster, & Hulme, 2012; Wagner et al., 1994).

Explicit skill: Phonological awareness. Phonological awareness emerges around age 3, and usually matures by age 10 with complex sound deletion and sound segmentation abilities (Mattingly, 1972; Wagner et al., 1994). Common examples of measures that evaluate phonological awareness are elision, blending of sounds in words, and sound matching tasks. An elision task requires the deletion of a syllable, onset, rime, or phoneme at different positions (beginning, middle, or end) from orally presented words. For example, a participant would be instructed to say the word “cup”, without saying “/k/” or to say the word “driver”, without saying “/v/”. For a blending task, words are orally presented as sound units, such as onset-rimes (e.g., t-oy) and syllables (e.g., ma-th-e-ma-ti-cs) and a child is instructed to blend these oral units and say the full word. Finally, in a sound matching task, a child might be presented with four pictures (one primary picture and three response options). Participants are asked to listen to the beginning or ending sound of the primary picture and decide which of the three response options begin or end with the same sound (Wagner, Torgesen, & Rashotte, 1999). Higher scores generally indicate better phonological awareness skills (Anthony & Francis, 2005; Gillon, 2018).

Much of the evidence for the important role of phonological awareness in reading comes from reading age (RA) and chronological age (CA) matched design studies (Goswami & Bryant, 1989; Irannejad & Savage, 2012; Jackson & Butterfield, 1989; Jarrold & Citroen, 2013; Nimmo & Roodenrys, 2004). In these studies, older children with poor reading are matched on RA with younger, typically developing readers, and on CA and IQ with older, typically developing readers (Campbell & Stanley, 2015). The general finding is children with poor reading obtain significantly poorer phonological awareness (e.g., poorer at recognising phonological oddities) and reading scores compared with both RA and CA matched controls (Bowey, Cain, & Ryan, 1992; Eden, Olulade, Evans, Krafnick, & Alkire, 2015). However, caution should be taken when interpreting the results of matched control designs, since poor readers might also differ in other cognitive functions such as metacognitive skills, including executive functioning, which may account for observed differences (Johnston, Rugg, & Scott, 1987; Liberman, Shankweiler, Liberman, Fowler, & Fisher, 1977).

Young children’s phonological awareness skills have been shown to both concurrently and longitudinally predict non-word reading accuracy and the accuracy and speed of word identification in the early primary school years. Moreover, this influence of phonological awareness is still present, even after controlling for age, IQ, receptive and expressive vocabulary, and measures of print awareness (Hulme et al., 2005; Melby-Lervåg, 2012; Muter, Hulme, Snowling, & Stevenson, 2004). Some researchers have proposed that instead of phonological awareness, letter-knowledge is the strongest predictor of reading (Lervåg, Bråten, & Hulme, 2009; Muter et al., 2004). However, most studies assessing letter knowledge do not differentiate between letter-sound and letter-name, assessing them through a composite measure (Caravolas, Hulme, & Snowling, 2001; McBride-Chang, 1999). The importance of this distinction was observed in a longitudinal study of 132 Australian kindergarten children finding that, compared with letter-naming ($\beta = .13$), letter-sound knowledge ($\beta = .30$) was more predictive of word reading in Grade 1 (Dally, 2006). This supports the argument that the ability to distinguish between and among speech sounds is likely to be more important than knowing letter names.

Implicit skills: Phonological memory and RAN. In contrast to phonological awareness skills, phonological memory and RAN are implicit in nature (Alegria, Pignot, & Morais, 1982; Speelman & Kirsner, 2005; Wagner & Torgesen, 1987; Wolff, 2014). Phonological memory tasks evaluate the capacity to store phonological representations in short term memory (Baddeley, 2007, 2012; Fukuda, Woodman, & Vogel, 2015; Katz, Shankweiler, & Liberman, 1981; Matsukura & Vecera, 2015). For example, these tasks include 'memory for digits' where children are orally presented with a sequence of numbers (ranging from two to eight digits in length) and asked to repeat them in the order that they were heard, with the length of numbers being increased as the task progresses. Another method of evaluating phonological memory is through non-word repetition tasks, where participants are required to repeat a series of nonsense words (e.g., nigong, shaburiehuvoimush), with words becoming longer and more difficult as the task progresses. Higher scores indicate better phonological memory skills. Studies using structural equation modelling (SEM) support the argument that better phonological memory performance is associated with better reading outcomes, although controlling for phonological awareness significantly reduces this relationship (Melby-Lervåg & Hulme, 2010; Torgesen, 1988, 1998).

RAN tasks generally consist of a visual presentation of five familiar stimuli, such as colours, letters, digits, or objects, which are presented in random order 10 times across five rows (e.g., Denckla & Rudel, 1974). In the RAN task, participants are instructed to quickly name the stimuli from left to right. The time is then recorded, with lower scores indicating better (i.e., faster) performance. Across different orthographies, it has been found that performance on phonological memory and RAN tasks correlates with later reading development, after controlling for variations in IQ, verbal abilities, and orthographic knowledge (Caravolas et al., 2012; Lervåg et al., 2009; Parrila, Kirby, & McQuarrie, 2004).

Research has, however, shown that phonological awareness predicts early reading over and above phonological memory and RAN (Brady & Shankweiler, 2013; Melby-Lervåg, 2012), but as reading becomes proficient, RAN takes precedence, especially in predicting reading fluency (Araújo, Reis, Petersson, & Faísca, 2015; Cardoso-Martins & Pennington, 2004; Kirby, Parrila, & Pfeiffer, 2003; Wolf & Bowers, 1999). This outcome may reflect the fact that early reading, like phonological awareness, is more attention demanding and relies on strengths in explicit rather than implicit processing, or the fact that early reading depends heavily on letter to sound relationships and therefore phonological awareness (de Groot, van den Bos, Minnaert, & van der Meulen, 2014; Swanson, Trainin, Necoechea, & Hammill, 2003). However, as skilled reading develops, there is a developmentally changing role of phonological processing such that greater efficiency in encoding and accessing phonological representations, as measured by RAN and phonological memory, begins to facilitate accurate and fluent reading (de Groot et al., 2014). Moreover, the finding that RAN predicts reading fluency, while accounting for phonological awareness, suggests that there is a qualitatively different mechanism that underpins the varied roles of phonological processing skills in reading efficiency (Elliott & Grigorenko, 2014; Wolf & Bowers, 1999). That is, the gradual transition to more efficient reading is characterised by less reliance on sub-lexical processing skills and more upon automatised processes (LaBerge & Samuels, 1974; Speelman & Kirsner, 2005; Stanovich, 1980).

However, findings for the later stages of reading are mixed. It has been found that in transparent orthographies, including Dutch and Norwegian, as the reader becomes more proficient, they rely less on phonemic awareness, and RAN becomes a more sensitive measure. Lervåg et al. (2009) conducted a 3-year longitudinal study of 233 Norwegian children and found that RAN was significantly related to reading development. It was postulated that RAN may exert its influence on reading via tapping recognition circuits. However, this was conducted in a transparent orthography, so the findings might not apply to the English language, which is opaque. Cross-linguistic studies however demonstrate that across both transparent and opaque orthographies, RAN is a good long-term predictor of reading development. Nevertheless, findings remain controversial within the English orthography as the association between RAN and reading is thought to be present, because both constructs (i.e., RAN and reading) tap a global construct responsible for facilitating the speed of retrieving phonological representations from memory (Kirby et al., 2003; Landerl & Wimmer, 2008; Norton & Wolf, 2012). In this way, it might be that this global construct becomes the dominant, but distal, predictor of reading (Protopapas, Altani, & Georgiou, 2013; Rodríguez, van den Boer, Jiménez, & de Jong, 2015).This suggests that, in comparison with RAN, efficiency in accessing information from phonological memory might be a more important predictor of more skilled reading. Altogether, the findings demonstrate that (a) a broad range of phonological processing skills is fundamental to reading development, and (b) the changing and independent nature of these skills is influenced by reading stage. Intact phonological processing skills support the learning of words, and hence the ability to accurately and efficiently identify oral and written words. Accuracy and efficiency, in turn, enable more attention resources to be allocated to text comprehension, or to continuously obtain information from long-term memory (Adams, 1990; Astle & Scerif, 2011; Barrouillet, Bernardin, & Camos, 2004; Barrouillet, Gavens, Vergauwe, Gaillard, & Camos, 2009; Conway, Kane, & Engle, 2003; Lam, White-Schwoch, Zecker, Hornickel, & Kraus, 2017).

In recent years, the status of phonological processing skills in reading has been questioned (Hulme et al., 2005). While Castles and Coltheart (2004) spoke primarily about the status of phonological awareness, the logic of their argument and the issues they raised are also applicable to the other phonological processing skills (i.e., phonological memory and RAN). For the purpose of this doctoral research, the most relevant point from this debate is the view that instead of employing a narrow methodological criterion, approaches should be adopted to target the factors that may moderate the relationship between phonological processing skills and reading, within the context of longitudinal and experimental designs (Castles & Coltheart, 2004; Hulme et al., 2005).

Supporting this suggestion is evidence from an Australian sample of 132 kindergarteners (age ranged between 4 years and 10 months and 6 years and 6 months) showing a low to moderate impact of kindergarten word recognition upon phonological processing skills in Grade 1 (r = .24 to .62), with a less robust effect in Grade 2 (r = .20 to .55) (Dally, 2006). Subsequent regression analysis showed that, similar to Wagner et al. (1994), kindergarten word recognition, as measured by tasks that rely upon letter-sound knowledge, was found to significantly influence phonological awareness, but not RAN and phonological memory skills in Grade 2

(Dally, 2006). This suggests that phonological awareness might be more influenced by third party variables. In contrast, RAN and phonological memory are more stable linguistic traits (Dally, 2006). However, there is contrasting evidence of a double dissociation across English (aged 5 years) and Czech (aged 6 years) children regarding the relationship between letter-sound knowledge and the ability to manipulate phonemes (Caravolas et al., 2001). That is, knowledge of letter-sound does not imply that children will be good at phoneme manipulation, as children were found to be able to manipulate phonemes for which they had no previous knowledge of the associated letter-sound (McBride-Chang, 1999). More recently, it has also been noted that although phonological skills are important for reading, other factors, including general cognitive resources, should also be considered in relation to reading development (Castles et al., 2018).

Non-Linguistic (Cognitive) Factors Influencing Reading

Rapid and accurate access to word recognition has been previously linked to the efficiency of attention (Dice & Schwanenflugel, 2012; Dittman, 2013, 2016; LaBerge & Samuels, 1974). Attention refers to the regulation of processing incoming stimuli for goal-oriented responding. It comprises three principal mechanisms: (a) selective attention, which is the ability to appropriately choose relevant stimuli; (b) focusing attention, which is the ability to sustain attention to stimuli and appropriately disengage; and (c) modulating attention, which determines the extent to which selected stimuli will be processed (Alvarez & Emory, 2006; Johnson, 2002; Petersen & Posner, 2012).

There has been a previous distinction between whether phonological processing skills play a distal (indirect) or a proximal (direct) role in reading (Jackson & Coltheart, 2001). For example, if children who are found to have reading difficulties have an inefficient phonological system, this inefficiency can be considered a proximal cause of reading difficulties. The determinants, such as poor attention skills, which might have prevented the typical development of the phonological system, can be considered a distal cause of reading difficulties (Facoetti, 2001; Facoetti, Corradi, Ruffino, Gori, & Zorzi, 2010; Facoetti et al., 2003; Facoetti, Paganoni, Turatto, Marzola, & Mascetti, 2000; Facoetti et al., 2006; Franceschini, Gori, Ruffino, Pedrolli, & Facoetti, 2012; Ruffino, Gori, Boccardi, Molteni, & Facoetti, 2014). Alternatively, it is possible that the relationship between attention, phonological processing, and reading is reciprocal (e.g., Dally, 2006), such that attention could be a proximal cause, while phonological processing, more distal. Consequently, previous researchers have argued that more central cognitive functions, specifically attention, may be another critical component of reading (Arrington, Kulesz, Francis, Fletcher, & Barnes, 2014; Kamza, 2017; Waechter, Besner, & Stolz, 2011). It has also been suggested that a more comprehensive theory of reading development and its related difficulties, requires an understanding of *both* the linguistic and non-linguistic (cognitive) skills considered to contribute to accuracy and efficiency in reading (Posner & Rothbart, 2007). In the next section, the attention network theory will be introduced, in relation to previous early and later theories of attention. Then, the assessment of attention network efficiency in vision and audition will be discussed, considering the advantages of such an assessment in determining interactions within and across attention modality.

The Attention Network Theory

The early selection attention theory of Broadbent (1958) exemplifies a seminal understanding of the characteristics and function of attention. Given its limited capacity, attention is required to oversee the information processing system, and a brief sensory store (i.e., a bottleneck) filters information (Kahneman, 1973; Moray, 1967). In contrast to early selection theories, late selection perspectives argue that all information is processed before the bottleneck so that both physical and semantic information are analysed (Deutsch & Deutsch, 1963). In a series of experiments it was shown that, with appropriate instruction, participants could simultaneously perform two attention tasks without one interfering with the progress of the other, a finding that contrasts with early selection views (Neisser, 1976). Despite these competing views, the common principles of both early and late perspectives, which have influenced subsequent attention theories, are that the attention system (a) has a limited capacity, and (b) adopts different strategies to conserve its resources to enable more efficient performance. In subsequent years, however, behavioural and neuro-imaging evidence have supported the attention network theory. The theory argues that there are three distinct, but interrelated attention systems, each with their own distinct neural network (Fan et al., 2009; Posner & Petersen, 1990).

Firstly, the alerting network, which is responsible for stimuli selection and regulation arousal levels, develops in the first year of life and continues to develop throughout childhood and into adulthood. The alerting of attention makes further reference to the capacity to sustain a state of preparedness to facilitate more efficient information processing (Coull & Nobre, 1998; Mezzacappa, 2004). It involves both an internal and external change in the state of preparedness and plays a fundamental role in achieving optimal performance in the processes that involve higher cognitive tasks (Raz, 2004). The functions of alerting have been linked to parietal, frontal, and thalamic brain regions and is influenced by the norepinephrine system (Posner & Rothbart, 2007).

Secondly, the orienting network, which is responsible for the shifting of attention in response to incoming stimuli, acts similarly to a spotlight of attention (Flevaris, Bentin, & Robertson, 2010; Lamb, Robertson, & Knight, 1989). The spotlight theory of attention explains that managing competition from different sources is achieved by regulating both the location and number of items that receive attention at any given time (Enns & Di Lollo, 2000; LaBerge, Carlson, Williams, & Bunney, 1997; Pelli, 2008; Reynolds & Heeger, 2009; Sperling & Weichselgartner, 1995). The spotlight metaphor has been influential in views that seek to explain how the features of a stimulus determine if it is given attention. These properties might include familiarity, strength, and clarity of stimuli (Hakerem & Sutton, 1966; Kahneman, Beatty, & Pollack, 1967; Maltzman & Raskin, 1965; Sokolov, 1963; Unger, 1964; Zimny, Pawlick, & Saur, 1969). Treisman (1996) proposed that problems with information selection and binding can emerge based on the requirement to be knowledgeable in how to accurately combine multiple sources of information. For example, during reading, sensory information such as different features of letters arrive in parallel from different systems, and the reader is tasked with efficiently and accurately binding these features. Treisman (2006) later proposed that to correctly bind information, these features are relocated to a specific window. When the spotlight of attention is bound by this window, unselected information is excluded from processing. Then, the selected features are processed serially, in the first instance, and localised using focused attention. Finally, any information that has been found to be in this central fixation of attention is correctly bound. Therefore, orienting of attention, as well as focal attention functions as the "glue" that combines once separated features into one unit. The visual orienting network has been associated with brain areas involving the frontal eye fields, as well as the superior and inferior lobule, which are influenced by the cholinergic systems (Corbetta, Kincade, Ollinger, McAvoy, & Shulman, 2000).

Finally, the executive attention network, which is responsible for selective control through inhibition, emerges in the second year of life, and significantly improves between ages 4 and 7 years, after which conflict resolution skills gradually mature (Corbetta et al., 2000; Posner & Rothbart, 2007). Previous competition models of attention suggest that executive attention serves the purpose of regulating competition among multiple sources of information (Bundesen, 1987; Bundesen & Habekost, 2008). Deficits in the executive attention network might increase errors in processing resulting from attentional overload (Treisman & Gelade, 1980). This occurs when multiple items are briefly presented, thus preventing accurate selection of relevant information (Lavie, Beck, & Konstantinou, 2014; Lavie, Hirst, De Fockert, & Viding, 2004). These errors are called illusory conjunctions or wrongful combinations (e.g., combining the letter 'C' with the '|' symbol that is usually found on the letters such as 'D' and 'E') (Fallon, Mattiesing, Dolfen, Manohar, & Husain, 2018; Mitko, Prinzmetal, Esterman, & List, 2015; Treisman & Schmidt, 1982). Such combinations might result from having only a brief exposure to items or stronger competition from irrelevant information. The executive attention network has been linked to brain areas involving the anterior cingulate and lateral prefrontal cortex, which are influenced by the dopamine system (Posner & Rothbart, 2007).

The attention network test. The application of the Attention Network Theory motivated the construction of an attention network test (ANT), which has been employed across different age ranges. The task combines the spatial cueing paradigm and the flanker task, aimed at measuring attention network efficiency within a single paradigm, using RT and accuracy scores (Eriksen & Eriksen, 1974; Fan et al., 2002; Posner, 1980; Rueda et al., 2004). The task involves a target presentation (arrow) in three possible configurations: alone or flanked by incongruent or congruent distractors. These are preceded by four possible warning cues: no cue, an asterisk at either the centre of the screen (central cue), in both possible target locations (double cue), or in an always valid (spatial cue) location. Assessing attention network efficiency (called "alerting, orienting, or executive effects") is attained via a subtraction method that uses information from the RT data of accurate trials (Macleod et al., 2010). To obtain the alerting, orienting, and executive effects, there is a subtraction of the RT for the double cue, spatial cue, and congruent condition from the RT of the no cue, central cue, and incongruent condition, respectively. Previous research has generally found that the RTs for the double cue, spatial cue, and congruent conditions (facilitatory conditions) are significantly faster, compared to the RTs for the no cue, central cue, and incongruent conditions (inhibitory conditions) (Dagenbach & Carr, 1994; Macleod et al., 2010; McDonald & Ward, 1999; Pozuelos, Paz-Alonso, Castillo, Fuentes, & Rueda, 2014; Wright & Ward, 2008). Larger difference scores for the alerting and orienting networks are interpreted as higher efficiency within these networks. Note, however, that for the alerting effect, a larger score must be interpreted in light of the no cue RT. A very high no cue RT may mean a low level of engagement in the task or tonic alertness. Thus, when the no cue RT is high, one cannot interpret a large alerting score as necessarily a better use of the cue. However, in the absence of a high no cue RT, the larger the alerting cue the more successful an individual is in reaching the alert state following the cue. In contrast, smaller RT scores for the executive effect are generally interpreted as evidence of a more efficient executive attention network (Macleod et al., 2010; Posner, 2008; Weinbach & Henik, 2013).

A child version of the visual ANT (using fishes instead of arrows) demonstrated that, compared to pre-schoolers aged 4 to 6 years, early to middle childhood children, aged 7 to 10 years, had reduced RTs and increased accuracy, most notably in the orienting and executive attention circuits (Mezzacappa, 2004; Pozuelos et al., 2014; Rueda et al., 2004). Rueda et al. (2004) compared the findings of children with adults aged 19 to 41 years (using the adult version of the ANT), which revealed that no significant performance differences existed in executive attention circuit efficiency between 10-year olds and adults. However, the children had difficulties in alerting attention. Differential developmental patterns were also observed in participants, aged 61 to 87 years, where, although orienting was intact, ageing adversely affected the executive attention circuit, and like the young children in Rueda et al. (2004), older adults were less efficient in using alerting cues to aid task performance (Jennings, Dagenbach, Engle, & Funke, 2007). Altogether, these findings demonstrate that with development, the capacity to rapidly select, focus, and modulate becomes more efficient and, more critically, that differential developmental patterns exist for each circuit.

Attention network interactions within modality. One of the hallmarks of the attention network theory approach is determining if the networks display within-modality independence or interdependence. For example, initial work on the interaction among the three visual attention networks supported the idea that the networks were independent in both adults and children (Fan et al., 2002; Rueda et al., 2004). However, one of the first studies that was aimed specifically at examining interactions among attention networks in childhood (6–12 years), using a modified version of the visual ANT, found evidence to the contrary (Pozuelos et al., 2014). The modified task was the same as the child visual ANT, except that an auditory (instead of a visual) alerting cue was used. An interaction between alerting (elicited via the auditory cue) and visual orienting networks was found (Pozuelos et al., 2014). More specifically, alerting cues increased attention shifts, which in turn increased the efficiency of orienting attention. In addition, there was a reduced flanker effect when targets were preceded by spatial cues, indicating that spatial cues are beneficial for the resolution of conflict in children, a finding that aligns with adult populations (e.g., Callejas, Lupiánez, & Tudela, 2004). However, auditory alerting cues did not reduce the ability to efficiently resolve (visual) conflict, a finding that contrasts with adult populations using a similar modified version of the visual ANT (Callejas et al., 2004; Weinbach & Henik, 2011, 2012, 2013). In previously developed auditory versions of the ANT, similar interactions have been observed. For example, on the one hand, the auditory attention networks, assessed through pitch discrimination, were not found to be significantly correlated (Roberts, Summerfield, & Hall, 2006). In contrast, other evidence has shown an interaction between auditory alerting and orienting networks in tasks that assess the auditory attention networks using both frequency and spatial cue dimensions (Spagna, Mackie, & Fan, 2015). Note, however, that the interaction between auditory attention networks (e.g., Roberts et al., 2006; Spagna et al., 2015) was only found in an adult population, as an auditory ANT has not yet been developed for children. Nevertheless, these findings suggest that, under specific conditions, there are within-modality interactions among attention networks in vision and audition.

Attention network interactions across vision and audition. Previous research has further examined whether attention networks are modality specific or supramodal. Principal component analysis has shown that the visual orienting effect and the orienting measure of the Test of Attention in Listening are common indicators of the same factor, suggesting the supramodality of orienting attention (Stewart & Amitay, 2015). Conversely, Spagna et al. (2015) observed no evidence for a relationship between auditory and visual orienting, suggesting a modality specific orienting network. Similarly, inconsistencies have been identified with the alerting network, with evidence in favour of (Roberts et al., 2006), and against (Spagna et al., 2015), supramodality.

More consistent findings have been observed for a supramodal executive attention network (Roberts et al., 2006; Spagna et al., 2015; Stewart & Amitay, 2015). However, the literature distinguishes among different types of executive attention, which in turn might determine their distinct or supramodal nature. For example, neuro-imaging data and results from behavioral paradigms, including the Stroop task, have identified an executive attention network that initiates control, and another that maintains control (Alain, Arnott, Hevenor, Graham, & Grady, 2001; Arnott & Alain, 2011; Dosenbach, Fair, Cohen, Schlaggar, & Petersen, 2008; Rossi, Bichot, Desimone, & Ungerleider, 2007). The visual and auditory ANTs, as previously described, did not include feedback on experimental trials or variation in interstimulus interval (ISI). Thus, the nature of executive attention in these tasks aligns primarily with the maintenance rather than initiation of executive control (Dosenbach et al., 2008; Zhang, Hughes, & Rowe, 2012). Therefore, the observed supramodal nature of executive attention could reflect a supramodal maintenance of control function, rather than initiation of control (Finoia et al., 2015; Haroush, Deouell, & Hochstein, 2011).

Using an attention network framework to conceptualise attention is advantageous because it reflects an amalgamation of the functions of attention. A primary advantage of the ANT is that it permits the assessment of the efficiency of the three attention networks using a single 15-minute task. It also permits an investigation of their interactions, within and across modalities. This allows researchers to control for different types of attention while assessing how attention is related to other psychological phenomena, such as phonological processing and reading. However, one of the limitations of the framework is that it has focused primarily upon assessing the visual attention network. More recently, auditory ANTs have begun to be developed, but they are limited because their results are either confounded by the impact of verbal processing or elicit unreliable attention network effects (Roberts et al., 2006; Spagna et al., 2015). As such, they might be unreliable assessments of the auditory attention networks. Moreover, there are no current versions of an auditory ANT for school aged children.

Summary

Rather than debate the differences in the structure of attention systems, as did earlier and later attention selection theorists, the focus of the attention network theory has been directed at examining the efficiency of and interactions among specific attention networks, which potentially influence cognitive and linguistic functions. The theory proposes that although different attention systems have assigned roles, attention should not be viewed as a singular, limited capacity entity. Instead, attention represents an integrated system in which one system might bias the functioning of the other, within and across modality (Duncan, 1996). For example, although the visual attention system might have a limited capacity, this limitation can be overcome, since the system can learn to efficiently direct its resources by only using processes that are required to accurately and efficiently complete a task (Reynolds & Desimone, 2000).

Indeed, Watzl (2017) proposed that attention functions are a necessary preliminary for all human activity. Supporting this proposition are recent experiments exploring the role of attention in the processing of linguistic information (Reynolds & Besner, 2006, 2008; Risko, Stolz, & Besner, 2010; Waechter et al., 2011). The final sections of this review will focus on providing more support for this proposition, in particular, by firstly examining the relationship between attention and reading development in typically developing children and then in children with DD.

Attention and Reading in Typically Developing Populations

Previous views of attention and reading have argued that visual word recognition does not require attention (Augustinova & Ferrand, 2014; Jennings, 2015). In contrast, other studies have shown that there are different types of attention required by reading ─ some are essential (e.g., spatial and selective attention), but others, such as alerting, are only employed to augment performance (Posner & Rothbart, 2007; Reynolds & Besner, 2006; Waechter et al., 2011). Previous authors have distinguished between phasic and tonic alertness. On the one hand, phasic alertness refers to a response in the presence of an external warning cue, whereas tonic alertness refers to an internal control of vigilance that occurs without the provision of a cue (Posner, 2008; Sturm & Willmes, 2001; Weinbach & Henik, 2012). In contrast to phasic alertness, tonic alertness has been closely linked with sustained attention (Oken, Salinsky, & Elsas, 2006; Parasuraman, Warm, & See, 1998), and this type of attention has been previously linked to reading performance (Facoetti et al., 2000; Lam & Beale, 1991; Stern & Shalev, 2013). However, caution should be taken in interpreting studies that identify an association between sustained attention and reading, as one that synonymously reflects a relationship between alertness and reading. This is because the attention model proposed by Posner and Petersen (1990) has distinguished between the concepts of alertness and sustained attention, with the former including some level of cognitive processing.

Compared to alerting attention, the concept of orienting attention has been less controversial and there is also evidence for the role of orienting in reading. In a series of priming experiments, the influence of spatial attention upon reading words aloud was examined, while distractor words were simultaneously presented in the surrounding visual field (Waechter et al., 2011). The validity of spatial cues, which promoted either distributed or more focused spatial attention, was manipulated. It was observed that in the distributed attention condition (i.e., attention was distributed across target and distractor words), distractor effects were present. However, such effects were eliminated in the more focused, spatial attention condition. Waechter et al. (2011) concluded that spatial attention is fundamental for orthographic processing.

Similarly, McCann, Folk, and Johnston (1992) showed that spatial cues had a robust effect upon performance in a lexical decision task. In their experiment, on some trials, a small rectangle briefly preceded where a target (i.e., letter string) would be located (valid trials). On other trials, cues would be presented at the opposite location to where targets would be located (invalid trials). A robust spatial cuing effect was found, such that letter strings on valid trials were read significantly faster compared to invalid trials, for both high and low frequency words. McCann et al. concluded that spatial attention is necessary for the recognition of visually presented words, and that given the equivalent performance for both types of word frequencies, spatial attention has an impact upon processes that precede any influence of word frequency upon lexical processing (cf. Meschyan & Hernandez, 2002; Rastle, 2015). Despite the facilitatory effect of spatial cues, there is also evidence of inhibitory effects of the same cues, called the inhibition of return, at longer ISIs (e.g., > 750 ms). This effect is however useful in that it regulates the length of fixation time upon an object (Klein, 2000; Posner, Rafal, Choate, & Vaughan, 1985).

Another type of attention, central attention, which is defined as resources used for all general operations, such as memory retrieval and selection of responses, is used to successfully perform two tasks simultaneously (Ruthruff, Allen, Lien, & Grabbe, 2008). If automatic processes are involved in visual word recognition, then it should not be influenced by central attention. Using the psychological refractory paradigm (PRP), Reynolds and Besner (2006) examined the role that central attention plays in reading via both lexical and sub-lexical routes. They examined the processing of an input into the orthographic lexicon using a long-lag repetition paradigm that included a lag of 80 items. Their results suggest that there were no requirements for central attention, with the repetition of words using the lexical route (cf. Ruthruff et al., 2008). However, when sub-lexical processing was examined, including the repetition of non-words, they found that processing via this route recruited central attention. This suggested that more skilled reading does not require central attention while using a visually mediated access, but central attention is recruited during the assembly of a phonological code.

Executive attention is also important for word reading. For example, the ability to accurately read a mixed list of exception and non-words suggests that there is an internal parameter that regulates word recognition (Coltheart et al., 2001). An internal task switching parameter allows exception words, read by a lexical route, not to be subject to regularisation. In addition, this parameter allows non-words, read by a sub-lexical route, not to be subject to lexicalisation. Findings from task-switching paradigms support this proposition. In one experiment, reading route was manipulated by varying word type (Reynolds & Besner, 2006, 2008). The researchers reasoned that if an individual could control word recognition despite variations in word type, this would indicate that executive control is in fact related to reading, and that word reading is not an entirely automatic process. Hence, participants had to switch between the reading of regular words, irregular words, and non-words. Participants showed a switch cost when they switched between the reading of exception words and non-words, and vice-versa. This cost was, however, absent when switching between regular words and irregular words, as well as between regular words and non-words. These results support the view that executive attentional control is an important contributor to reading performance.

It is, however, important to note that attention is also influenced by other cognitive processes, of which executive functioning plays a key role. Executive functioning is distinguished from executive attention, in that it largely refers to supervisory processes that direct and control other cognitive processes. It includes functions such as inhibition, planning, emotional regulation, sequencing, monitoring, and working memory (Meltzer, 2007; Miyake et al., 2000). These processes have been found to contribute to both typically developing (Fernandez-Duque, Baird, & Posner, 2000; Yap & Balota, 2015) and disordered (Stoodley & Stein, 2013) reading. However, a previous meta-analysis using longitudinal data sets showed that attention skills contribute to reading achievement over and above the effects of executive functioning related skills (Duncan et al., 2007).

Attention, phonological processing, and reading in typically developing readers. In line with evidence supporting the association between attention and reading, LaBerge and Samuels (1974) proposed that the attention system provides additional activation to the acoustic and articulatory information contained in the phonological system. According to their view, the relationship between the (visual) attention and phonological systems might function in two distinct ways. The first is a connection between the two systems that is based on automatised visual units, whereas the second is based on connections between the two systems that are not yet well learnt, and therefore require additional attention for activation of the correct associations. Fluent reading is considered to develop with practice involving an organisation between the stimulus (visual code) and response (articulation) alongside rules that govern pronunciation. When a stimulus is presented, there is an excitation in the episodic memory where the rules about the code are stored, including its response code. The reading process via the phonological system involves a mediated route to reading. Over time, with repeated exposure, this mediated pathway is reduced in favour of a direct route between the stimulus and response code, as proposed by the dual-route model of reading (Coltheart et al., 2001). However, LaBerge and Samuels (1974) emphasised that although the direct route is used primarily in skilled reading, the mediating route through the episodic memory is oftentimes used as a method of checking or clarifying the responses that have been selected via the direct route.

More recently, the interaction between attention and phonological processing has been investigated through longitudinal designs. For example, pre-kindergarteners' emergent literacy skills, including phonological awareness and its relation to attention, have been assessed (Dally, 2006; Dice & Schwanenflugel, 2012; Walcott et al., 2010). Across these studies, the methods employed to assess children's attention control were obtained subjectively via teacher or parent ratings. SEM analysis, controlling for maternal education level, revealed that attention predicted reading via emergent literacy skills. Furthermore, inattentive behaviour was associated with poorer phoneme deletion skills, which in turn negatively impacted non-word decoding (Dally, 2006; Dice & Schwanenflugel, 2012). It has also been shown that pre-school inattentive behaviour is directly linked to printed word identification at later grade levels (Grades 1 and 2), after controlling for phonological processing skills (Dally, 2006; Dittman, 2013). In a similar longitudinal design that used a more objective attention measure (i.e., a flanker fish task), path analysis showed that the relationship between visual attentional self-control and word decoding was mediated by phonological awareness in Dutch kindergarteners,[1] aged 5 years to 7 years (van de Sande et al., 2013). Consequently, it was emphasised that examining direct relations between attention and decoding, without considering phonological awareness, may not provide a comprehensive understanding of reading, since phonological awareness is a pre-requisite for decoding (Brady & Shankweiler, 2013; de Groot et al., 2014).

In contrast, for children aged 5 years to 9 years, Gray, Rogers, Martinussen, and Tannock (2015) did not identify mediation when assessing whether inattention, measured through teacher reports, was related to reading outcome via working memory, measured using visuo-spatial and auditory storage tasks. There was also no direct relationship between inattention and reading accuracy and fluency. However, since the analysis was conducted across reading stages, with a sample comprising primarily early stage readers, this outcome might be explained by the previous finding that phonological awareness is a more robust predictor of reading in the early

[1] The direct relationship between attention and decoding was not significant. According to Baron and Kenny (1986), in such instances, the assessment of mediation would not be permissible. However, Hayes (2009) suggests that further analysis to test for mediation is admissible when bootstrapping based on at least 1,000 draws from the data is used.

stages, over and above working memory (Brady & Shankweiler, 2013; Melby-Lervåg & Hulme, 2010; Ziegler & Goswami, 2005).

Altogether, these studies concluded that attention influenced the development of linguistic skills, and that children with poor attention control had poorer reading outcomes. These findings suggest that there may exist a direct relationship between attention and reading, such that it affects learning orthographic codes, but given its general nature, it is likely that attention may also influence the development of other skills and processes related to reading. Overall, these longitudinal findings are important from a methodological viewpoint, given that both linguistic and cognitive skills develop simultaneously (Posner & Rothbart, 2007). Furthermore, longitudinal designs permit an assessment of the same variable at different time points to determine its predictive value, thereby determining whether such skills precede or are by-products of reading acquisition (Cole & Maxwell, 2003). While this methodological approach is advantageous in confirming the predictive value of relationships across time, it is more prone to conflicting results, compared with cross-sectional or experimental designs. This is because there exists a varied number of extraneous variables (e.g., different teaching methods, different instrumentation, and attrition) that might influence testing across different time points (Meyer, Wood, Hart, & Felton, 1998; Torgesen, Wagner, Rashotte, Burgess, & Hecht, 1997).

Attention and Reading in DD

Other evidence for the importance of examining both cognitive and linguistic factors in reading comes from research involving children with DD. While DD is viewed as a difficulty in learning to read, causal accounts have considered factors that range from linguistic to cognitive to genetic imbalances (Castles & Coltheart, 1993; Galaburda, Menard, & Rosen, 1994; Gomes, Wolfson, & Halperin, 2007; Goswami, 2011; Stein, 2003). Although much research has been conducted to explore the potential explanations of DD, the field is far from unified. An overview of some key theories of DD, and their limitations in adequately explaining the reading difficulty, is presented in Table 2.1. Despite the support for these theories, there is an overarching limitation in that they fail to account for the attentional deficits in children with DD. Despite the lack of consensus, the phonological deficit theory has remained the most prominent and well-supported explanation of DD.

Therefore, its role in the current research remains important and will be explored in more detail.

Phonological deficit theory. The key premise of the phonological deficit theory of DD is that a direct relationship exists between phonological processing impairment and reading acquisition difficulties (Castles & Friedmann, 2014; Finn et al., 2014; Liberman, Shankweiler, & Liberman, 1989; Morken, Helland, Hugdahl, & Specht, 2017; Ramus, 2003; Ramus & Szenkovits, 2008). Thus, DD is said to develop from a processing difficulty in the phonological system, which is related to the speech stream (Bird & Bishop, 1992; Boada & Pennington, 2006; Hulme & Snowling, 1992). For example, Elbro and Jensen (2005) showed that in comparison with their RA matched controls, children with DD performed poorer on measures of non-word reading and phoneme awareness. Furthermore, children with DD had longer RTs in the association of pseudo names to pictures, as well as weaker performance on a task assessing the acquisition of new phonological representations. Based on a body of research, in comparison with their typically developing RA and CA matched controls, children with DD perform more poorly on tasks that assess aspects of phonological processing, including non-word repetition, phonological memory, digit repetition, object naming, sound matching, phoneme awareness, sound blending, and rime judgments (Castles & Friedmann, 2014; Griffiths & Snowling, 2002; Jackson & Butterfield, 1989; Melby-Lervåg et al., 2012).

Despite the evidence for the phonological deficit theory, its status in explaining DD has been contested, primarily because it does not sufficiently account for other observed deficits in DD, such as those presented in Table 2.1. Moreover, similar to the proposed theories/hypotheses in Table 2.1, the phonological deficit theory does not provide an adequate account for the observed attention deficits in children with DD. Nevertheless, the lack of evidence to argue that a phonological awareness deficit is a key explanation of reading difficulties does not undermine its importance (Castles & Coltheart, 2004). Rather, it indicates that contextualising phonological skills to potential cognitive influences, rather than studying these skills in isolation, would be an important explanatory framework to better understand reading. For this doctoral research, it would be fruitful to further argue that even if a relationship between phonological processing and reading is identified, how would the status of this relationship be affected by findings of auditory and visual-spatial attentional inefficiencies in children with DD?

Table 2.1: Key Theories of DD and their Limitations

Theories/ Hypotheses	Key Authors	Key Arguments	Limitations
Double-Deficit Hypothesis	Denckla and Rudel (1974); Wolf and Bowers (1999); Wolf, Bowers, and Biddle (2000); Wolf and Obregón (1992)	A deficit exists in both phonological awareness and RAN, and any disruption in timing mechanisms interferes with the accuracy of lexical-phonological representations, which in turn affects reading. The speed of converting written symbols into a verbal form is independent of phonological processing skills and has a unique contribution to reading. Thus, in addition to phonological deficits, DD is also caused by a deficit in naming speed.	There are no accounts for the sensorimotor and attentional deficits in children with DD.
Sensorimotor Theories of DD		Phonological impairment is a result of a deficit in either auditory, visual, or motor functioning, or a combination of all these factors.	There is no account for the attentional deficits in children with DD.
• Rapid Auditory Processing	Tallal (1980); Tallal, Miller, and Fitch (1993)	Auditory: An impairment in bottom up auditory processes makes it difficult to develop well-established phonological representations.	
• Visual Processing	Nicolson and Fawcett (2006); Singleton and Trotter (2005)	Visual: A difficulty with the visual analysis of the written word, which is a pre-requisite for conversion of graphemes to phonemes.	
• Cerebellar Deficit Hypothesis	Bellebaum and Daum (2007); Marvel and Desmond (2012); Timmann et al. (2010)	Motor: An impairment in the cerebellum, a structure responsible for motor control, phonological memory, and language.	

Magnocellular Deficit Hypothesis	Galaburda et al. (1994);Livingstone, Rosen, Drislane, and Galaburda (1991); Stein and Walsh (1997); Trussell (1997)	A faulty visual input to the magnocellular system creates a visual deficit. Deficits from other modalities (e.g., auditory) are also considered as a source from which the phonological impairments of DD manifests.	There is no adequate explanation of the deficits in time judgements in people with DD. There is no account for the attentional deficits in children with DD.

Attentional deficits in DD. Studies using coherent dot motions, flicker detection, and oscillation timing tasks have demonstrated that skilled readers have a significantly shorter attention dwell (processing) time, compared with readers who have a reading difficulty (Amitay, Ben-Yehudah, Banai, & Ahissar, 2002; Tallal, 2006). Similarly, Hari and Renvall (2001) previously proposed the sluggish attentional shift (SAS) theory of dyslexia. This theory explains that the nature of the sluggish attentional shift results from prolonged amodal (across modalities) attentional dwell time, an outcome that has been investigated primarily in the Finnish and Italian context. Given the prolonged nature of this dwell time, the accurate development of cortical representations needed for reading might be impacted, thereby detrimentally impacting both reading and reading acquisition. The sluggish nature of attention in children with DD potentially helps to explain the deficits in visual and auditory processing that is advanced by the sensorimotor and magnocellular theories.

An important aspect of the SAS is its focus on determining the extent to which people with dyslexia are slow at reading. Rather surprisingly, it was observed that people with DD are able to rapidly process sounds that have a gap of less than 1 ms between them, and their performance, although slower than typically developing readers, was not significantly worse (Hari, Sääskilahti, Helenius, & Uutela, 1999; Witton, Richardson, Griffiths, Rees, & Green, 1997). However, given the finding that adults with DD show a prolonged attentional blink, and that children with DD distribute their attentional resources in a less focused way compared with typically developing children, perhaps because of poor executive attentional control, it has been argued that the neural circuity of people with dyslexia is not atypical. Instead, it is argued that the processing difficulty is related to a deficit in automatisation of attention (Cao, Bitan, Chou, Burman, & Booth, 2006; Facoetti et al., 2000; Hari & Renvall, 2001; Hari et al., 1999). Consequently, a primary argument of the SAS theory is that the observed sluggish attentional shifts reduce a rapid access to phonological representations, which are required for reading and reading acquisition. These phonological representations need an environment of stability for accurate development; the sluggish attentional shifts do not provide this optimal environment for people with DD (Castles & Friedmann, 2014; Tallal, 2006; Tallal et al., 1993).

Indeed, Facoetti and colleagues have been instrumental in providing evidence to show that visuo-spatial attention is related to reading deficits (Facoetti, 2001;

Facoetti, Corradi, et al., 2010; Facoetti et al., 2003; Facoetti & Molteni, 2001; Facoetti et al., 2000; Facoetti, Ruffino, Peru, Paganoni, & Chelazzi, 2008; Facoetti, Turatto, Lorusso, & Mascetti, 2001; Facoetti et al., 2006; Franceschini et al., 2012). One of their initial findings, using the visual spatial cuing paradigm, was that in comparison with typically developing readers, children with DD showed the expected costs and benefits from invalid and valid peripheral visual cues, respectively, in influencing their RT performance (Facoetti et al., 2000). However, when visual central cues were used, readers with dyslexia could appropriately use cues to significantly aid their performance, but, their RTs were significantly slower compared to the RTs of typically developing readers. Together, these findings suggest that the attentional deficit observed in children with DD may not be general. Instead, the results suggest that the deficit may be specific to the orienting of attention. Moreover, these findings align with a cognitive (orienting) deficit view, rather than a developmental lag in attentional control account since, although not significant, children with DD exhibited the same pattern of RTs for valid and invalid visual peripheral cues (i.e., faster RTs on valid cue trials), as their typically developing peers. Yet, in contrast with the typically developing readers, children with DD were unable to use these peripheral cues to their advantage (Francis, Shaywitz, Stuebing, Shaywitz, & Fletcher, 1996; Kuppen & Goswami, 2016; Ramus, 2014; Stanovich, Nathan, & Zolman, 1988; Valdois et al., 2004).

Group differences were also explored in how attentional resources were distributed in typically developing readers and readers with DD (Facoetti & Molteni, 2001). Participants were instructed to maintain focus on a visual fixation point ("+") on which a target (white dot) could be presented ('within attentional focus' conditions). Targets could also be located at different distances along the horizontal line of the fixation point ('out of attentional focus' conditions). Participants were also asked to quickly press a spacebar when the white dot appeared on the screen. The primary finding was that the visuo-spatial attention of children with DD was distributed asymmetrically, in line with the hypothesis of a visual gradient attentional disorder. In applying this to the context of decoding the written word, a visual gradient attentional disorder would deter readers with DD from focusing on the target word, thereby reducing their reading performance. In addition, the visual attention-span deficit hypothesis further explains that difficulties in visual attention are independent of phonological skills (Bosse, Tainturier, & Valdois, 2007).

Moreover, it has been shown that children with DD do not benefit from using auditory spatial cues to enhance their RT performance (Facoetti et al., 2003). Given the manifestations of problems with the auditory modality in this population, such as difficulties with discrimination of phonemes and acoustically similar words, these findings are likely to reflect the difficulties associated with the rapid shifting of attention among different sounds for accurate discrimination (Melby-Lervåg et al., 2012; Tallal, 1980). This finding is especially important, since evidence shows that phoneme identification is highly dependent upon the efficiency of auditory spatial distribution (Mondor & Bryden, 1991, 1992). However, other studies, using psychoacoustic and sensorimotor tasks, report no presence of low level auditory and visual processing deficits among readers with difficulty (Ramus, 2003; Rosen, 2003; White et al., 2006). One plausible explanation for this finding can be conceptualised as a developmental delay in the auditory or visual system such that, at the time of testing, the attention deficit had possibly normalised, but the effects would have already been detrimental to the development of phonological processing skills. Therefore, the effects of a deficient visual or auditory attention network, or both, may only predict reading through phonological processes. Given that poor attention may negatively affect information processing across development, thereby causing poor quality auditory or visual representations, or both, it is possible that people with DD will present with a cognitive architecture in which attention deficits impact upon reading via poor phonological and visual-orthographic processing. In turn, this constrains the development of more fluent reading. Moreover, deficits in the attention network may account for the other types of deficits proposed by other theories of DD, such as the deficient skills in RAN proposed by the double deficit theory (Katzir, Kim, Wolf, Morris, & Lovett, 2008) and sluggish motor functioning of the cerebellar hypothesis (Nicolson & Fawcett, 2007), which in themselves may depend upon an individual’s ability to maintain control over attention processes.

Altogether, these findings support the proposition that both visuo-spatial and auditory attention are important for the process of reading and its development. Furthermore, attention deficits might help to explain the observed deficits that are advanced by other theories of DD. However, these studies have not adequately examined the specific relationship between attention, phonological processing, and reading in children with DD. In fact, and quite surprisingly, research aimed at examining a possible interaction between attention and reading that is mediated through phonological processing in children with DD is sparse. In one study, Marzocchi, Ornaghi, and Barboglio (2009) found that measures of attention were poorer in Italian children with DD, aged 7 to 12 years, compared to their RA matched controls. However, there were no differences between the readers with DD and controls in attention after controlling for phonological processing skill, which was measured using digit span and rapid naming of digits. This study is, therefore, consistent with poor attention being associated with DD, but the relationship being mediated by deficits in phonological processing. It is possible that deficits in attention contributed to problems in phonological processing and hence reading. Similarly, in Dutch children with DD, aged 9 to 12 years, it was found that in addition to phonological processing, interference control, as measured by the Simon task (Craft & Simon, 1970) and a stop-signal task, predicted RAN, but not reading accuracy or fluency (Bexkens, Wildenberg, & Tijms, 2015). Unfortunately, as there were no consistent distinctions between the visual and auditory modality for each type of attention in these previous studies, the relative contribution of each modality to the association between attention and reading remains unclear. Nevertheless, these findings suggest that phonological processing skills might not be the only predictor in reading for children with DD, and that attention might determine how efficiently these skills are used.

Significance of the Current Programme of Research

A welcomed development concerning a unified explanation of DD has been advanced by multiple deficits or multi-factorial models (Menghini et al., 2010; Ramus et al., 2003). A multi-factorial approach is not aimed at undermining the important or possibly, the independent role that phonological processing or alternate deficits may play within reading acquisition. Rather, this approach aims to unify a disjointed field to provide a more effective way of identifying and remediating DD. Therefore, the focus of the current study is to demonstrate that although a multi-factorial explanation may best explain DD, there might be a specific reading pathway used by typically developing early and later stage readers; these pathways might differ based on reading stage and reading ability. Moreover, in response to using models of mediation, the current direction of research into reading development has started to focus on a relationship between attention and reading that is mediated by phonological processing skills. However, there are three principal limitations in the current research regarding this relationship.

Firstly, because the samples in previous studies (e.g., Dice & Schwanenflugel, 2012; Dittman, 2016; van de Sande et al., 2013) comprised only early stage readers (for example children aged 4 to 8 years), it cannot be determined if the finding that phonological processing mediates the relationship between attention and reading extends to older readers or which attention processes are important across development. It has been argued that beginning readers are tasked with learning to decode, which is slow and reliant on phonological processing skills, especially phonological awareness (Anderson, 1992; Castles & Coltheart, 2004; Logan, 2002; Stanovich, 1980). More advanced, fluent reading requires lexical restructuring and, arguably, the development of orthographic coding skills at this stage of reading will depend more upon more efficient attention mechanisms (Speelman & Kirsner, 2005). Reading performance at the later stage of reading development is less dependent on individual differences in phonological processing but on factors supporting direct and efficient activation of meaning from established orthographic units within the lexicon. Therefore, if individual differences in attention processes are related to reading at this later stage, this relationship will rely to a lesser extent on the specific impact that attention has on phonological processing. As well, since there is evidence of a developmentally changing role of phonological processing as reading becomes more skilled, it is possible that the underlying relationship between attention and phonological processing operates differentially according to reading stage (de Groot et al., 2014). As well, there is evidence of a developmentally changing role of attention networks (e.g., Posner, Rothbart, & Voelker, 2016), which could potentially influence the configuration of the mediation between attention, phonological processing, and reading. Moreover, it cannot be determined if the findings from studies with beginning readers would be the same for children with DD. Although there is some evidence of a relationship between attention and reading that is mediated via phonological processing in children with DD, research in this area, particularly for English readers, is very sparse. Therefore, an understanding of the confluence of attention and phonological processing in predicting reading development may help in explaining DD more comprehensively.

Secondly, the research to date is limited, because the approach to assessing attention has been principally measured subjectively, relying predominantly on parent or teacher reports without considering distinct attention processes and their development and possible interactions, as proposed in current views of attention, such as the attention network theory (Petersen & Posner, 2012). Despite the potential advantage of the attention network framework in understanding possible relationships between attention processes and reading, little research has examined if there is a changing role and impact of attention network mechanisms on reading across development. Therefore, while valuable, teacher and parent reports do not provide a method for more direct assessment of the components of attention, and for determining if such components interact to influence reading.

Thirdly, when attention was objectively assessed, it was only studied in vision (van de Sande et al., 2013). A uni-modal focus is problematic since there are differences between vision and audition. For example, the visual channel perceives stimuli for a much longer duration and has greater spatial organisation compared to stimuli received in the auditory channel (Gomes, Duff, Barnhardt, Barrett, & Ritter, 2007; Gomes, Molholm, Christodoulou, Ritter, & Cowan, 2000). Furthermore, children with reading difficulties show deficits in both visual and auditory attention, suggesting that an examination of attention in both modalities is important in the relationship with reading. As well, there is still no agreement regarding the nature of the auditory processing deficits among children with DD (Witton & Talcott, 2018). Moreover, excluding an assessment of auditory attention could omit invaluable information regarding how visual and auditory attention may operate differently according to reading stage. That is, during the early stages of reading one could expect auditory attention to play a dominant role, because the reader relies predominantly upon the sub-lexical reading route and phonological coding skills. In contrast, as reading becomes proficient, perhaps visual attention takes precedence because deriving meaning from text involves directly accessing lexical orthographic codes without first translating into phonological codes (Castles & Coltheart, 2004; Vidyasagar & Pammer, 2010). Taken together, much uncertainty still surrounds the extent to which attention directly impacts upon reading or the extent to which it is related to reading through a relationship with phonological processing, as well as how attention modality might affect the configuration of the mediation.

Chapter 3 : Methodology

Chapter Overview

This chapter provides a description of the research rationale, aims and hypotheses, participants, apparatus, measures, and procedures used in the three studies that comprise this programme of research.

Research Rationale

There is a lack of a comprehensive understanding regarding the interactive effects between attention and phonological processing concerning their combined role in reading among typically developing populations. Furthermore, the research of such interactive effects is even sparser for children with DD, especially within alphabetic scripts. The review of literature in Chapter 2 demonstrated that (a) over 30 decades of research have found that phonological processing reliably predicts reading development, (b) efficiency in attention processes are predicted as underpinning the development of phonological processing skills, which in turn influence reading in beginning readers; and, (c) by current knowledge, no research to date has employed the attention network approach to examine the relationship between visual and auditory attention networks, phonological processing, and reading in typically developing early and later stage children, or whether the interaction between these variables are evidenced in children with DD. Consequently, there is a gap in our understanding of the role that non-linguistic factors, such as attention, play in both typically developing reading and its specific role in DD. As such, cross-sectional, longitudinal, and quasi-experimental approaches will be used in this doctoral research to examine the possible relationship between attention networks, phonological processing, and reading. Figure 3.1 provides a brief overview of the studies that comprise this programme of research.

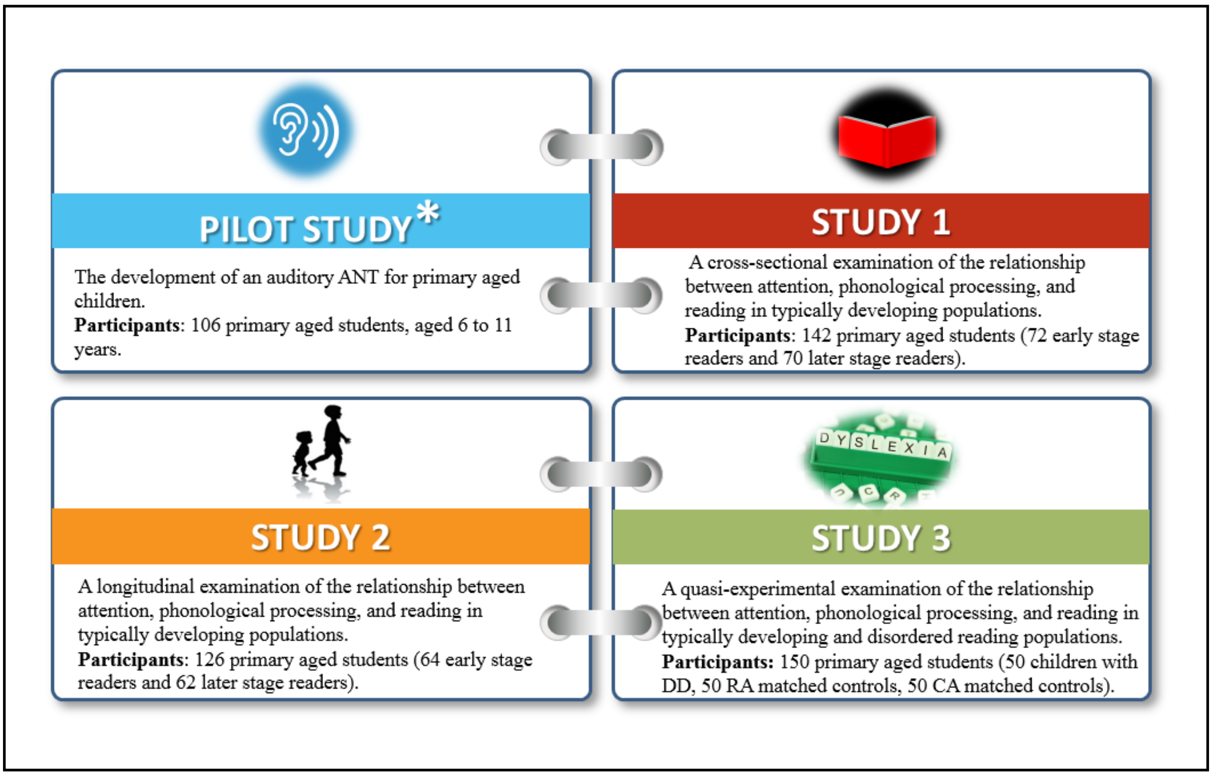


Figure 3.1. An overview of the studies that comprise the current thesis.
*Comprehensive details of the pilot study for the development of the auditory ANT designed for children are provided in Appendix A.

Aims and Hypotheses

Study 1. Using a cross-sectional design, Study 1 examined the relationship between the visual and auditory attention networks, phonological processing, and reading across early and later stages of reading. The aims of Study 1 were:

a) To determine if there was a group difference in the relationship between visual and auditory attention networks, phonological processing, and reading between typically developing early versus later stage readers.
b) To determine if there was a group difference in the modality of attention that influences reading (via phonological processing or directly) between early versus later stages readers.

Hypotheses. Study 1 hypothesised that (a) in the early stages of reading, phonological processing would mediate the relationship between attention and reading, but during later stages the mediated pathway would diminish and the direct pathway from attention to reading would be strengthened and; (b) in the early stages of reading, auditory attention would be more significant for reading, compared with visual attention, but during later stages visual attention would be more significant for reading, compared with auditory attention.

Study 2. Study 2 aimed to assess the stability in the pattern of mediation between the attention network and phonological processing in predicting reading at early and later stages of reading. Study 2 used a longitudinal design, following up participants from Study 1 to assess the mediation hypothesis.

***Hypotheses*.** Study 2 hypothesised that for early stage readers, phonological processing at Time 1 (T1) would mediate the relationship between attention at T1 and reading at T2. However, for later stage readers, attention at T1 would be a stronger predictor of reading at T2, in comparison with the indirect path through T1 phonological processing.

Study 3. Using a quasi-experimental design, Study 3 examined whether group differences existed in the relationship between visual and auditory attention networks, phonological processing, and reading between typically developing children and children with DD. The aims of Study 3 were:

a) To determine group differences in the relationship between visual and auditory attention networks, phonological processing, and reading in children with DD (aged 9 to 10 years) compared with their RA (aged 6 to 7 years) and CA (aged 9 to 10 years) matched controls. RA and CA matched controls were drawn from a subset of Study 1 participants.
b) To determine if there was a group difference in the modality of attention that influences reading (via phonological processing or directly) between children with DD and their typically developing matched controls.

Hypotheses. Study 3 hypothesised that the strength and modality of the hypothesised mediation pathway would vary as a function of group (same as that predicted for Study 1). As a reminder, Study 1 hypothesised that (a) in the early stages of reading (RA matched controls in Study 3), phonological processing would mediate the relationship between attention and reading, but during later stages (CA matched controls in Study 3) the mediated pathway would diminish and the direct pathway from attention to reading would be strengthened and; (b) in the early stages of reading, auditory attention would be more important for reading, compared with visual attention, but during later stages the visual attention would be more important, compared with auditory attention. In addition to this, it was further predicted that children with DD would present with a similar pattern of mediation as their RA matched controls, although, it was expected that they would perform less efficiently on measures of attention, and more poorly on measures of phonological processing and reading. As well, it was hypothesised that for children with DD, auditory attention would be more significant for reading compared with visual attention.

Methods

Participants-Typically developing (Study 1 and Study 2). Figure 3.2 provides an overview of the data collection process for the typically developing participants in Study 1 and Study 2. Typically developing participants, who were either in the early (Years 1 and 2) or later (Years 4 and 5) stages of reading development were recruited from six primary schools in the metropolitan area of Perth, Western Australia.[2] Inclusion criteria were as follows:

a) No history of developmental disorders, as reported by parents;
b) Normal hearing, normal or corrected-to normal-vision, as reported by parents;
c) A score of at least 85 on the Word Identification (WI) and Passage Comprehension (PC) sub-tests of the Woodcock Reading Mastery Test-Three [WRMT-III] (Woodcock, 2011), indicating typically developing reading readiness skills, and a score of at least 90 on the Test of Non-Verbal Intelligence-Four [TONI-4] (Brown, Sherbenou, & Johnsen, 2010).

The study was conducted in accordance with the ethical guidelines of the Curtin University Human Research Ethics Committee and the Western Australia Department of Education. After obtaining ethics approval, principals from 20 primary schools in Perth were contacted through email and telephone calls. All principals were provided with information about the studies (see Appendix B). Of the 20 schools, six principals provided consent to participate.

Parent and child information letters and consent forms (see Appendix B) were distributed to every student in Years 1 (aged 6.5 to 6.11 years), 2 (aged 7.0 to 8.0 years), 4 (aged 9.0 to 9.11 years) and, 5 (aged 10.0 to 10.5 years) across the six primary schools in Term 3 (July-September), 2016, Term 4 (October-December),

[2] In Western Australia, Years 1 and 2 refer to the child's 1st and 2nd year of primary schooling, respectively, after their first year (i.e., kindergarten) of formal schooling. Years 4 and 5 refer to a child's 4th and 5th year of primary schooling, respectively. Primary schooling in Western Australia ranges from Year 1 to Year 6.

2016, and Term 1, (February-April), 2017. One hundred and forty-eight parents and children provided written consent and assent, respectively, to participate.

Typically developing children who provided a parent/guardian consent form to participate met with the primary researcher (in a quiet room on their school grounds) in which the tasks to be completed were explained in a child-friendly form and to confirm their eligibility. In addition to their written assent, children were also asked to verbally confirm that they understood their requirements as a participant and were comfortable with participating. All children agreed to participate. If participants achieved age-appropriate scores (as described above in the first paragraph of the participants section in this chapter) on reading and IQ tasks in this first session, they were confirmed as a participant. Each participant completed one to two 30 to 40-minute sessions with the researcher in Term 3 (July-September), 2016, Term 4 (October-December), 2016, or Term 1 (February to April) and Term 2 (April-June), 2017.

The final typically developing sample comprised 142 primary-aged children, aged 6—10 years. The Year 1 and 2 group (early stage readers) comprised 72 students (*M* age = 7.08 years, *SD* = .63 years, 37 males), and the Year 4 and 5 group (later stage readers) comprised 70 students (*M* age = 10.01 years, *SD* = .53 years, 31 males). In the early stage reader group, 54 participants spoke only English at home, and 18 participants spoke a second language at home. These languages included Cantonese, Bengali, Gularati, Swahili, Mandarin, Khmer, Arabic, Dzongkha, Japanese, Serbian, Marathi, Urdu, Chinese, and German. In the later stage reader group, 56 participants spoke only English at home, and 14 participants spoke a second language at home. These languages included Malayalam, Tamil, Cantonese, Vietnamese, Hazaragi, Bengali, Mandarin, Khmer, Arabic, Dzongkha, and Japanese. Each student had been taught in English for at least 12 months after starting kindergarten in Australia.

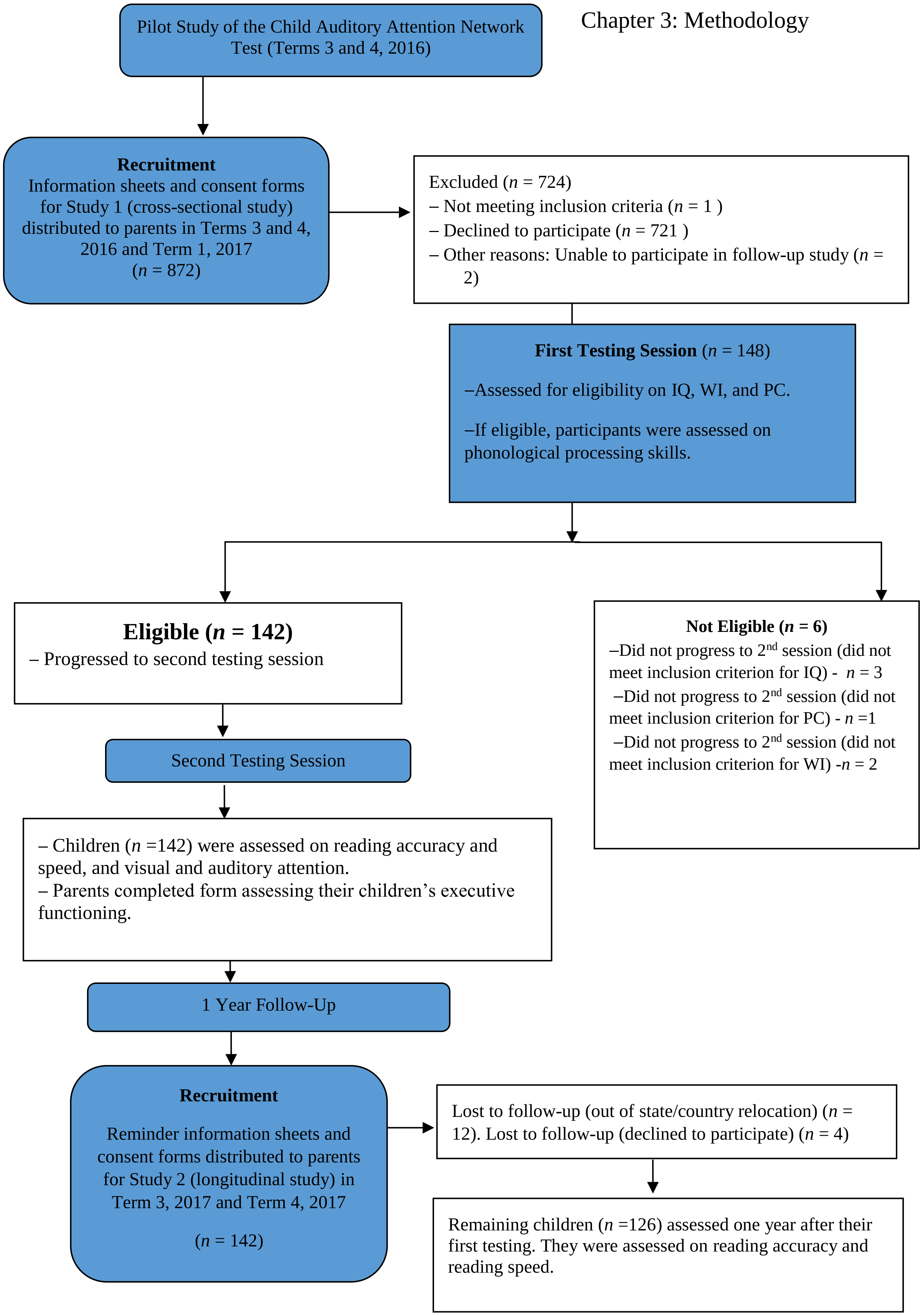


Figure 3.2. Timeline of data collection events for Study 1 (cross-sectional) and Study 2 (longitudinal). IQ = intelligence quotient; PC = passage comprehension; WI = word identification.

At the time of distribution of parent and children information sheet and consent form in Study 1, parents were also informed of the longitudinal nature of the study. Six months before the date of the first follow-up testing, principals were contacted to remind them of the longitudinal nature of the study, as well as the researcher's proposed testing plan. All principals agreed for their respective primary school to participate in the follow-up assessments (i.e., allowing the researcher to use a quiet room at school to conduct assessments). Then, a reminder was distributed to each parent and child, giving them the option to opt out of the follow-up assessments (see Appendix B). Unless stated otherwise, all eligibility criteria for inclusion in assessments from Study 1 applied to Study 2.

The final typically developing sample for Study 2 comprised 126 primary-aged children, aged 6─11 years. The Year 2 and 3 group (early stage readers) comprised 64 students (*M* age = 8.1 years, *SD* = .51 years, 33 males), and the Year 5 and 6 group (later stage readers) comprised 62 students (*M* age = 10.6 years, *SD* = .73 years, 28 males). Ninety-five participants spoke only English at home, and 31 participants spoke a second language at home. These languages included Cantonese, Bengali, Swahili, Mandarin, Khmer, Arabic, Dzongkha, Japanese, Serbian, Urdu, Chinese, and German. All parents were provided with a written non-diagnostic report of their child's performance on each standardised test, including recommendations if children exhibited unexpected scores within the below average range (see Appendix C).

Participants-Children with DD (Study 3). Figure 3.3 provides an overview of the data collection process for Study 3. Children with DD were recruited from two Language and Literacy Learning Centres (LLLC) in Perth, Western Australia. These centres provide intensive language-based intervention, by specialist tutors, for people with DD from kindergarten through to adulthood. Diagnosis of DD is reported after extensive psycho-educational assessments either by a Registered Psychologist or Speech Pathologist. Some of the typical tests used in these assessments examine verbal and non-verbal IQ, phonological processing skills, comprehension skills, and executive functioning. If no improvements in phonological processing and reading are observed after six months of intensive language-based intervention, then the label of DD is applied (American Psychiatric Association, 2013).

For participation in Study 3, eligible children (i.e., with an official diagnosis of DD) also needed to be within the range of 9 years, 0 months to 10 years, 5 months, have normal hearing, normal or corrected-to normal-vision, as reported by parents and English as their primary language.

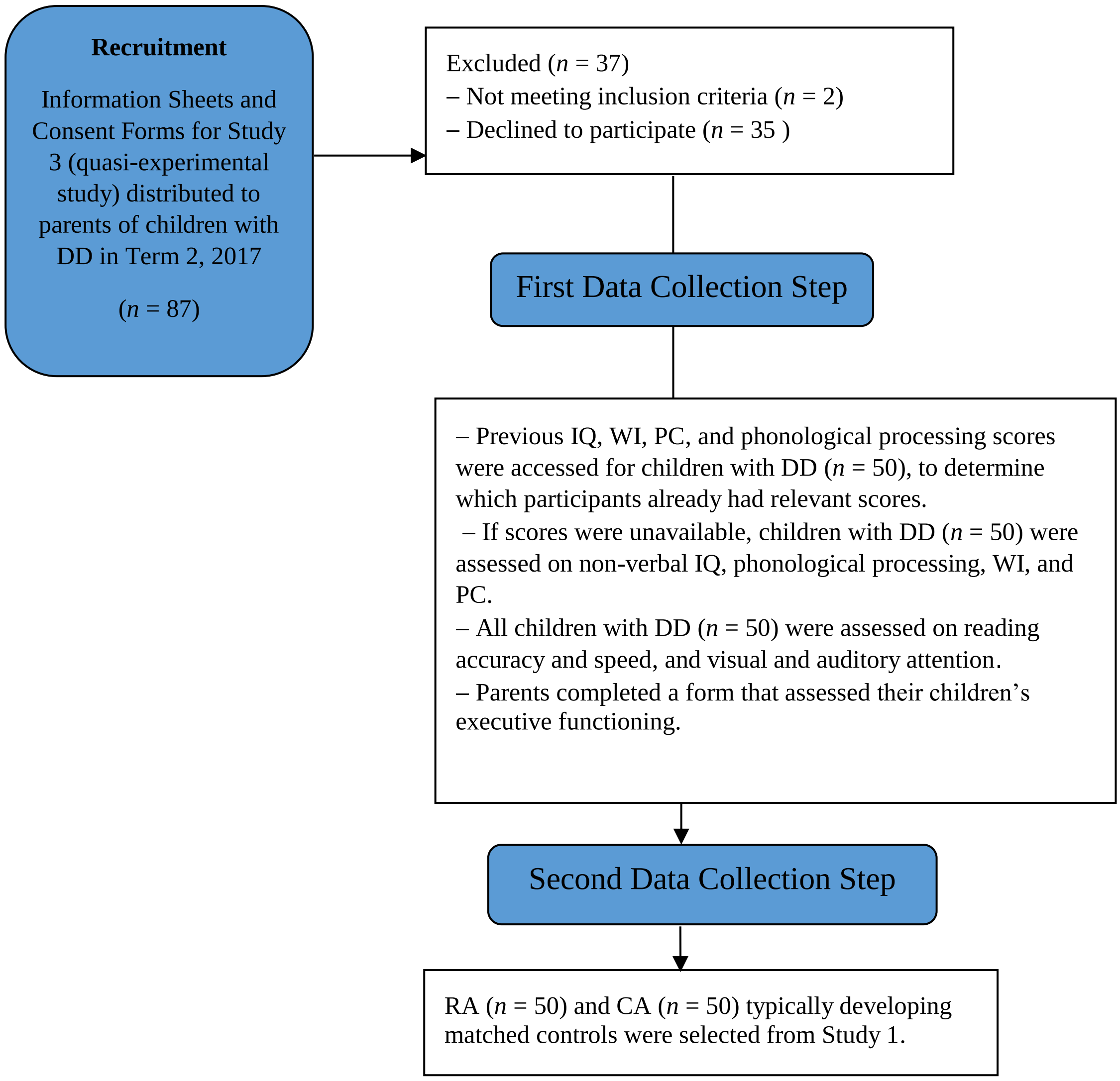


Figure 3.3. Timeline of data collection events for Study 3 (quasi-experimental study). IQ = intelligence quotient; PC = passage comprehension; WI = word identification.

To recruit children with DD, the researcher contacted or individually met with the Directors from two LLLCs to provide further details about the research studies and to obtain permission. Following confirmation of permission, a general email and flyer with the details of Study 3 was circulated by the Directors to all parents with eligible children from the two LLLCs. This information was distributed in Term 2 (April-July), 2017. Parents who were interested in participating made direct contact with the researcher. Following this, parent and children information letters and consent forms were distributed.

Fifty-two parents provided consent for their child/children to participate. However, two children were excluded because they also had a diagnosis of autism. All parents were given the option of doing the testing at home or in a quiet experimental room at Curtin University. Only one parent selected the option of assessment at Curtin University. The researcher met with each child and parent and explained the requirements in a child-friendly manner. If available, the researcher also obtained consent from parents to access previous reading, IQ, and phonological processing scores for each child. All parents agreed to this and made provisions where available. All assessments were conducted over a one-hour session (approximately), with appropriate breaks between each task. The final DD sample comprised 50 primary-aged children, aged 9 to 10 years (*M* age = 10 years, *SD* = .23 years, 24 males, *M* reading age = 7.5 years). All children with DD spoke only English at home.

For Study 3, 50 RA matched, and 50 CA matched typically developing matched controls were selected from Study 1. The Year 1 and 2 group (RA matched controls) comprised 50 students (*M* age = 7.2 years, *SD* = .41 years, 23 males; *M* reading age = 7.5 years), and the Year 4 and 5 group (CA matched controls) comprised 50 students (*M* age = 10 years, *SD* = .50, 24 males). In the RA matched control group, 41 participants spoke only English at home, and 9 participants spoke a second language at home. These languages included Cantonese, Mandarin, Khmer, Arabic, Dzongkha, and German. In the CA matched control group, 45 participants spoke only English at home, and 5 participants spoke a second language at home. These languages included Cantonese, Bengali, Swahili, Mandarin, and German.
All parents of children with DD were provided with a written non-diagnostic report of their child’s performance on each standardised test, including recommendations if children exhibited unexpected scores within the below average range (see Appendix C).

Apparatus, Stimuli, and Measures

Auditory stimuli were created using the Praat computer (Boersma & Weenink, 2016) software package and visual stimuli for the child visual ANT (cVANT) were the exact replication of Rueda et al. (2004). Visual and auditory stimulus reaction timing and data recording were controlled by an Acer Aspire E5-521 (15. 6” monitor) personal computer via Inquisit 4 (Borchert, 2015) and DmDx software (Forster & Forster, 2003), respectively. Auditory stimuli were presented via headphones (Logitech, Headset H151). SEM analyses were performed by M*plus* Version 5.2 (Muthén & Muthén, 2008), but descriptive and other inferential statistics were performed by SPSS 24 (Corp, 2016). The words for the reading accuracy task were printed on cards in Arial 36-point font. The back of the cards was numbered sequentially based on the number of words (1─120). The back was also colour coded such that numbers were placed in either a red (which represented regular words), blue (which represented irregular words), or yellow (which represented irregular words) circle.

TONI-4 (Form B). The TONI-4 (6 practice items and 60 test items) was individually administered, to screen for non-verbal intelligence, with an overall testing time of approximately 15─20 minutes. Testing was administered as per the standardised test guidelines. Its developers report validity and reliability scores within the range of .74 to .99 (Brown et al., 2010).

WRMT-III (Form A). The WI (accurate pronunciation of words), comprising 46 test items, and PC (provision of an appropriate response to complete a sentence), comprising 1 practice item and 38 test items, subtests were individually administered, with an overall testing time of approximately 15 minutes. Testing was administered as per the standardised test guidelines. Raw scores were converted to standard scores. Validity and reliability scores are reported to be within the range of .88 to .98 for WI, and .85 to .95 for PC (Woodcock, 2011).

cVANT. The cVANT was developed by Rueda et al. (2004) to assess the efficiency of the visual alerting, orienting, and executive attention networks in children. Although there are no consistent validity and reliability estimates provided by its original developers, the task has been used in different domains (e.g., see review of Macleod et al., 2010), and the expected attention network effects have been consistently observed. Assessing visual attention network efficiency (called "visual alerting, visual orienting, or visual executive effects") is attained via a subtraction method using the RT data of accurate trials (Macleod et al., 2010). To obtain the alerting, orienting, and executive effects, there is a subtraction of the RT for the double cue, spatial cue, and congruent condition from the RT of the no cue, central cue, and incongruent condition, respectively. Previous research has generally found that the RTs for the double cue, spatial cue, and congruent conditions (facilitatory conditions) are significantly faster, compared to the RTs for the no cue, central cue, and incongruent conditions (inhibitory conditions) (Dagenbach & Carr, 1994; Macleod et al., 2010; McDonald & Ward, 1999; Pozuelos, Paz-Alonso, Castillo, Fuentes, & Rueda, 2014; Wright & Ward, 2008). Larger difference scores for the alerting and orienting networks are interpreted as higher efficiency within these networks. Note, however, that for the alerting effect, a larger score must be interpreted in light of the no cue RT. A very high no cue RT may mean a low level of engagement in the task or tonic alertness. Thus, when the no cue RT is high, one cannot interpret a large alerting score as necessarily a better use of the cue. However, in the absence of a high no cue RT, the larger the alerting cue the more successful an individual is in reaching the alert state following the cue. In contrast, smaller RT scores for the executive effect is generally interpreted as evidence of a more efficient executive attention network (Macleod et al., 2010; Posner, 2008; Weinbach & Henik, 2013).

Child auditory ANT-spatial localisation (cAANT-SL). The cAANT-SL was designed, developed, and trialled across a series of experiments to ensure that the design was appropriate for the age group in the current series of studies.[3] The final version of the test, the cAANT-SL, was then used in the current studies. On each trial, participants listened to either a 400 ms dog bark (presented to the left or right ear with a SPL of 69.99 dB) or two 400 ms monaurally, sequentially presented barks. When two barks were presented, the first bark served as the target and the second bark as the flanker (distraction). Congruent and incongruent conditions were accomplished by presenting the two barks to the same ear (both target and distractor in left or right ear) or to different ears (target in left ear and distractor in right ear, vice versa), respectively, on different trials in a sequential manner with monaural presentation. This approach to developing the congruent and incongruent conditions

[3] Please see Appendix A for a series of experiments on the development of the cAANT-SL.

was similar to that used by Spagna et al. (2015). Participants were asked to determine the ear of the target bark using a key press. They were provided with 3000 ms to respond after target onset. Cue development was like Roberts et al. (2006), where two dichotically independent tones (560_600Hz or 600_560Hz) created the double cue, two dichotic tones of the same frequency (560Hz or 600Hz) created the central cue, and monaural tones (560Hz or 600Hz), to the left or right ear, created the spatial cue. All cues went through a spectral (hamming) filter so they had a pulse like sound. Cues lasted for 100 ms and were mid-frequency. Both target and cue stimuli had sampling frequencies of 44100 Hz and were saved as individual wav files. Assessing auditory attention network efficiency (called “auditory alerting, auditory orienting, or auditory executive effects”) is attained via the same subtraction method using the RT data of accurate trials, as described in the previous paragraph where the calculation of visual attention network effects is described.

Comprehensive Testing of Phonological Processing (CTOPP). The CTOPP, a 30-minute task, is one of the most widely used measures of phonological processing among children (Wagner et al., 1999). It includes an assessment of three oral language skills: phonological awareness, phonological memory and RAN. Firstly, phonological awareness was assessed through tasks that evaluate (a) the deletion of onset, rimes, or phonemes from orally presented words and; (b) the blending of sound units to form whole words. Together, each task resulted in a composite phonological awareness score. Secondly, phonological memory was assessed through tasks that evaluate memory for digits and non-words, which provides a composite phonological memory score. Finally, RAN was assessed through tasks that evaluate the rapid naming of randomly presented colours and objects (children aged 6 years) or digits and letters (children older than 6 years), which provides a composite RAN score. Each task was administered according to standardised guidelines provided in the manual and results in individual subtest standard scores that are used to compute each composite score. Its developers have reported internal consistency estimates that exceed .80, and test–retest coefficients within the range of .70 to .92. The developers of the CTOPP have also reported split-half reliability estimates for each composite for early and later stages of reading, as defined by the current research (Wagner et al., 1999). For early stage readers (mean age of 7 years), the following reliability estimates apply: phonological awareness (.92), phonological memory (.86), and RAN (.87). For later stage readers (mean age of 10 years) the following reliability estimates apply: phonological awareness (.92), phonological memory (.84), and RAN (.93).

Castles and Coltheart Test 2 (CC2). The CC2 is a 15-minute standardised, single word reading accuracy test developed by Castles et al. (2009), for children aged 6 years to 11 year 5 months. Details of the norming procedure for use among an Australian sample are extensively described in Castles et al. (2009). The CC2 assesses the capability to use grapheme-phoneme correspondence rules (sub-lexical route) to the reading of regular and non-words. It also assesses the ability to apply print to speech rules (lexical route) to the reading of exception words (Coltheart et al., 2001). Testing was administered according to standardised guidelines, and results in *z*-scores that are computed based on the means and standard deviations for each age group. Its developers have previously reported split half reliability estimates for each word type (regular word, $r = .85$; exception word, $r = .84$; and non-words, $r = .90$).

Reading speed task. The reading speed task, developed specifically for the present research, is a 5-minute, 48-item task that assesses the ability to efficiently recognise exception words and non-words. Together, these words assess reading speed via the lexical and sub-lexical routes. There were 2468 words that were generated from the Medical Research Council (MRC) Psycholinguistic Database (Coltheart, 1981), with the search criteria set to words with 2 to 6 phonemes, 1 to 2 syllables, and 4 to 7 letters. The Kučera-Francis (KF) written frequency criterion was set to a range of 1 to 3,000,000. Familiarity rating ranged between 100 (minimum) to 700 (maximum). Of these, 27 exception words (3 words allocated for practice trials), with an age of acquisition between 1.4 years and 3.5 years were selected. Some examples included in the final exception word list included *house, enough,* and *thought*. The selected words had a KF written frequency ranging from 104 to 1617. Non-words were then developed by changing the initial consonant or consonant clusters in 24 additional words from the above-mentioned database, using the previously described search criteria. Each non-word (for both practice and experimental words) was matched to each exception words based on the number of letters. Some examples comprising the final non-word list included *drig*, *cland*, *strill*, and *drapple*. The non-words were developed in a way that ensured, as best as possible, that there was only one single correct pronunciation for each word. Each word was presented randomly in a single task and participants had a 6000 ms second period within which to name each word. Scores were the average RT of correct items for each word type. A brief overview of the pilot study to test the difficulty of this task is presented in Appendix D. As well, a complete list of words used in the final reading speed task is provided in Appendix D.

Behaviour Rating Inventory of Executive Function (BRIEF). The BRIEF was administered and completed within 5 to 10 minutes in a paper and pencil format by parents (Gioia, Isquith, Guy, & Kenworthy, 2000). It measures three sub-constructs of executive functions: (a) behaviour regulation index, which is assessed by the summation of items that evaluate inhibition, shifting, and emotional control; (b) metacognition index, which is assessed by the summation of items that evaluate the capacity to retain information in working memory, initiate, plan, organise materials, and monitor tasks; and (c) global executive composite, which is evaluated by a summation of the BRI and MI. Parents were asked to rate each item on the BRIEF on a 3 point Likert type scale (*1 = Never, 2 = Sometimes and 3 = Often*) according to how much of a problem that behaviour had been over the last 6 months. Total scores for the behaviour regulation index and metacognition index were obtained by summing responses of items contributing to the assessment of each sub-construct. A BRIEF score over 65 indicates poor executive functioning. The test–retest reliability for the BRIEF scale yielded scores within the range of .79 to .89, internal consistency yielded scores within the range of .80 to .98, and, content, construct and criterion validity have been established.

Procedure

All typically developing participants were screened to confirm a non-verbal IQ score at or above 90 using the TONI-4, and a reading (WI and PC) score at or above 85 using the WRMT-III. Children were individually assessed in a quiet room at their school during typical school hours or at home after school hours at suitable times negotiated with parents or teachers.

For Study 1, testing was conducted across two sessions, with the first session comprising administration of the TONI-4, WRMT-III, and CTOPP. The second session comprised the administration of the CC2 (pencil and paper administration), the reading speed task, the cVANT, and the cAANT-SL. The attention tasks were administered in a counterbalanced fashion. Parents were provided with the BRIEF after the completion of the second session. For Study 2, the CC2 and the reading speed tasks were administered.

For Study 3, the non-verbal IQ task, WRMT-III-WI and PC task, CC2 task, reading speed task, cVANT, and the cAANT-SL were administered. For the participants with DD, previous IQ, reading and CTOPP scores were accessed, with the permission of parents, when available. The CTOPP was administered if phonological processing skills (within the last 2 years) were not previously assessed. Seven participants did not have a previous CTOPP assessment. Parents were also asked to complete the BRIEF.

cVANT. Participants were administered the child version of the visual ANT (Rueda et al., 2004). Participants were instructed that they would be required to feed a hungry fish and they needed to respond as quickly and accurately as they could to the direction (left or right) of the middle fish. Responses were made via the keyboard using the “E” (left) and “I” (right) keys. Participants were advised that on some trials, the fish would be presented alone (pointing either left or right) and at other times, the target fish would be flanked by 4 other fishes that would be pointing in the same or opposite direction. They were instructed to focus only on the fish in the middle. Participants were further advised that this middle fish would be presented either above or below a cross (“+”). They were instructed to maintain fixation on this cross throughout the experiment. Finally, participants were advised that one or two black dot (s) may appear before the fishes and that these were cues to inform them that the target fish would soon appear. It was emphasised that sometimes the cues would indicate where the target fish would be presented on the screen.

Figure 3.4 illustrates the configuration of the cVANT, cue conditions, target conditions, and an example of the procedure. Each trial began with a fixation period that ranged between 400─1600 ms. Then, a warning cue (none, double cue, central cue, or spatial cue) was presented for 150 ms, followed by a short fixation period of 450 ms, followed by target presentation. The target fish was presented in three possible conditions. In the neutral condition, target fishes were presented alone, either above or below a fixation point. In the congruent condition, the flanker fishes were pointed in the same direction as the target. In the incongruent condition, the flanker fishes were pointed in the opposite direction of the target. Throughout the task the target fish was (a) pointing left or right, and (b) above or below a fixation point (+) in equal proportion. The target fish remained on the screen until a response was detected; participants were given 1700 ms to respond. Accuracy and RTs were measured and recorded. There was a post target fixation period for a variable duration, after which, the next trial started. Visual and auditory feedback were provided only on practice trials. If the participant responded correctly, the target fish would blow bubbles and a child recording saying "Woohoo" was heard. If their response was incorrect, a single tone, without a fish display, was heard. Each trial lasted for 4100 ms. Throughout the experiment, the background colour was magenta and the colour of the fishes was yellow. The cVANT comprised 144 trials across three experimental blocks. Each trial represented one of 12 conditions, that is, four cue conditions (none, double, central, and spatial) X three target conditions (neutral, congruent, and incongruent) in equal proportion. A block of practice trials, which took approximately 3 minutes, preceded the experimental blocks. Each block comprised 48 trials and the entire task took approximately 15 minutes to complete. Target direction, target location, and cue type were randomly presented within experimental blocks.

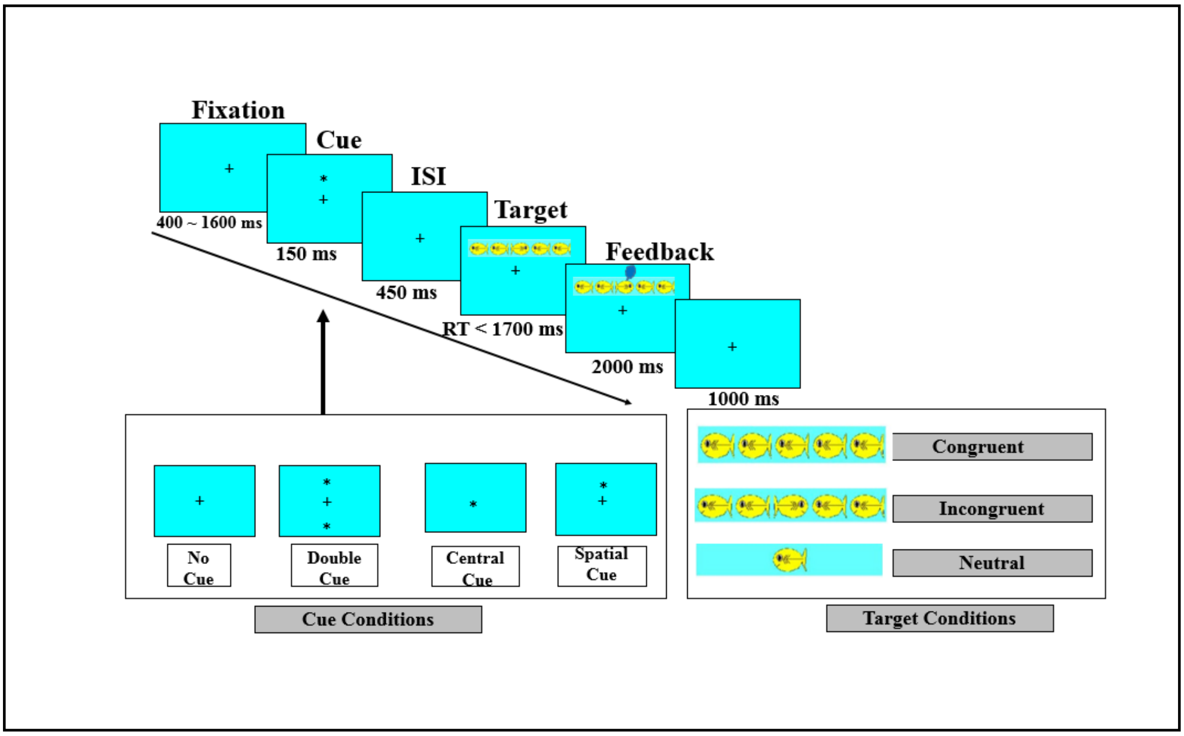


Figure 3.4. An example of the configuration of the cVANT. Adapted from "Development of Attentional Networks in Childhood," by Rueda et al. (2004), *Neuropsychologia*, 42, p.1031. Copyright 2004 by Elsevier.[4]

[4] Please see copyright permission in Appendix E.

cAANT-SL. The task was presented as a secret spy game and children were informed that they needed to listen for a secret code. They were informed that the secret code was the sound of a dog barking. The task of the participant was to indicate whether the secret code (dog bark) appeared in the left or right ear. Participants were advised that sometimes, they would hear one bark and at other times, they would hear two barks. They were instructed that when two barks were heard, the secret code was only the first bark. Participants were informed that sometimes, secret codes were preceded by a cue. They were told that sometimes the cue predicted where the secret code would appear. The congruent condition was created by presenting two sequentially presented barks to either the left or right ear. The incongruent condition was created by presenting two sequentially presented barks, one to the left ear, then one to the right ear, or vice versa. In the neutral condition, a single bark was presented to either the left or right ear. They were instructed to respond as quickly and accurately as they could to the ear of target presentation. Responses were made via the keyboard using the "E" (left ear) and "I" (right ear) keys. The task comprised 144 trials equally presented across three experimental blocks. A block of 12 practice trials (with each cue condition presented in equal proportion) preceded the experimental blocks. Within each experimental block, there were 48 trials. Each trial represented one of 12 conditions that included four cue conditions (none, double, central, and spatial) X three target conditions (neutral, congruent, and incongruent) in equal proportion.

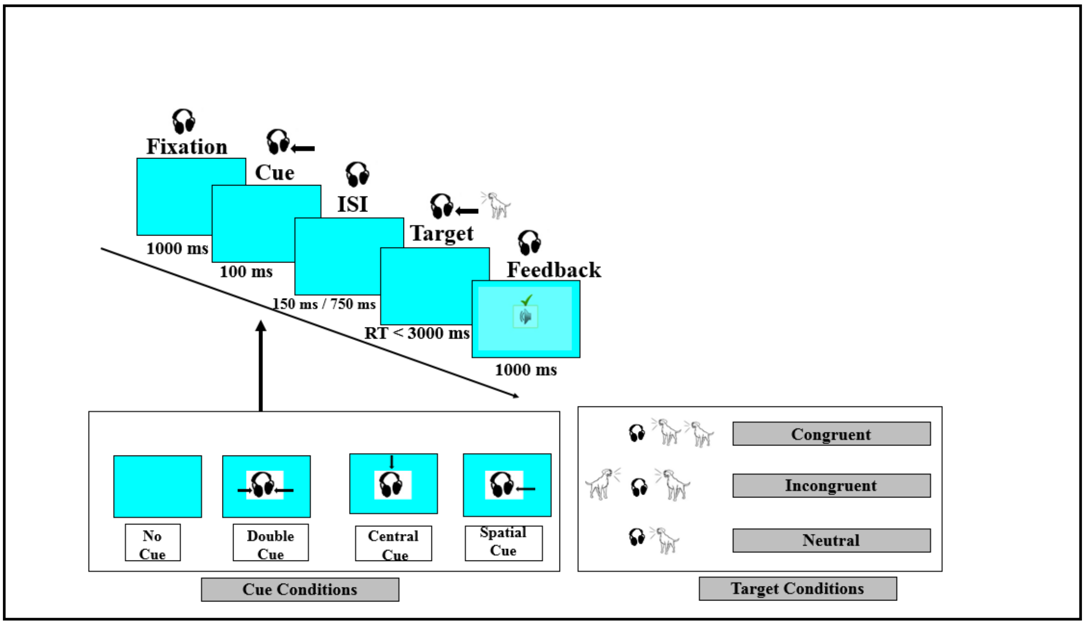


Figure 3.5. The configuration of the cAANT-SL.

Figure 3.5 illustrates the configuration of the cAANT-SL, cue conditions, target conditions, and an example of the procedure. Each trial started with a blank fixation screen presented for 1000 ms. Then, one of four cue conditions (none, double cue, central cue, or spatial cue) was presented for 100 ms, followed by a short blank fixation screen of either 150 ms (for central and spatial cue conditions) or 750 ms (for no cue and double cue conditions), followed by target presentation. The target bark was presented in three possible conditions (neutral, congruent, or incongruent). All targets were stereo sound files. For targets presented alone in the neutral condition, such as to the right ear only, the sound in the other channel (left ear) was silenced. Participants were given a maximum of 3000 ms to respond before the next trial started. Accuracy and RTs were measured from the onset of the auditory target in the nominated ear. In the practice blocks, visual feedback was presented after each correct or erroneous response. No feedback was given on experimental blocks. Throughout the experiment, the background colour was magenta. After each experimental block, there was time for a short break and the participant manually commenced subsequent blocks by pressing the space bar until all three blocks were completed. Cues and targets were presented at 60 dB SPL from a wireless stereo Logitech headset. Target location and cue type were randomly presented within experimental blocks. The task took 15 minutes to complete.

Chapter 4 : Results of Study 1

Chapter Overview

This chapter presents the results from Study 1. Study 1 used a cross-sectional design to examine the predictive relationship between the visual and auditory attention networks and reading, and whether this is mediated via phonological processing, across early (Years 1 and 2, aged 6 to 7 years) versus later (Years 4 and 5, aged 9 to 10 years) stages of reading acquisition.

Aims

The aims of Study 1 were:

a) To determine if there was a group difference in the relationship between visual and auditory attention networks, phonological processing, and reading between typically developing early versus later stage readers.
b) To determine if there was a group difference in the modality of attention that influences reading (via phonological processing or directly) between early versus later stages readers.

Hypotheses. Study 1 hypothesised that (a) in the early stages of reading, phonological processing would mediate the relationship between attention and reading, but during later stages the mediated pathway would diminish and the direct pathway from attention to reading would be strengthened and; (b) in the early stages of reading, auditory attention would be more significant for reading, compared with visual attention, but during later stages the visual attention would be more significant, compared with auditory attention.

Analysis Plan and Rationale

Stage 1. Missing, error, and outlier data were checked or removed. Then, the assumptions underlying repeated measures analysis of variance (ANOVA) and SEM were tested. For repeated measures ANOVA, these assumptions included independence, sphericity, and normality. For SEM, these assumptions included testing for univariate normality, univariate outliers, and multivariate outliers. Finally, an assessment of power of the sample size was conducted. This was aimed at determining if the sample sizes of 72 (early stage readers) and 70 (later stage readers) were robust to detect meaningful relationships between attention (visual and auditory), phonological processing, and reading (accuracy and speed), through SEM.

Stage 2. Descriptive summaries, including means, ranges, and standard deviations of measures (i.e., screening measures, visual and auditory attention network effects, phonological processing scores, reading accuracy scores and reading speed scores, and executive functioning scores) were calculated. In addition, inferential statistics were conducted, including independent samples *t*-test, for scores on phonological processing, reading accuracy, executive functioning, and non-word reading speed scores, comparing performance between early and later stages of reading. The Mann-Whitney *U* was used to compare scores on exception word reading speed between early and later stages of reading.

For each ANT test in each group, two-way repeated measures ANOVA were used to test for effects of cue type (no cue, double cue, central cue, spatial cue), congruency (neutral, congruent, incongruent), and their interaction, on mean RT and error rates. This was conducted to confirm that any observed influence of attention upon both phonological processing and reading in the SEM analysis emerged from a genuine attention network effect in each group. Then, for each ANT test, a three-way mixed (cue, congruency, and group) design ANOVA was then conducted to identify group differences in ANT performance. Finally, a two-way mixed design (word type and group) was conducted to determine group differences in reading speed for exception and non-words. Follow-up analyses for attention network ANOVAs were conducted using least significant difference contrasts with an alpha level of .05 Interactions were assessed using simple effects analysis. Effect sizes were reported using *d* for independent samples *t*-test (and their respective non-parametric variants for non-normal data) and partial eta squared (η_p^2) for repeated measures ANOVAs. Both descriptive and inferential statistics were performed using SPSS 24 (Corp, 2016).

Stage 3. To examine whether the mediation pathway in the relationship between attention, phonological processing, and reading differed between early and later stage readers, multiple-group SEM analysis, using the M*plus* 5.2 software program for Windows was undertaken (Muthén & Muthén, 2008; Vandenberg & Lance, 2000). There are at least three advantages of using a (multiple-group) SEM approach (Byrne, 2012).

Firstly, SEM permits the grouping of measures that assess similar constructs (Kline, 2011; Markus, 2012). For example, measures of phonological awareness, phonological memory, and RAN have been evidenced in the reading literature as a latent variable that represent a phonological processing construct (Wagner et al., 1999; Wagner, Torgesen, Rashotte, & Pearson, 2013). Grouping variables provides a more robust measurement of specific cognitive processes (Kline, 2011). It also provides a less biased interpretation of the results thus, reducing Type I and Type II errors (Markus, 2012). Secondly, SEM was used because it permits both an assessment of the pattern of mediation, as well as the total, indirect, and direct effects of the relationship between variables (Hayes, 2009, 2013; Preacher & Hayes, 2008). Of note is that norm-referenced standard scores for the phonological processing construct, and the *z*-score transformation of raw scores for the reading accuracy construct were used in the current SEM analysis. This minimised multicollinearity during the estimation of parameter coefficients (Aiken, West, & Reno, 1991). Thirdly, and of importance to confirming genuine differences across groups, the multiple-group SEM analysis permits the assessment of measurement and structural invariance, that is, a determination of how measurement and structural parameters might be the same or different across groups (Byrne, 2012). A lack of invariance (particularly, measurement invariance) would threaten any conclusion regarding the causal structure of variables across groups. More critically, the test of invariance allows researchers to specify a grouping factor. In the current research, the grouping factor was stage of reading or reading ability. Once invariance is established, one can be confident that any observed pathway differences between groups reflect genuine group differences (Cheung & Rensvold, 2002; Marsh et al., 2009).

Estimation methods. To accommodate the intra-school dependencies in the data, the standard errors for each of the path coefficients were computed with a sandwich estimator (Rabe-Hesketh, Skrondal, & Pickles, 2005). To correct for non-normal distributions, the MLR estimation method was used (Kline, 2011). Several researchers have advanced the use of the bootstrapping technique to obtain unbiased standard errors when testing for mediating effects (MacKinnon, Lockwood, Hoffman, West, & Sheets, 2002; Preacher, Rucker, & Hayes, 2007; Shrout & Bolger, 2002). Given that MLR was used as the estimator for non-normal data, bootstrapping was not necessary. In fact, bootstrapping is unavailable for MLR. However, simulation results found that parameter estimates and standard errors produced by

MLR is equivalent to that produced with bootstrapping (Muthén & Muthén, 2018). In all other SEM analysis using normal data, the maximum likelihood (ML) estimation method was used to estimate the standard error for the indirect effect using a bootstrapping technique based on 1,000 draws from the data.

Invariance testing. Invariance testing across multiple groups employs a hierarchical ordering of nested models (Bentler & Kano, 1990). That is, one model is nested within another. In the first instance, however, the hypothesised model should be initially fit for each group (separately). If the model does not fit similarly for both groups, then proceeding to test for invariance in a multiple-group fashion is not warranted. Instead, a single-group SEM approach should be adopted (Milfont & Fischer, 2010; Nitzl Christian, personal communication, 2018). Given the hypothesis of pathway differences between early and later stage readers in Study 1, a baseline model (Model 1) that excludes any constraints should be established. This means that all paths from attention to reading are not fixed to be equal between early and later stage readers. For the remaining models, factor loadings (Model 2), intercepts (Model 3), error variances (Model 4) and factor variance-covariance (Model 5), in that order, are proposed to be constrained, and thus invariant across groups. Factor means invariance was not performed, as the aim of this study was to assess group differences in pathways rather than between means (Bengt Muthén, personal communication, 2018).

When nested modelling, as described in the previous paragraph, is employed, the two models are assessed as significantly different if the difference between the chi-square values for the two models exceeds the critical value associated with the difference in the degrees of freedom of the two models (Jöreskog, 1978). Given that the data for reading accuracy was normally distributed, the nested modelling approach compared the chi-square values for null and alternative models derived from the ML estimation method. The approach to invariance testing for normally distributed data used the X^2 difference test, involving the difference of the X^2 values of a model with assumed invariance (χ^2_{INVAR}) and a model with no assumed invariance ($\chi^2_{\text{NO\_ INVAR}}$), as well as the difference of the degrees of freedom ($df_{\text{diff}} = df_{INVAR} - df_{\text{NO\_ INVAR}}$) (Bollen, 1989b; Dimitrov, 2006; Schermelleh-Engel, Moosbrugger, & Müller, 2003). Conversely, given that the data for exception word reading speed among early stage readers was non-normal, the nested modelling approach employed chi-square testing based on scaling correction factors derived from the MLR estimation method (Satorra & Bentler, 2010). The approach to invariance testing for non-normal data involved a two-step procedure using data from the M*plus* output. Firstly, the *cd*, which is the difference test scaling correction, was calculated using the formula (d0 * c0 ─ d1*c1)/(d0 ─ d1).[5] Secondly, the *TRd*, which is the Satorra-Bentler scaled chi-square difference test, was calculated using the formula (T0*c0 ─ T1*c1)/cd.[6]

Invariance is confirmed if the chi-square difference test between the two models is not statistically significant (Muthén & Muthén, 2008). In that case, there is robust evidence of measurement and structural invariance across groups (Milfont & Fischer, 2010). Moreover, if the fit indices for the unconstrained or less constrained model are better than the more constrained invariant model, then the "grouping" being examined (e.g., stage of reading in Study 1) is viewed as moderating any observed differences between groups (Preacher et al., 2007).

The invariance analysis, as detailed below, follows a three-step procedure as per the combined suggestions of Marsh et al. (2009) and Muthén and Muthén (2008):

(a) Fit separate confirmatory factor analysis (CFA) models for the latent variables. Given the sample size, the analysis of visual and auditory attention in its relationship with phonological processing and reading accuracy/reading speed was conducted separately.

(b) Establish measurement invariance for the latent variables.

- Model 1 (configural invariance), in which the factorial structure is constrained to be equal across group. Model 1 is tested by running a multiple-group CFA and serves as the baseline model.

- Model 2 (metric invariance), in which all factor loadings are constrained to be equal across group. Model 2 should confirm if participants across each group respond to items in the same way, that is, if the magnitude of the relationship between the factor loadings and their underlying constructs are equal across group. Previous research suggests that at least partial invariance must be achieved before proceeding to test Model 3 (Vandenberg & Lance, 2000).

[5] d0 is the degrees of freedom in the nested model, c0 is the scaling correction factor for the nested model, d1 is the degrees of freedom in the comparison model, and c1 is the scaling correction factor for the comparison model (Muthén & Muthén, 2018).
[6] T0 and T1 are the MLR chi-square values for the nested and comparison model, respectively (Muthén & Muthén, 2018).

- Model 3 (scalar invariance), in which all regression intercepts are constrained to be equal across group. Model 3 should confirm if the observed variable scores are related to the latent variable scores, that is, if participants who attain a specific score on observed variables would obtain the same scores on latent variables, regardless of their stage of reading.

- Model 4 (error invariance), in which all error variances are constrained to be equal across group. Model 4 model should confirm if participants attained the same levels of measurement errors for each item, regardless of their stage of reading.

(c) Establish structural invariance for latent variables.

- Model 5 (factor variance-covariance invariance, visual attention), in which all factor variance and covariances are constrained to be equal across group. Model 5 should confirm if the range of scores on observed and latent variables differs across groups. In addition, the invariance of the factor variance-covariance model confirms the stability of the relationships across group.

-Model 6 (factor variance-covariance invariance, auditory attention), which is the same as Model 5, but for auditory attention.

Assessing model fit. Given that the assessment of model fit is influenced by different factors such as analysis type, sample size, and robustness of relationships, the current study did not promote a singular fit index (Bentler & Hu, 1995). Instead, several broadly used goodness-of-fit indices were consulted. The Tucker-Lewis index (TLI; Tucker & Lewis, 1973) and the comparative fit index (CFI; Bentler, 1990) relate the fit of an estimated model to a more constrained baseline model. Given that the input matrix heavily influences the CFI and TLI, their fit indices represent the extent of the correlation among variables. TLI's and CFI's that exceed .90 (with a range from zero to one) suggest an adequate fit of the model to the data (Bentler & Hu, 1995). Moreover, a widely used misfit index, the Root Mean Square Error of Approximation (RMSEA), was assessed. RMSEA values that are ≤ .08 indicate that the model represents an adequate fit to the data (Bentler & Hu, 1995).

Kenny (2015), however, suggested that RMSEA values ≤ .10 are acceptable, given that ranges in sample values might inflate this value. Kenny, Kaniskan, and McCoach (2015) further advised that models with relatively low degrees of freedom should not rely entirely on the RMSEA as a measure of assessing model fit, since the RMSEA measure is positively biased, such that there is a tendency for very large values with smaller sample sizes (< 200). The chi-square and probability of close fit

(P close, $p \geq .05$ for acceptable fit) and standardised root mean square residual (SRMR, usually $\leq .08$ for acceptance) values were also reported (Browne & Cudeck, 1993). Finally, and, arguably, most importantly, the theoretical significance of variable interactions was considered, since some hypothesised paths might have presented with large effect sizes, yet, still not significant at the .05 alpha level (Byrne, 2012).

Reliability and effect size. Squared multiple correlations (amount of variance explained by each indicator for each latent variable) and composite reliability (*CR*) of each construct were calculated and reported, where applicable. To determine the effect size of the indirect effect, the completely standardised indirect effect was used (Miočević, O'Rourke, MacKinnon, & Brown, 2018). In M*plus*, the standardised coefficient produced by the SEM mediation analysis using bias-corrected bootstrapping is equivalent to the effect size of the indirect effect (Muthén, 2017). The value of the effect size for the indirect effect is often interpreted in line with similar conventions as the coefficient of determination (R^2), where small, medium, and large effect sizes are represented as .1, .3, and .5, respectively (Cohen, 1988). However, Kenny (2018) has recently advised that since the indirect effect is the outcome of two effects (i.e., the pathway between the independent and mediating variable and the pathway between the mediator and dependent variable), it is appropriate that these values are squared. Therefore, .01, .09 and .25 would reflect a small, medium, and large effect size, respectively. The interpretation of the indirect and total (combination of indirect and direct effects) effects in the present research conformed to Kenny's suggestions. In contrast, the interpretation of the direct effect conformed to Cohen's (1998) initial suggestion, since the direct effect does not combine two effects. Additionally, the 95% confidence interval (CI) for total, indirect, and direct effects are reported. If the CI does not contain zero, then the hypothesis of no significant effect was rejected, meaning that we can be confident that statistically significant effects do exist (du Prel, Hommel, Röhrig, & Blettner, 2009). However, if the CI does contain zero but the effect size for the parameter estimate was meaningful (e.g., large effect size), then this finding was interpreted in relation to previous literature, and possible contribution to theory (Schechter, 2017). Finally, a non-significant indirect or direct effect suggests that the data are unable to provide a precise estimate that is distinguishable from zero. However, this does not imply that there are zero effects. In such cases, it is advised to first examine the parameter estimates and determine the precision of these estimates based on the standard errors or the 95% confidence intervals. Then, the focus should be on what can be deduced about the estimate, considering the value of the parameter estimations (Schechter, 2017).

Stage 4. Depending on the presence of significant effects in the SEM analysis of Stage 3, subsequent analysis was conducted to clarify the nature of the relationship between the attention networks, phonological processing, and reading. This involved (a) determining the specific relationship between the observed variables for the visual and auditory attention networks and phonological processing, reading, and executive functioning using Pearson's correlation, and (b) determining, through SEM analysis, if observed significant SEM relationships operated bi-directionally.

Stage 1. Missing Data, Error and Outlier Removal, Assumption Testing, and Power Analysis

The proportion of missing data was assessed to ensure that missing values did not exceed 5% for each variable that was included in the analysis for the relationship between attention, phonological processing, and reading. For both early and later stage readers, each variable had at least 97% of data available (range of data availability = 97.1% to 100%). Given that the missing values used in the final analysis accounted for less than the recommended 5%, missing data were not imputed (Tabachnick & Fidell, 2007). Given that the cVANT, cAANT-SL, and the reading speed task relied on analysing raw scores from an experimental task, the assumption testing for the individual analyses of these tasks included excluding error trials and trimming for RT outliers in the first instance. This issue does not arise if measures are generated from standardised tests, such as the CTOPP (phonological processing), CC2 (reading accuracy), and BRIEF (executive functioning) tasks used in the current study.

Errors, where participants pressed the wrong button, or failed to respond within the response period (10.3% of trials among early stage readers, and 4.9% of trials among later stage readers for the cVANT, as well as, 20.1% of trials among early stage readers, and 8.4% of trials among later stage readers for the cAANT-SL) and RT outliers, defined as RTs less than 200 ms and scores falling 2 *SD* above or below the mean within each condition (5.0% of trials among early stage readers, and 4.9% of trials among later stage readers for the cVANT, as well as 4.3% of trials among early stage readers, and 4.0% of trials among later stage readers for the cAANT-SL) were excluded when calculating the mean RT for each condition for each participant. The data for the cVANT were pooled across target direction and position, whereas data for the cAANT-SL were pooled across target location (left ear or right ear) since preliminary analysis showed that these effects were negligible.

Similarly, errors, where participants failed to respond within the response period or said the wrong word for the reading speed task, were excluded. Errors (19.7% of trials among early stage readers, and 7.5% of trials among later stage readers) were defined as incorrect pronunciations, which were assigned a score of 0. Correct pronunciations were assigned a score of 1. RT outliers (4.8% of trials among early stage readers, and 3.9% of trials among later stage readers) were defined, firstly, as scores on correct trials lower than 200 and greater than 6000 ms, and, secondly, scores that fell more than 2 standard deviations above or below the participant's mean for each word type condition.

Assumption testing. For the SEM analysis, the assumption testing (i.e., independence, sphericity, and normality) included all experimental measures: standardised measures (from norm-referenced tests), and the specific measures that are extracted from experimental tasks (i.e., three attention network measures for visual and auditory modalities, exception and non-word naming speed). Where sphericity was violated, the reported results reflected the Greenhouse and Geisser corrected values.

The visual and auditory attention, phonological processing, reading accuracy, reading speed (for later stage readers), and executive functioning data were normally distributed. Non-standardised skewness scores for these data ranged from 0 to 1.60 for early stage readers and from -0.41 and 1.80 for later stage readers, well within the suggested limit of ±2 (Field, 2013; Gravetter, 2014). Similarly, kurtosis values ranged from -0.17 to 2.70 for early stages readers, and -0.06 to 5.00 for later stage readers, well within the suggested limit of ±7 (Field, 2013; Pallant, 2013).

Conversely, for early stage readers, the mean RTs for exception word reading speed scores were positively skewed (2.81), with a kurtosis value of 11.46, which is common for RT distributions (Luce, 1986). Moreover, younger children are likely to have slower overall RTs and therefore be more variable in their performance. For example, one early stage reader could only correctly read 12 (7 exception words and 5 non-words) of the 48 words. Inspection of his RAN subtest showed that this child scored 79, defined as falling within the ‘poor’ range. There was a reduction (0.96) in skewness for exception words when this outlier was removed. Nevertheless, it was decided to include this participant.[7]

To investigate univariate outliers, attention, phonological processing, reading, and executive functioning scores were standardised to *z*-scores, within each group, through SPSS. Mean standardised reading speed scores for the total sample of early stage readers (3.67 for exception words and 3.60 for non-words) mildly departed from the suggested ±3.29 limit (Tabachnick & Fidell, 2007). For later stage readers, scores for reading speed (3.32 for exception words and 4.40 for non-words), visual orienting attention (3.58), and visual executive (4.02) attention fell outside the suggested ±3.29 limit. Subsequent analysis of box plots showed that these outliers fell within the non-extreme range (i.e., 1.5 to 3 box lengths from the upper or lower point of the box), for both early and later stage readers. More importantly, including or excluding these outliers did not change the relationships between variables, thus these data were retained in the analysis.

To investigate multivariate outliers (performed separately for early and later stages of reading), Mahalanobis distances through linear regression analysis, and corresponding probability values were computed for predictor (i.e., attention network, phonological processing) scores. A probability score below .001 is considered as an outlier (Huberty, 2005). The lowest probability value for early (p = .01) and later (p = .01) stage readers was greater than .001, indicating that multivariate outliers were not present in the current data set.

Power analysis. Given that several approaches to understanding power have been suggested, and the argument that sample size power calculations should be viewed as preliminary hypothetical estimates, no single power calculation approach was advocated (Wolf, Harrington, Clark, & Miller, 2013). Instead, several perspectives have been adopted for the current study.

[7] This case was still included because it was reflective of a child with good attention skills, but low phonological processing skills in one of the three phonological components that were assessed. Therefore, including him would provide a more realistic representation of natural human variability, which has significant implications concerning the extent to which results are generalisable. Including or removing this participant did not change the relationships between the variables.

Although Markus (2012) previously suggested that multiple-group SEM should comprise at least 100 cases per group, French and Finch (2008) suggested that sample size determination is not entirely fixed, and instead depends on data conditions. In relation to the current study, one of these data conditions involved the strength of the relationships between variables. It should therefore be recognised that previously suggested procedures of establishing SEM power (e.g., G * power) do not account for the previous finding of robust and well-established relationship between phonological processing skills and reading (Melby-Lervåg et al., 2012). Moreover, Kenny (2015) suggested that simpler models (with previously supported strong correlations), like that proposed by the current study, can detect robust effects with smaller sample sizes (< 100 cases per group).

Given the previously established correlations between phonological processing and reading, the use of the bootstrapping procedure, and that the majority of the data is neither highly kurtotic nor departs greatly from normality (where it departs from the acceptable range for normality and kurtosis MLR estimation accounts for this), it is rational to accept that, with the current sample size (72 participants for early stage readers and 70 participants for later stage readers), the stability of the parameter estimates can be trusted, as well as the power to reject models (Hoogland & Boomsma, 1998).

Stage 2. Descriptive and Inferential Statistics via SPSS.24

The means, ranges, and standard deviations for the standardised and RT measures are reported in Table 4.1. This includes the TONI-4 IQ standardised scores, the standardised Woodcock-Johnson WI and PC scores, the CTOPP phonological processing scores (raw and standardised composite scores), the CC2 reading accuracy (raw and *z*-scores), and the BRIEF executive functioning scores across early and later stage readers. RT data for the cVANT, cAANT-SL, and the reading speed task are also presented. A series of independent samples *t*-tests were conducted on phonological processing (composite scores), reading accuracy (number correct out of 40 trials for each word type and raw data transformed to *z*-scores), and executive functioning (scores calculated based on Likert type scale) scores. Then, for each ANT, a two-way repeated measures ANOVA was conducted for each group. Then, for each ANT test, a three-way mixed (cue, congruency, and group) design

ANOVA was conducted to identify group differences in ANT performance. Finally, a two-way mixed design (word type and group) was conducted to determine group differences in reading speed for exception and non-words.

Phonological processing. Average performance in phonological processing skills on the CTOPP for each subtest is indexed by composite scores within the range of 90 to 110 (Wagner et al., 1999). As Table 4.1 illustrates, the mean performance for each phonological processing subtest fell within a typically developing (average) range for both early and later stage readers. Later stage readers had significantly lower standardised scores, $t(140) = 2.41$, $p = .02$, $d = .20$, and raw scores, $t(114.45) = 4.66$, $p < .001$, $d = .39$, on the phonological awareness task, compared with early stage readers. Similarly, later stage readers had significantly lower standardised, $t(140) = 2.36$, $p = .02$, $d = .20$, and raw, $t(140) = 2.38$, $p = .02$, $d = .20$, phonological memory scores compared with early stage readers. Finally, there were no significant group differences in RAN standardised, $t(140) = 0.84$, $p = .40$, $d = .07$, and raw, $t(140) = 0.84$, $p = .40$, $d = .07$, scores.

Reading accuracy. Average performance in reading accuracy on the CC2 across children aged 6 years and 5 months to 11 years and 5 months is indexed by a *z*-score within the range of -1 to +1 (Castles et al., 2009). As Table 4.1 illustrates, the mean performance on the reading accuracy (*z*-scores), for each word type (regular, exception and non-words), fell within the typically developing (average) range for both early and later stage readers.

Raw scores (total number correct). Compared with early stage readers, later stage readers had significantly higher raw scores on the regular word, $t(97.46) = 5.32$, $p < .001$, $d = .45$, exception word, $t(132.57) = 7.10$, $p < .001$, $d = .60$, and non-word, $t(122.21) = 4.15$, $p < .001$, $d = .35$, reading accuracy task.

Z-scores. Compared with early stage readers, later stage readers had significantly lower *z*-scores on the exception word, $t(140) = 3.59$, $p < .001$, $d = .30$, and non-word, $t(140) = 3.76$, $p < .001$, $d = .32$, reading accuracy task. The difference in scores on the regular word reading accuracy task was not significantly different between groups, $t(140) = 1.05$, $p = .30$, $d = .09$.

Percentage correct. The following represents the percentage correct for each word type in early stage readers: regular words ($M = 75.5\%$, $SD = 23.0\%$), exception words ($M = 41.6\%$, $SD = 16.6\%$), and non-words ($M = 63.7\%$, $SD = 26.8\%$). For later stage readers, the percentage correct for each word type was, regular words (*M*

= 91.2%, *SD* = 10.0%), exception words (*M* = 59.2%, *SD* = 12.7%), and non-words (*M* = 79.4%, *SD* = 17.3%).

Table 4.1: Means and Standard Deviations of Attention Network Effects, Phonological Processing, Reading, and Executive Functioning for Early and Later Stage Readers

	Early (*n* = 72)		Later (*n* = 70)	
	M (min, max)	*SD*	*M* (min, max)	*SD*
Screening				
IQ	107.29 (90, 131)	9.32	109.49 (92,138)	9.32
WI	120.76 (90, 145)	17.81	117.43 (86, 143)	15.25
PC	111.14 (90,137)	11.64	107.24 (87,140)	14.18
Phon. Processing				
Phon. aware SS	112.11 (88,136)	11.58	107.32 (82, 130)	12.05
Phon. aware raw	26.86 (16,44)	6.93	22.44 (14, 30)	4.02
Phon. memory SS	104.29 (79, 139)	14.26	98.89 (61, 127)	12.94
Phon. memory raw	21.43 (13, 33)	4.75	19.61 (7, 29)	4.33
RAN SS	102.83 (67, 139)	13.72	104.67 (76, 139)	12.15
RAN Raw	20.94 (9, 33)	4.57	21.56 (12,33)	4.05
Reading Accuracy				
Regular *Z*	0.78 (-1.29, 2.62)	1.02	0.59 (-2.33, 2.99)	1.13
Regular raw	30.18 (4, 40)	9.19	36.47 (18, 40)	3.99
Exception *Z*	0.69 (-1.54, 2.44)	0.96	0.11 (-2.03, 1.81)	0.99
Exception raw	16.65 (1, 31)	6.65	23.69 (12,35)	5.07
Non-word *Z*	0.91 (-1.06, 2.65)	0.90	0.28 (-1.69, 2.70)	1.06
Non-word raw	25.47 (2, 39)	10.71	31.74 (8, 40)	6.95
Exec. Functioning	53.06 (32,73)	9.16	50.94 (37,67)	6.88
cVANT Effects				
Alerting (ms)	66 (- 45, 182)	46	53 (-50, 160)	40
Orienting (ms)	38 (-79, 152)	54	49 (-66, 208)	44
Executive (ms)	92 (-11, 188)	45	70 (-46, 237)	41
cAANT-SL Effects				
Alerting (ms)	-4 (-295, 304)	109	26 (-175, 246)	79
Orienting (ms)	58 (-188, 418)	115	35 (-110, 202)	73
Executive (ms)	157 (-186, 468)	125	116 (-78, 322)	92
Reading Speed				
Exception RT (ms)	864 (466, 2443)	305	688 (432, 1113)	134
Non-word RT (ms)	1049 (493, 2457)	391	790 (456, 1628)	190

Note. IQ = Intelligence Quotient; WI = Word Identification; PC = Passage Comprehension; Phon. aware = phonological awareness; SS = standard score; raw = raw score; Phon. Memory = phonological memory; Regular = regular words; Exception = exception words; *Z* = *z*-score; Exec. Functioning = executive functioning; ms = milliseconds.

Executive functioning. Higher scores for executive functioning on the BRIEF indicate greater degrees of executive dysfunction. Scores at or above 65 are clinically significant (elevated range). As Table 4.1 illustrates, the mean performance for executive functioning fell within the non-elevated range for both early and later stage readers. There were no significant differences in executive functioning between early and later stages of reading, $t(113) = 0.83$, $p = .41$, $d = .08$.

Visual attention. Table 4.2 provides the mean RTs in each condition of the cVANT, along with marginal means, for early and later stage readers. ANOVA showed a main effect of cue for both early, $F(3, 210) = 66.83$, $p < .001$, $\eta_p^2 = .49$, and later, $F(3, 207) = 89.08$, $p < .001$, $\eta_p^2 = .56$, stage readers. There was also a main effect of congruency for early, $F(2, 140) = 164.74$, $p < .001$, $\eta_p^2 = .70$, and later, $F(2, 138) = 150.71$, $p < .001$, $\eta_p^2 = .69$, stage readers. The interaction between cue and congruency was significant for early, $F(6, 420) = 2.19$, $p = .04$, $\eta_p^2 = .03$, but not for later, $F(6, 414) = 1.82$, $p = .09$, $\eta_p^2 = .03$, stage readers.

Planned contrast between the no cue and double cue conditions revealed significant visual alerting benefits, with an advantage for the double cue condition, for both the early (66 ms), $F(1, 70) = 142.93$, $p < .001$, $\eta_p^2 = .67$, and later (53 ms), $F(1, 69) = 116.61$, $p < .001$, $\eta_p^2 = .63$, stage readers. A contrast between the central cue and spatial cue conditions showed significant visual spatial-orienting benefits for the spatial cue condition for both early (38 ms), $F(1, 71) = 34.92$, $p < .001$, $\eta_p^2 = .33$, and later (49 ms), $F(1, 69) = 86.12$, $p < .001$, $\eta_p^2 = .56$, stage readers. Finally, a contrast between the incongruent and congruent flanker conditions revealed that visual executive control benefits were significant for early (92 ms), $F(1, 70) = 283.31$, $p < .001$, $\eta_p^2 = .80$, and later (70 ms), $F(1, 69) = 193.37$, $p < .001$, $\eta_p^2 = .74$, stage readers.

Cue by congruency interaction in early stage readers. Simple effect analysis showed that for early stage readers, the difference between the neutral and congruent conditions appeared to vary across different levels of cue. That is, there was a marginally significant greater RT for the congruent condition, compared with the neutral condition, when targets were preceded by a spatial cue ($p = .09$). However, this marginal difference disappeared in the no cue ($p = .11$), double cue ($p = .67$), and central cue ($p = .39$) conditions.

In contrast, the cue by congruency interaction disappeared in the comparison between the incongruent and neutral conditions (significantly greater RT for incongruent conditions across all levels of cue, $p < .001$). Similarly, the cue by congruency interaction disappeared in the comparison between the incongruent and congruent conditions (significantly greater RT for incongruent conditions across all levels of cue, $p < .001$). In the case of this latter finding (i.e., comparing the congruent and incongruent conditions), the absence of the cue by congruency interaction does not impact upon the calculation of the visual executive effect from the cVANT in early stage readers, because the effect did not change across levels of cue conditions.

Table 4.2: Mean RT in Milliseconds and Standard Deviations in the cVANT for Early (*n* = 72) and Later Stage (*n* = 70) Readers

	Cue Type				
Congruency Type	No Cue	Double	Central	Spatial	Total Mean
Early Stage					
Neutral	864 (101)	793 (112)	826 (125)	771 (113)	813 (100)
Congruent	876 (83)	796 (104)	814 (101)	787 (99)	818 (86)
Incongruent	945 (92)	898 (106)	915 (95)	881 (112)	910 (87)
Total Mean	895 (81)	829 (96)	851 (94)	813 (97)	
Later Stage					
Neutral	712 (101)	654 (94)	671 (102)	625 (104)	665 (91)
Congruent	725 (100)	662 (102)	683 (106)	639 (97)	677 (95)
Incongruent	783 (104)	746 (103)	758 (97)	700 (104)	747 (94)
Total Mean	740 (94)	687 (93)	704 (95)	655 (94)	

Note. RT difference between the no cue and double cue conditions = alerting effect;
RT difference between the central and spatial cue conditions = orienting effect;
RT difference between incongruent and congruent conditions = executive effect.

Group interactions in the cVANT. A three-way mixed design ANOVA, including cue, congruency, and group was conducted for the cVANT. There was a main effect of group, $F(1, 139) = 103.07$, $p < .001$, $\eta_p^2 = .43$. There was no significant interaction between cue and group, $F(3,417) = 1.74$, $p = .16$, $\eta_p^2 = .01$. In contrast, the interaction between congruency and group was significant, $F(2,278) = 4.11$, $p = .02$, $\eta_p^2 = .03$. The interaction between cue, congruency, and group was not significant, $F(6, 834) = 1.13$, $p = .35$, $\eta_p^2 = .01$.

To examine the congruency by group interaction, simple effect analysis was used to compare different levels of group (early vs. later stages of reading) for each level of congruency. The analysis showed a significantly greater RT for the incongruent condition, relative to the congruent condition in early stage readers, compared to later stage readers ($p = .003$). However, this group difference in RT disappeared for the congruent relative to the neutral conditions (p = .43) and for the incongruent relative to the neutral conditions (p = .10). This suggests that early stage readers found it more difficult to resolve visual conflict compared with later stage readers.

Error analysis in the cVANT for early stage readers. Table 4.3 provides the mean error percentages in each condition of the cVANT, along with marginal means, for early and later stage readers. The analysis of errors for early stage readers in the cVANT found a main effect of cue, $F(3, 213) = 5.61$, $p = .001$, $\eta_p^2 = .07$, and congruency, $F(2, 142) = 58.86$, $p < .001$, $\eta_p^2 = .45$. The difference between errors in the no cue (M = 12.4% ± 1.1%) and double cue (M = 10.3% ± 1.3%) conditions was marginally significant (p = .06). There were significantly (p =.002) more errors in the spatial cue (M = 14.0% ± 1.2%) compared with the central cue (M = 10.7% ± 1.4%) conditions. The difference in errors between the no cue and spatial cue conditions was marginally significant (p = .07). The difference in errors between double and spatial cue conditions was significant (p = .001). No significant error differences were found between the no cue and central cue conditions (p = .13), as well as between the double and central cue conditions (p = .63). There were significantly (p < .001) more errors in the incongruent (M = 17.8% ± 1.3%) compared with the neutral (M = 9.8% ± 1.2%) and congruent (M = 8.0% ± 1.2%) flanker conditions. The difference in error percentage between neutral and congruent conditions was significant (p = .02).

The cue by congruency interaction was significant, $F(6, 426) = 8.10$, $p < .001$, $\eta_p^2 = .10$. Simple effect analysis showed that the difference between the neutral and incongruent conditions appeared to vary across different levels of cue. That is, there were significantly more errors in the incongruent condition, relative to the neutral condition, when targets were preceded by no cue (p < .001), double cue (p = .002), and spatial cue (p < .001) conditions. However, this difference disappeared in the central cue (p = .23) condition.

A comparison between neutral and congruent conditions did not show any significant differences across levels of cue. That is, errors were not significantly different between neutral and congruent conditions for the no cue (p = .16), double cue (p = .63), central cue (p = .11), and spatial cue (p = .13) conditions. Similarly, a comparison between congruent and incongruent conditions did not show any significant differences across levels of cue. That is, errors were all significantly different between congruent and incongruent conditions across all levels of cue ($p < .001$).

Table 4.3: Mean Error Percentage Data and Standard Deviations for the cVANT in Early (*n* = 72) and Later (*n* = 70) Stage Readers

	Cue Type				
Congruency Type	No Cue	Double	Centre	Spatial	Total Mean
Early Stage					
Neutral	10.5 (11.9)	8.6 (12.3)	10.8 (13.5)	9.3 (11.6)	9.8 (10.2)
Congruent	8.3 (12.9)	8.0 (12.1)	8.7 (11.7)	7.2 (12.8)	8.0 (10.0)
Incongruent	18.4 (15.4)	14.5 (17.0)	12.7 (16.3)	25.5 (17.8)	17.8 (11.4)
Total Mean	12.4 (9.3)	10.3 (11.4)	10.7 (11.8)	14.0 (10.4)	
Later Stage					
Neutral	5.8 (7.1)	4.6 (6.3)	4.5 (7.2)	4.3 (6.0)	4.8 (4.6)
Congruent	4.3 (6.5)	3.1 (4.7)	3.9 (5.4)	2.7 (5.4)	3.5 (3.8)
Incongruent	5.6 (8.0)	6.0 (9.3)	6.7 (9.9)	6.7 (9.5)	6.2 (6.5)
Total Mean	5.2 (5.2)	4.6 (5.1)	5.0 (5.5)	4.6 (4.7)	

Error analysis in the cVANT for later stage readers. The analysis of errors for later stage readers in the cVANT found no main effect of cue, $F(3, 207) = 0.75$, $p = .52$, $\eta_p^2 = .01$, but a main effect of congruency, $F(2, 138) = 10.76$, $p < .001$, $\eta_p^2 = .14$. The cue by congruency interaction was not significant, $F(6, 414) = 0.85$, $p = .53$, $\eta_p^2 = .01$. There were significantly more errors in the incongruent (M = 6.2% ± 0.8%) compared with the neutral (M = 4.8% ± 0.5%, $p < .04$) and congruent (M = 3.5% ± 0.5%, $p < .001$) flanker conditions. The difference in errors between neutral and congruent conditions was significant ($p = .003$).

Group differences in visual attention network effects in the cVANT. The visual attention network effect scores for early and later stages of reading are provided in Table 4.1. An independent samples *t*-test was conducted to determine group differences in visual alerting, orienting, and executive attention network effects. The analysis showed a marginally significant difference between groups in visual alerting, $t(140) = 1.85$, $p = .07$, $d = .16$, with a larger mean alerting effect score for early stage readers (M = 66 ms ± 6 ms), compared with later stage readers (M = 53 ms ± 5 ms). There was no statistically significant difference between groups for visual orienting effect scores, $t(135.53) = 1.32$, $p = .19$, $d = .11$. Finally, the analysis showed a statistically significant difference between groups for the visual executive effect, $t(140) = 2.98$, $p = .003$, $d = .25$, with a larger mean visual executive effect score for early stage readers (M = 92 ms ± 5 ms), compared with later stage readers (M = 70 ms ± 5 ms).

Auditory attention. Table 4.4 provides the mean RTs in each condition of the cAANT-SL, along with marginal means, for early and later stage readers. ANOVA showed a main effect of cue for both early, $F(3, 207) = 6.28$, $p < .001$, $\eta_p^2 = .08$, and later, $F(3, 204) = 8.00$, $p < .001$, $\eta_p^2 = .11$, stage readers. There was also a main effect of congruency for early, $F(2, 138) = 146.98$, $p < .001$, $\eta_p^2 = .68$, and later, $F(2, 136) = 162.31$, $p < .001$, $\eta_p^2 = .71$, stage readers. The interaction between cue and congruency was not significant for both early stage readers $F(5.16, 355.76) = 2.02$, $p = .07$, $\eta_p^2 = .03$, and later stage readers, $F(6, 408) = 1.06$, $p = .38$, $\eta_p^2 = .02$.

Planned contrasts between the no cue and double cue conditions revealed no significant auditory alerting benefits (-4 ms, faster mean RT for the no cue condition), $F(1, 71) = 0.10$, $p = .76$, $\eta_p^2 < .001$, for early stage readers. However, there were significant auditory alerting benefits for later stage readers (26 ms), $F(1, 69) = 9.07$, $p = .004$, $\eta_p^2 = .12$. A contrast between the central cue and spatial cue conditions showed significant auditory spatial-orienting benefits for the spatial cue condition for both early (58 ms), $F(1, 69) = 17.48$, $p < .001$, $\eta_p^2 = .20$, and later stage (35 ms), $F(1, 68) = 15.37$, $p < .001$, $\eta_p^2 = .18$, readers. Finally, a contrast between the incongruent and congruent flanker conditions revealed that auditory executive control benefits were significant for both early (157 ms), $F(1, 69) = 109.70$, $p < .001$, $\eta_p^2 = .61$, and later stage (116 ms), $F(1, 68) = 107.65$, $p < .001$, $\eta_p^2 = .61$, readers.

Group interactions in the cAANT-SL. A three-way mixed design ANOVA, including cue, congruency, and group was conducted for the cAANT-SL. There was a main effect of group, $F(1,137) = 43.94$, $p < .001$, $\eta_p^2 = .24$. The interaction between cue and group, $F(3, 411) = 1.73$, $p = .16$, $\eta_p^2 = .01$, was not significant. In contrast, the interaction between congruency and group was significant, $F(2, 274) = 3.73$, $p = .03$, $\eta_p^2 = .03$. The interaction between cue, congruency, and group was not significant, $F(6, 822) = 0.47$, $p = .83$, $\eta_p^2 = .00$.

Table 4.4: Mean RT in Milliseconds and Standard Deviations in the cAANT-SL for Early (*n* = 72) and Later Stage (*n* = 70) Readers

	Cue Type				
Congruency Type	No Cue	Double	Central	Spatial	Total Mean
Early Stage					
Neutral	1132 (157)	1182 (178)	1186 (194)	1135 (195)	1159 (174)
Congruent	1238 (150)	1233 (220)	1260 (195)	1196 (200)	1232 (182)
Incongruent	1418 (209)	1385 (248)	1405 (250)	1347 (259)	1389 (209)
Total Mean	1263 (175)	1267 (196)	1284 (189)	1226 (215)	
Later Stage					
Neutral	968 (167)	969 (214)	978 (198)	943 (183)	965 (184)
Congruent	1057 (180)	1023 (219)	1056 (213)	1017 (203)	1038 (197)
Incongruent	1180 (244)	1137 (266)	1165 (274)	1133 (260)	1154 (247)
Total Mean	1069 (189)	1043 (228)	1066 (224)	1031 (204)	

Note. RT difference between the no cue and double cue conditions = alerting effect; RT difference between the central and spatial cue conditions = orienting effect; RT difference between incongruent and congruent conditions = executive effect.

To examine the congruency by group interaction, simple effect analysis was used to compare different levels of group (early vs. later stages of reading) for each level of congruency. The analysis showed a marginally significant difference between groups in the neutral condition, with slower RTs for early stage readers, $F(3, 420) = 2.47$, $p = .06$, $\eta_p^2 = .02$, compared with later stage readers. However, this RT advantage for later stage readers disappeared for both the congruent, $F(3, 420) = 1.53$, $p = .21$, $\eta_p^2 = .01$, and incongruent conditions, $F(3, 420) = 0.50$, $p = .68$, $\eta_p^2 = .00$. This suggests that later stage readers have a faster speed of processing compared with early stage readers.

Error analysis in the cAANT-SL for early stage readers. Table 4.5 provides the mean error percentages in each condition of the cAANT-SL, along with marginal means, for early and later stage readers. The analysis of errors for early stage readers in the cAANT-SL revealed a main effect of cue, $F(3, 210) = 39.86$, $p < .001$, $\eta_p^2 = .36$, and congruency, $F(2, 140) = 35.72$, $p < .001$, $\eta_p^2 = .34$. The cue by congruency interaction was not significant, $F(6, 420) = 1.27$, $p = .29$, $\eta_p^2 = .02$. There were significantly ($p < .001$) more errors in the double cue ($M = 24.2\% \pm 2.2\%$), central cue ($M = 26.4\% \pm 2.1\%$), and spatial cue ($M = 17.4\% \pm 1.6\%$) conditions compared with the no cue conditions ($M = 12.2\% \pm 1.4\%$). There were significantly more errors in the double cue conditions compared with the spatial cue ($p < .001$) conditions. Errors in the double cue and central cue conditions were marginally different ($p =$

.09). There were significantly (p < .001) more errors in the incongruent (M = 25.6% ± 1.8%) compared with the neutral (M = 17.7% ± 1.8%) and congruent (M = 16.7% ± 1.7%) flanker conditions. The difference in error between neutral and congruent conditions was not significant (p = .22).

Table 4.5: Mean Error Percentage Data and Standard Deviations for the cAANT-SL in Early (*n* = 72) and Later (*n* = 70) Stage Readers

	Cue Type				
Congruency Type	No Cue	Double	Centre	Spatial	Total Mean
Early Stage					
Neutral	9.7 (14.1)	22.9 (21.6)	24.9 (21.4)	13.4 (14.1)	17.7 (14.9)
Congruent	8.5 (12.6)	20.9 (22.3)	23.6 (20.1)	14.0 (16.0)	16.7 (14.4)
Incongruent	18.3 (15.5)	28.8 (20.0)	30.5 (21.4)	25.0 (17.5)	25.6 (15.1)
Total Mean	12.2 (11.9)	24.2 (18.5)	26.4 (17.5)	17.4 (13.2)	
Later Stage					
Neutral	3.9 (6.3)	8.0 (11.9)	10.0 (13.6)	5.1 (8.0)	6.7 (8.2)
Congruent	2.9 (5.3)	6.8 (11.3)	8.0 (9.8)	4.2 (6.5)	5.5 (6.6)
Incongruent	10.1 (12.0)	13.2 (14.0)	15.2 (15.6)	10.3 (12.1)	12.2 (10.7)
Total Mean	5.6 (8.8)	9.3 (10.2)	11.1 (10.8)	6.5 (7.2)	

Error analysis in the cAANT-SL for later stage readers. The analysis of errors for later stage readers in the cAANT-SL found a main effect of cue, $F(3, 204) = 15.68$, $p < .001$, $\eta_p^2 = .19$, and congruency, $F(2, 136) = 36.86$ $p < .001$, $\eta_p^2 = .35$. The cue by congruency interaction was not significant, $F(6, 408) = 0.20$, $p = .98$, $\eta_p^2 = .00$. There were significantly (p < .001) more errors in the double cue (M = 9.3% ± 1.2%) and central cue conditions (M = 11.1% ± 1.3%) compared with the no cue (M = 5.6% ± 0.7%) conditions. Errors in the no cue and spatial cue (M = 6.5% ± 0.9%) conditions were not significantly different (p = .17). There were significantly more errors in the double cue conditions compared with the spatial cue condition (p = .004). There were significantly more errors in the central cue compared with the double cue conditions (p = .04). Similarly, there were significantly more errors in the central cue compared with spatial cue conditions (p < .001). There were significantly (p < .001) more errors in the incongruent (M = 12.2% ± 1.3%) compared with the neutral (M = 6.7% ± 1.0%) and congruent (M = 5.5% ± 0.7%) flanker conditions.

The difference in error percentages between the neutral and congruent flanker conditions was marginally significant (p = .06).

Group differences in auditory attention network effects in the cAANT-SL. The auditory attention network difference scores for each early and later stages of reading are provided in Table 4.1. An independent samples *t*-test was conducted to determine group differences in auditory alerting, orienting, and executive attention network effects. The analysis showed a statistically significant difference between groups for auditory alerting, $t(129.13) = 2.03$, $p = .04$, $d = .17$, with a larger mean alerting effect score for later stage readers (M = 26 ms ± 9 ms), compared with early stage readers (M = - 4 ms ± 13 ms). This suggests that RT processing for later stage readers benefitted from using auditory warning cues. There was no statistically significant difference between groups for mean auditory orienting effect scores, $t(117.39) = 1.40$, $p = .16$, $d = .12$. Finally, the analysis showed a statistically significant difference between groups for the auditory executive effect, $t(140) = 2.20$, $p = .03$, $d = .18$, with a larger mean auditory executive effect score for early stage readers (M = 157 ms ± 15 ms), compared with later stage readers (M = 116 ms ± 11 ms), suggesting that later stage readers found it easier to resolve auditory conflict.

Reading speed. A Mann-Whitney *U* test indicated that exception word reading speed was significantly slower for early stage readers (Mean Rank = 89.21) compared with later stage readers (Mean Rank = 51.79), $U = 1140.00$, $p < .001$, $d = .46$. Similarly, independent samples *t*-test showed that non-word reading speed was significantly slower for the early stage readers, $t(94.63) = 4.89$, $p < .001$, $d = .60$, compared with later stage readers.

Percentage error. The following represents the percentage of errors for each word type in early stage readers: exception words (M = 11.0%, SD = 20.4%) and non-words (M = 24.8%, SD = 23.9%). For later stage readers, the percentage of errors for each word type was, exception words (M = 4.5%, SD = 8.4%) and non-words (M = 18.3%, SD = 21.6%).

Group interactions in reading speed. A two-way mixed design ANOVA was conducted to determine if there was a main effect of group and an interaction between word type and group in the reading speed task. There was a main effect of word type, $F(1, 135) = 152.20$, $p < .001$, $\eta_p^2 = .53$, and group, $F(1, 135) = 26.52$, $p < .001$, $\eta_p^2 = .16$. The interaction between word type and group, $F(1,135) = 11.12$, $p =$

.001, $\eta_p^2 = .08$, was significant. Table 4.1 shows that although reading speed for early stage readers was significantly slower compared to later stage readers for both word types, the difference in reading speed was larger for non-words, compared with exception words.

Stage 3. SEM Analysis via M*plus* Version 5.2

Table 4.6 provides the factor loadings from the initial SEM analysis for visual and auditory attention for early and later stage readers. Firstly, separate CFA measurement models for each reading stage, as implemented through M*plus*, were tested to determine whether the proposed latent constructs (attention, phonological processing, reading accuracy, and reading speed) were reliably measured by their indicators (Hayes, 2013; Tabachnick, 2013). The analysis was conducted separately for visual and auditory attention. Although the factor loadings for the phonological processing, reading accuracy, and reading speed latent variables ranged between .57 and 1.00, and, more critically, were statistically significant, the visual and auditory attention constructs were problematic. That is, initial inspections revealed that the loadings for the visual and auditory attention constructs were either well below the suggested .50─.70 range or had a *p* value of greater than .05 (Tabachnick & Fidell, 2007). As shown in Table 4.6, their loadings were not sufficient to classify each network variable, for each modality, under a latent construct of "Visual Attention" or "Auditory Attention". This implies that the networks are independent (cf. Pozuelos et al., 2014). Consequently, the attention network measures were treated as observed variables.

Table 4.6: SEM Factor Loadings for Visual and Auditory Attention in the Early and Later Stages of Reading

Construct	Indicator	Factor Loading	Probability
	Early Stages of Reading (*n* = 72)		
Visual Attention	Alerting	0.02	.96
	Orienting	0.03	.96
	Executive	0.00	.97
Auditory Attention	Alerting	0.23	.18
	Orienting	0.71	.08
	Executive	-0.04	.82
	Later Stages of Reading (*n* = 70)		
Visual Attention	Alerting	0.25	.02
	Orienting	-0.06	.60

	Executive	__	__
Auditory Attention	Alerting	0.30	0.01
	Orienting	0.14	0.23
	Executive	__	__

Note. Dashes indicate that factor loadings could not be computed because of the negative (small) residual variance of the indicator. Hence, the variance for these loading were fixed at 1, as suggested by Muthén (2013).

Reading accuracy. Figure 4.1 illustrates the re-defined hypothesised model for the relationship between attention, phonological processing, and reading accuracy, with each attention network represented as observed variables, rather than a single latent construct. The fit of the measurement portion of the model (i.e., the relationship between phonological processing and reading accuracy) was initially tested within each stage of reading, before including grouping as a factor. The results of this initial fitting are presented in Table 4.7, which shows a good fit to the data for early stage readers.

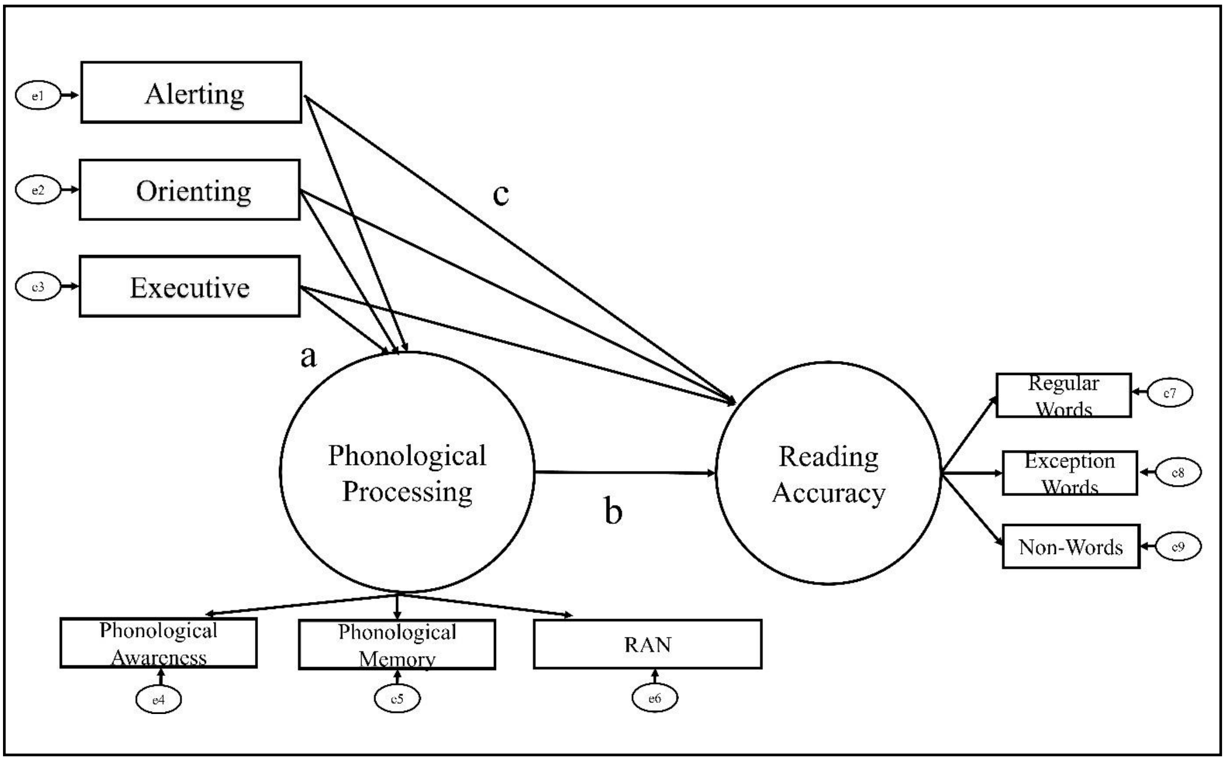


Figure 4.1. Hypothesised (modified) two-factor model for the relationship between attention (visual and auditory assessed separately), phonological processing, and reading accuracy; RAN = rapid automatised naming.

In contrast, warnings from the M*plus* software suggested that for later stage readers, the reading accuracy construct was problematic. The warning concerned the possibility of multicollinearity within the data for later stage readers, given that the parameter estimates regarding the correlation between phonological processing and reading accuracy was > 1. Consequently, the model was modified, and a revised model was developed by deleting the values of one of the three loadings for word reading accuracy, starting with the first indicator of regular word reading, until the best fitting model was identified. The fit indices in Table 4.7 illustrates that there were no significant changes in the fit across each revision when exception and non-words were removed. However, the removal of the regular word indicator improved model fit, and the correlation between phonological processing and reading accuracy was reduced to a value below 1. In line with the suggestions of Hayduk and Littvay (2012), the regular words indicator was removed for later stage readers.[8] Moreover, Table 4.7 illustrates that the fit indices of this modified model (i.e., removal of regular words) for later stage readers were statistically superior to the hypothesised model, given its lower chi-square score and higher *p* value.[9]

Table 4.7: Fit Indices for the Initial Models for the Relationship between Phonological Processing and Reading Accuracy for Early (*n* = 72) and Later Stage Readers (*n* = 70)

Model	X^2	*p-value*	*df*	CFI	TFI	RMSEA	SRMR	Correlation
ES: Initial model	12.93	.11	8	.97	.95	.09	.04	.80
LS: Initial model	4.46	.81	8	1.00	1.00	.00	.03	1.06
LS: Removal of RW	1.35	.85	4	1.00	1.00	.00	.02	0.99
LS: Removal of EW	1.99	.74	4	1.00	1.00	.00	.03	1.03
LS: Removal of NW	1.64	.80	4	1.00	1.00	.00	.03	1.15

Note. ES = early stage; LS = later stage; RW = regular words; EW = exception words; NW = non-words; X^2 = chi-square; *df* = degrees of freedom; CFI = comparative fit index; TFI = Tucker-Lewis index; RMSEA = root mean square error of approximation; SRMR = standardised root mean square residual.

[8] The removal of the regular word indicator is theoretically acceptable since this programme of research examines word reading (without distinguishing between different word types). Moreover, the inclusion of both exception word and non-word indicators retains the ability to provide reliable measurements of word reading accuracy, without biasing the assessment of reading to a specific reading pathway. Furthermore, it could be that regular words are redundant for older readers in this sample because they are sensitive to both lexical and sub-lexical pathways.

[9] The chi-square score and *p* value of close fit were given priority in determining model fit because they are a relatively stable measure for smaller (i.e., < 200) sample sizes (Kline, 2014).

However, the removal of regular words for later stage readers indicates that the factor of reading accuracy became conceptually different across early and later stage readers. This outcome suggests that a multiple-group SEM analysis was inappropriate. To conduct invariance testing, each group should contain the same number of latent and observed variables (Vandenberg & Lance, 2000). To achieve the aim of Study 1, which was to determine group differences between early and later stage readers, the invariant indicator of regular word reading accuracy was also removed from the early stage reading accuracy construct, so that tests of measurement and structural invariance could be conducted (Christian Nitzl, personal communication, 2018; Kenny, 2011). The removal of the regular words for early stage readers still provided a good fit to the data, X^2 (4) = 5.83, p = .21, CFI = .97, TLI = .94, RMSEA = .08,[10] and SRMR = .04 (Phonological Processing *CR* = 0.52, Reading Accuracy *CR* = 0.80). The new hypothesised model that will facilitate a meaningful group comparison, through multiple-group SEM analysis, is shown in Figure 4.2. For ease of presentation, results are presented firstly for reading accuracy and then for reading speed, each having "Group" as a factor. The separation of reading accuracy and reading speed was adopted, given that the number of data points does not permit a robust assessment of a model combining accuracy and speed indicators. For the same reason, this analysis has been further separated based on visual and auditory attention.

Moreover, given that the hypothesised model in Figure 4.2 now contained relationships between observed (alerting, orienting, and executive attention) and latent (phonological processing and reading) constructs, the analysis, as detailed below, followed a four-step procedure (instead of the three-step procedure that was proposed in the analysis plan and rationale of this Chapter) as per the combined suggestions of Bengt Muthén (personal communication, 2018) and Muthén and Muthén (2008):

(a) Separate CFA models for the latent variables (only for phonological processing and reading for both groups of readers) were fitted.

[10] Given that the *p* value of close fit was not statistically significant (despite the high RMSEA value), this suggests a well-fitting measurement model.

(b) Measurement invariance for the latent variable of phonological processing and reading in a multiple-group analysis was tested. Model 1 (configural invariance), Model 2 (metric invariance), Model 3 (scalar invariance), and Model 4 (error invariance) were nested.

(c) The mediation model, including attention network observed variables, phonological processing, and reading for both groups, was fitted.

(d) Structural invariance tests (i.e., testing the pathways) for the analysis of visual and auditory attention networks were conducted separately. Model 5 (factor variance-covariance invariance, visual attention) and Model 6 (factor variance-covariance invariance, auditory attention), were nested.

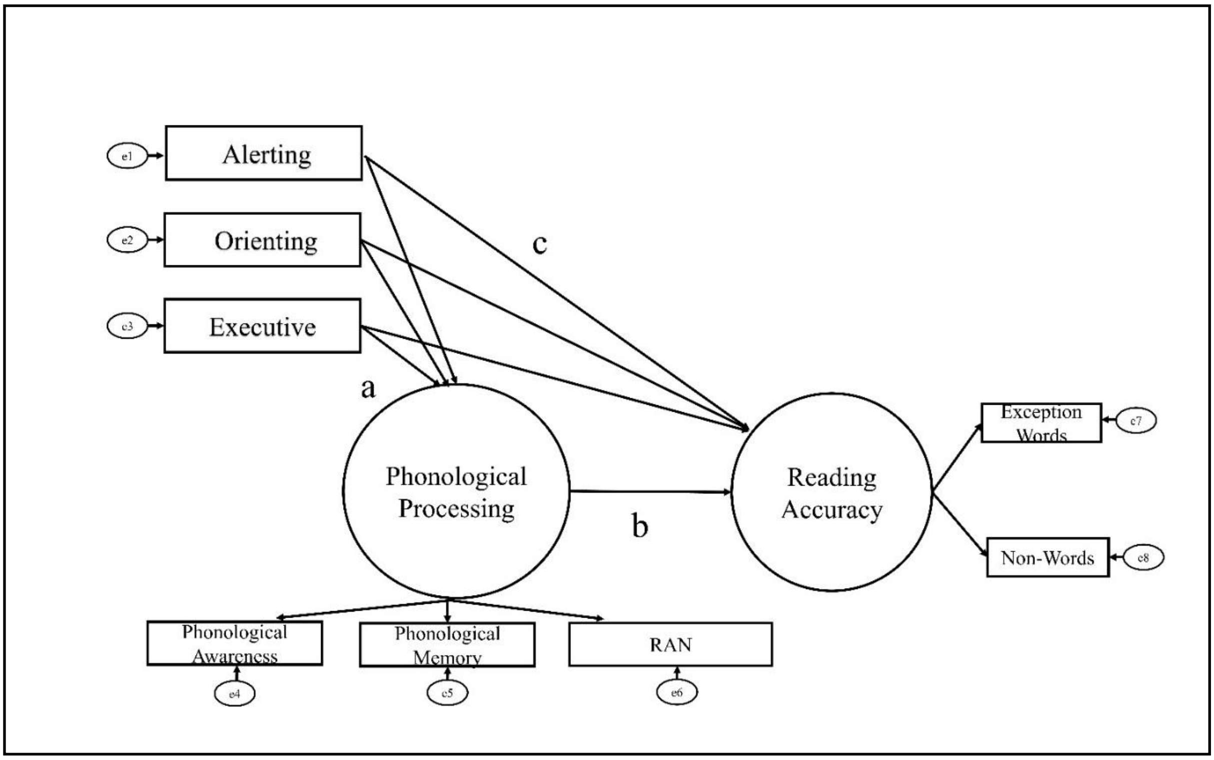


Figure 4.2. Hypothesised (modified by excluding regular word reading from the reading accuracy construct) two-factor model for the relationship between attention (visual and auditory assessed separately), phonological processing, and reading accuracy; RAN = rapid automatised naming.

Table 4.8 provides the fit indices for the test of group measurement (Models 1–4) and structural (Models 5–6) invariance in the relationship between attention, phonological processing, and reading accuracy. Invariance testing was conducted using a series of tests according to Bengt Muthén (personal communication, 2018). That is, these models were partially nested; the models differed in terms of their level of restrictiveness and the parameters that were constrained. Model 1, the least restrictive model, only constrained the factorial structure. Model 1 was the first step to establishing measurement invariance. Model 2 added the constraint of equal factor loadings. Model 3 added the constraint of equal item intercepts. Model 4 added the constraint of error invariance. Then, given that the observed attention variables were added to the model, the structural fit was assessed for both visual and auditory attention. Then, Model 5 (nested under Model 4) constrained factor variance-covariances for a model that included visual attention networks, phonological processing, and reading accuracy. Model 6 (nested under Model 4) constrained factor variance-covariances across the groups for a model that included auditory attention networks, phonological processing, and reading accuracy.

As the results in Table 4.8 show, the indices for Model 1 were a good fit to the data. The chi-square difference for Model 1 versus Model 2 (X^2 = 2.27, *df* = 3) was not statistically significant, indicating that the regression slopes across early and later stage readers were invariant. The chi-square difference for Model 2 versus Model 3 (X^2 = 7.22, *df* = 4) was not statistically significant, indicating that the intercepts across both stage of reading were equal. Finally, the chi-square difference for Model 3 versus Model 4 (X^2 = 4.49, *df* = 3) was not statistically significant, indicating that the errors across both groups were equal. Therefore, measurement invariance across reading group was confirmed at the metric, scalar, and error levels.

For structural invariance, the chi-square difference between Model 4 versus Model 5 (X^2 = 25.94, *df* = 20) was not statistically significant, indicating that there was covariance and variance invariance across group for a model that included visual attention, phonological processing, and reading accuracy did not differ significantly across group. Similarly, the chi-square difference between Model 4 versus Model 6 was not significantly different (X^2 = 16.41, *df* = 20), indicating that there was covariance and variance invariance across group for a model that included auditory attention, phonological processing, and reading accuracy did not differ significantly across group. Altogether, these tests confirm measurement and structural invariance for all latent and observed variables across early and later stage readers.

Table 4.8: Fit Indices of Group Invariance Testing for Attention Networks, Phonological Processing, and Reading Accuracy in Early (*n* = 72) and Later (*n* = 70) Stage Readers in Study 1

Model	X^2	*df*	*p*	CFI	TLI	RMSEA	SRMR	Comparison	Decision
Step 1-Measurement Invariance									
Model 1. Configural	7.18	8	.52	1.00	1.00	0.00	0.03	__	Accept
Model 2. Metric	9.45	11	.58	1.00	1.00	0.00	0.07	Model 1 vs. Model 2	Accept
Model 3. Scalar	16.67	15	.34	0.99	0.98	0.04	0.10	Model 2 vs. Model 3	Accept
Model 4. Error	21.16	18	.27	0.97	0.97	0.05	0.18	Model 3 vs. Model 4	Accept
Step 2-Mediation Model Fit									
Visual mediation model	35.90	33	.33	0.98	0.97	0.04	0.08	__	Accept
Auditory mediation model	32.67	33	.48	1.00	1.00	0.00	0.07	__	Accept
Step 3-Structural Invariance									
Model 5. Variance-covariance (visual)	47.10	38	.15	0.94	0.92	0.06	0.11	Model 4 vs. Model 5	Accept
Model 6. Variance-covariance (auditory)	37.57	38	.49	1.00	1.00	0.00	0.09	Model 4 vs. Model 6	Accept

Note. X^2 = chi-square; *df* = degrees of freedom; CFI = comparative fit index; TFI = Tucker-Lewis index; RMSEA = root mean square error of approximation; SRMR = standardised root mean square residual.

Early stage readers: Measurement model analysis. The results from the multiple-group CFA for the relationship between phonological processing and reading accuracy (standardised scores) in early stage readers are shown in Figure 4.3. There was a significant, positive relationship between phonological processing and reading accuracy ($p < .001$). Figure 4.3 also provides the values for the squared multiple correlation for each indicator (in italics), with the highest and lowest being non-words (.69) and RAN (.15) respectively. For example, this is interpreted as the construct of "phonological processing" accounts for 15% of the variance in RAN. Given that the indices were a good fit to the data, post-hoc modifications were not required, and there were no discrepancies, with the standardised residual variances ranging between .31 and .85, well within the suggested ≤ 2 criterion.

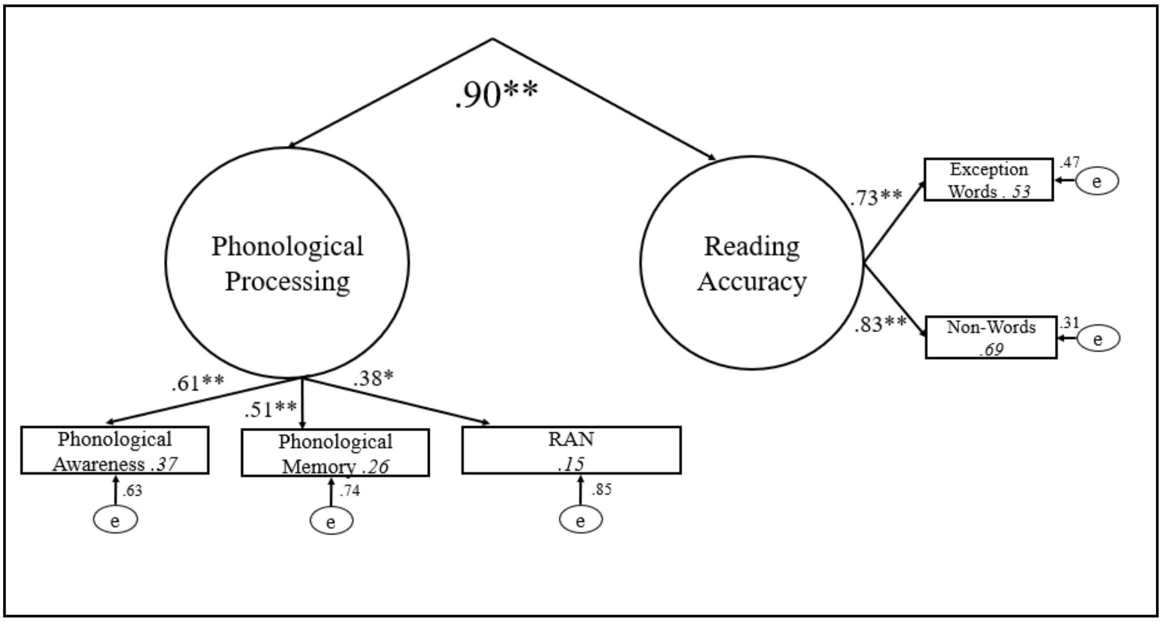


Figure 4.3. Measurement model with CFA results (standardised estimates) for the hypothesised reading accuracy model in early stage readers ($n = 72$). *Correlation was significant ($p < .05$) at the .05 level (2-tailed). **Correlation was strong and significant ($p < .001$) at the .05 level (2-tailed); RAN = rapid automatised naming.

The relationship between factor loadings for phonological processing and reading accuracy in early stage readers is presented in Table 4.9. There was a strong association between loadings of exception word and non-word reading accuracy, with both correlating with phonological awareness, phonological memory and RAN.

There were however weaker associations among the loadings of phonological awareness, phonological memory and RAN.

Table 4.9: Correlation between Factor Loadings for the Phonological Processing and Reading Accuracy Latent Variables in Early Stage Readers (*n* = 72)

	1	2	3	4
1. Phonological awareness				
2. Phonological memory	.31			
3. RAN	.23	.20		
4. Exception words	.40	.34	.25	
5. Non-words	.46	.38	.29	.61

Note. RAN = rapid automatised naming.

Structural analysis: Total, indirect, and direct effects of visual and auditory attention. Tables 4.10 to 4.13 illustrate the non-significant total, indirect, and direct effects of visual alerting, visual executive, auditory alerting, and auditory executive attention, in their interactions with phonological processing and reading accuracy.

Table 4.10: Total, Direct, and Indirect Effects between Visual Alerting, Phonological Processing, and Reading Accuracy in Early Stage Readers (*n* = 72)

Model	β Visual alerting	Phonological processing	95% CI, *p* value
Direct			
Visual alerting		0.17	[-0.30, 0.26], *p* = .89
Reading accuracy	-0.02	0.90	
Indirect			
Visual alerting		0.15	[-0.15, 0.46], *p* = .32
Reading accuracy			
Total			
Visual alerting		0.17	[-0.12, 0.39], *p* = .29
Reading accuracy	0.14	0.90	

Note. The single pathway between visual alerting and phonological processing was non-significant (*p* = .29); β = beta (standardised coefficient); CI = confidence interval.

Table 4.11: Total, Direct, and Indirect Effects between Visual Executive, Phonological Processing, and Reading Accuracy in Early Stage Readers (*n* = 72)

Model	β		95% CI, *p* value
	Visual executive	Phonological processing	
Direct			
Visual executive		0.04	[-0.33, 0.20], *p* = .62
Reading accuracy	-0.07	0.90	
Indirect			
Visual executive		0.03	[-0.26, 0.32], *p* = .82
Reading accuracy			
Total			
Visual executive		0.04	[-0.29, 0.22], *p* = .80
Reading accuracy	-0.03	0.90	

Note. The single pathway between visual executive attention and phonological processing was non-significant (*p* = .82); β = beta (standardised coefficient); CI = confidence interval.

Table 4.12: Total, Direct, and Indirect Effects between Auditory Alerting, Phonological Processing, and Reading Accuracy in Early Stage Readers (*n* = 72)

Model	β		95% CI, *p* value
	Auditory alerting	Phonological processing	
Direct			
Auditory alerting		0.07	[-0.19, 0.32], *p* = .61
Reading accuracy	0.07	0.90	
Indirect			
Auditory alerting		0.07	[-0.22, 0.36], *p* = .66
Reading accuracy			
Total			
Auditory alerting		0.07	[-0.12, 0.39], *p* = .31
Reading accuracy	0.13	0.90	

Note. The single pathway between auditory alerting and phonological processing was non-significant (*p* = .65); β = beta (standardised coefficient); CI = confidence interval.

Table 4.13: Total, Direct, and Indirect Effects between Auditory Executive, Phonological Processing, and Reading Accuracy in Early Stage Readers (*n* = 72)

Model	β		95% CI, *p* value
	Auditory executive	Phonological processing	
Direct			
Auditory executive		0.07	[-0.27, 0.24], *p* = .91
Reading accuracy	-0.02	0.90	
Indirect			
Auditory executive		0.07	[-0.22, 0.36], *p* = .63
Reading accuracy			
Total			
Auditory executive		0.07	[-0.20, 0.31], *p* = .68
Reading accuracy	0.06	0.90	

Note. The single pathway between auditory executive attention and phonological processing was non-significant ($p = .63$); β = beta (standardised coefficient); CI = confidence interval.

Figure 4.4 illustrates the path coefficients (with standard errors in parentheses) for the relationship between visual orienting and reading accuracy via phonological processing in early stage readers. Notably, the indirect effect of the visual orienting network was marginally significant and positive in its relationship with reading accuracy through phonological processing (95% CI [-0.02, 0.64], with a point estimate of 0.31, $p = .07$). This suggests that a larger visual orienting effect is associated with better phonological processing, and higher reading accuracy in early stage readers. The direct (95% CI [-0.49, 0.14], with a point estimate of -0.18, $p = .27$) and total (95% CI [-0.12, 0.39], with a point estimate of 0.13, $p = .30$) effects were non-significant.

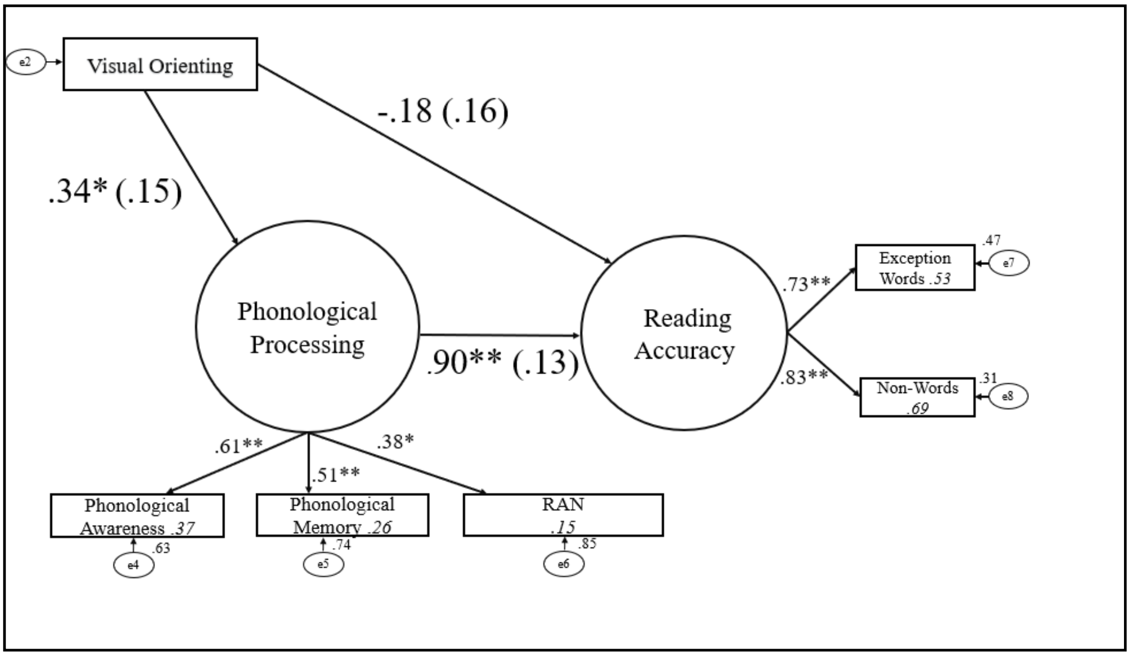


Figure 4.4. The relationship between visual orienting and reading accuracy through phonological processing in early stage readers (n = 72). Visual alerting and visual executive attention were also assessed in this model, but for ease of illustration, and given its large effect size, only visual orienting is illustrated. *Correlation was significant (p < .05) at the .05 level (2-tailed). **Correlation was strong and significant (p < .001) at the .05 level (2-tailed). The single pathway between visual orienting and phonological processing was significant (p = .03). Standard errors are provided in parentheses. RAN = rapid automatised naming.

In contrast to auditory alerting and auditory executive attention, Figure 4.5 illustrates a significant negative, indirect effect in the relationship between auditory orienting and reading accuracy through phonological processing for early stage readers. This suggests that a larger auditory orienting effect is associated with poorer phonological processing, and lower reading accuracy in early stage readers. The mediating effect was further supported by the non-zero value in the 95% bias-corrected bootstrap confidence interval (95% CI [-0.75, -0.03], with a point estimate of -0.39, p = .03). The direct effect of auditory orienting on reading accuracy was positive and marginally significant (95% CI [-0.01, 0.67], with a point estimate of 0.33, p = .06), suggesting that a larger orienting effect score is directly associated with higher reading accuracy scores. The total effect was negative and non-significant, (95% CI [-0.33, 0.20], with a point estimate of -0.06, $p = .64$). Although the total effect is a combination of the indirect and direct effect, its significance is not necessarily a pre-requisite for accepting the significant indirect effect produced in the model (Hayes, 2013; Rucker, Preacher, Tormala, & Petty, 2011). Furthermore, the inconsistent mediation (i.e., opposite signs for the indirect and direct effects), is likely to cause a smaller total effect (Kenny, 2018).

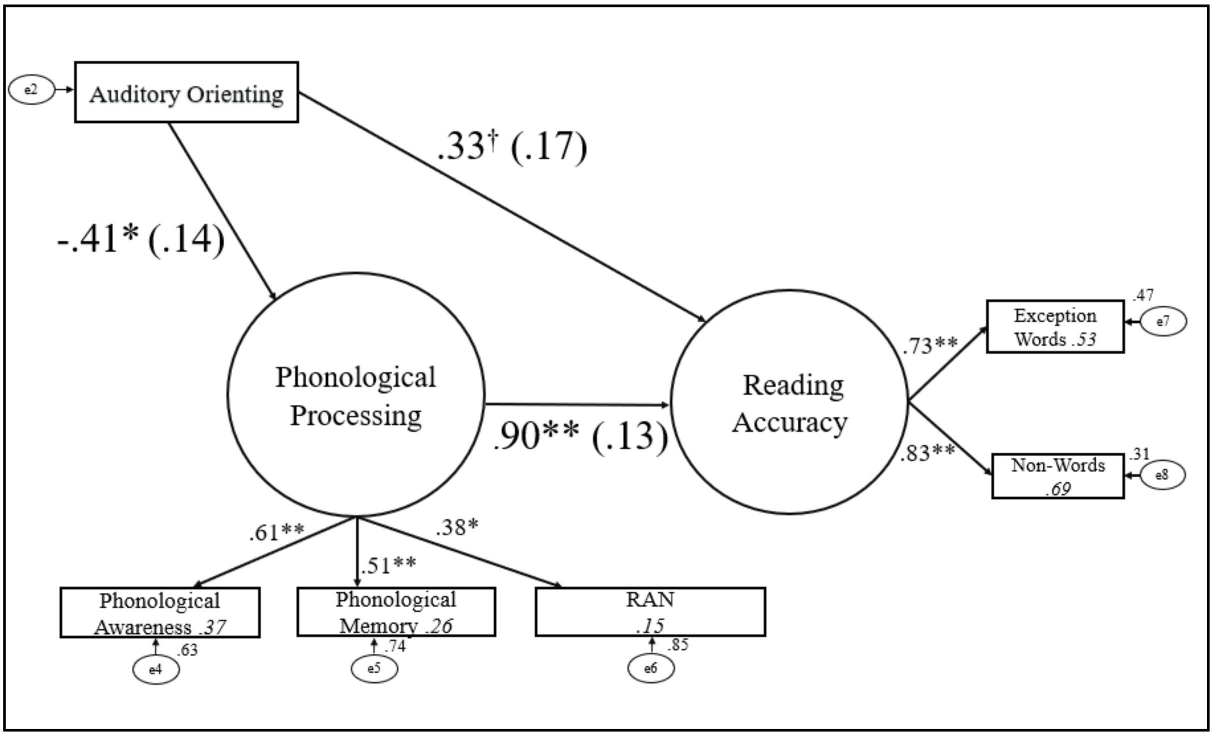


Figure 4.5. The relationship between auditory orienting and reading accuracy through phonological processing in early stage readers ($n = 72$). Auditory alerting and auditory executive attention were also assessed in this model, but for ease of illustration, and given its significance, only auditory orienting is illustrated. *Correlation was significant ($p < .05$) at the .05 level (2-tailed). **Correlation was strong and significant ($p < .001$) at the .05 level (2-tailed). The single pathway between auditory orienting and phonological processing was significant ($p = .01$). Standard errors are provided in parentheses. RAN = rapid automatised naming.

Later stage readers: Measurement model analysis. The results from the multiple-group CFA for the relationship between phonological processing and reading accuracy (standardised scores) in later stage readers are shown in Figure 4.6. There was a significant, positive relationship between phonological processing and reading accuracy ($p < .001$). Figure 4.6 also provides the values for the squared multiple correlation for each indicator (in italics), with the highest and lowest being non-words (.75) and RAN (.11) respectively. For example, this is interpreted as the construct of "phonological processing" accounts for 11% of the variance in RAN. Given that the indices were a good fit to the data, post-hoc modifications were not required, and there were no discrepancies, with the standardised residual variances ranging between .25 and .89, well within the suggested ≤ 2 criterion.

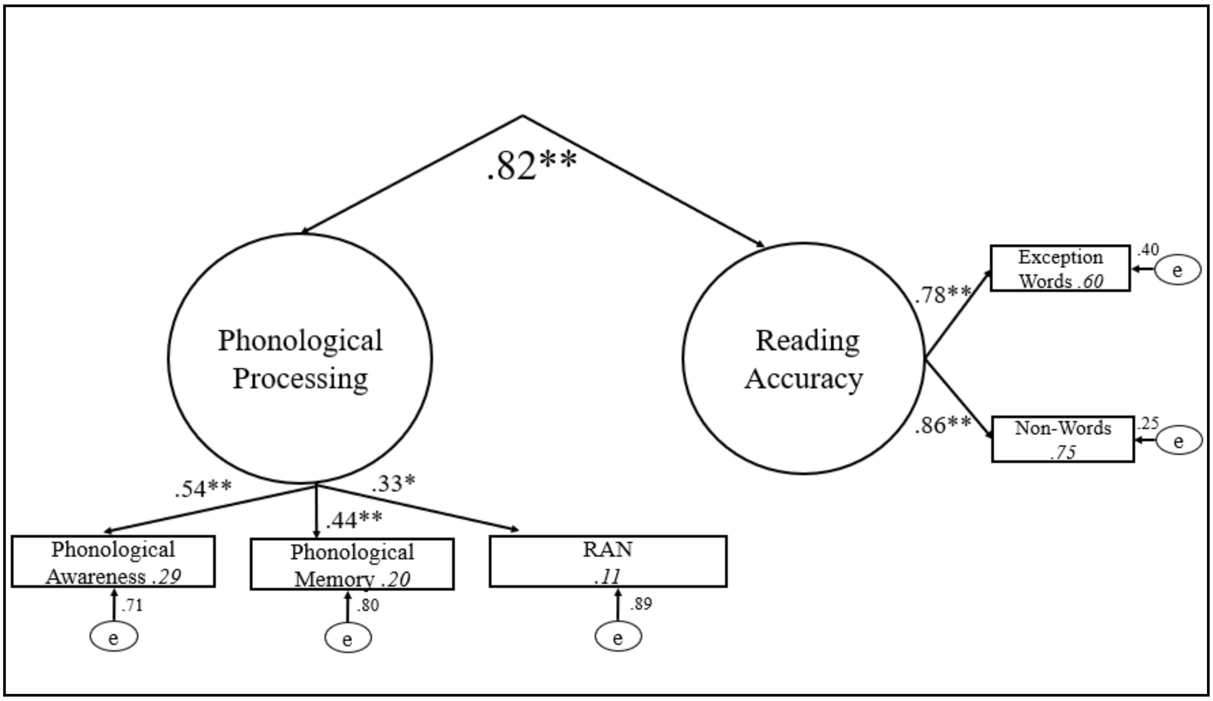


Figure 4.6. Measurement model with CFA results (standardised estimates) for the modified hypothesised relationship between phonological processing and reading accuracy in later stage readers ($n = 70$). *Correlation was significant ($p < .05$) at the .05 level (2-tailed). **Correlation was strong and significant ($p < .001$) at the .05 level (2-tailed). RAN = rapid automatised naming.

The relationship between factor loadings for phonological processing and reading accuracy in later stage readers is presented in Table 4.14. There was a strong association between the loadings of non-word and exception word reading accuracy, with both correlating with phonological awareness and phonological memory, but weaker associations with RAN. There were also weaker associations among the loadings of phonological awareness, phonological memory, and RAN.

Table 4.14: Correlation between Factor Loadings for the Phonological Processing and Reading Accuracy Latent Variables in Later Stage Readers (*n* = 70)

	1	2	3	4
1. Phonological awareness				
2. Phonological memory	.24			
3. RAN	.18	.15		
4. Exception words	.34	.28	.21	
5. Non-words	.38	.32	.23	.67

Note. RAN = rapid automatised naming.

Structural analysis: Total, indirect, and direct effects of visual and auditory attention. Tables 4.15 to 4.19 illustrate the total, indirect, and direct effects of visual alerting, visual executive, auditory alerting, auditory orienting, and auditory executive attention, in their interactions with phonological processing and reading accuracy for later stage readers. Of note is the significant total effect (p = .04) in Table 4.18, suggesting some influence of auditory orienting upon reading accuracy in later stage readers. The nature of this relationship is clarified later in the section that presents Pearson's correlation analysis to examine the specificity of significant SEM effects.

Table 4.15: Total, Direct, and Indirect Effects between Visual Alerting, Phonological Processing, and Reading Accuracy in Later Stage Readers (*n* = 70)

Model	β		95% CI, *p* value
	Visual alerting	Phonological processing	
Direct			
Visual alerting		0.03	[-0.32, 0.31], *p* = .97
Reading accuracy	-0.01	0.82	
Indirect			
Visual alerting		0.03	[-0.29, 0.35], *p* = .86

Reading accuracy			
Total			
Visual alerting		0.03	[-0.25, 0.29], *p* = .87
Reading accuracy	0.02	0.82	

Note. The single pathway between visual alerting and phonological processing was non-significant (*p* = .86); β = beta (standardised coefficient); CI = confidence interval.

Table 4.16: Total, Direct, and Indirect Effects between Visual Executive, Phonological Processing, and Reading Accuracy in Later Stage Readers (*n* = 70)

Model	β		95% CI, *p* value
	Visual executive	Phonological processing	
Direct			
Visual executive		0.15	[-0.36, 0.27], *p* = .71
Reading accuracy	-0.04	0.82	
Indirect			
Visual executive		0.14	[-0.19, 0.46], *p* = .41
Reading accuracy			
Total			
Visual executive		0.15	[-0.18, 0.36], *p* = .51
Reading accuracy	0.09	0.82	

Note. The single pathway between visual executive attention and phonological processing was non-significant (*p* = .40); β = beta (standardised coefficient); CI = confidence interval.

Table 4.17: Total, Direct, and Indirect Effects between Auditory Alerting, Phonological Processing, and Reading Accuracy in Later Stage Readers (*n* = 70)

Model	β		95% CI, *p* value
	Auditory alerting	Phonological processing	
Direct			
Auditory alerting		0.15	[-0.36, 0.25], *p* = .73
Reading accuracy	-0.05	0.82	
Indirect			
Auditory alerting		0.12	[-0.18, 0.41], *p* = .44
Reading accuracy			
Total			
Auditory alerting		0.15	[-0.22, 0.35], *p* = .67
Reading accuracy	0.06	0.82	

Note. The single pathway between auditory alerting and phonological processing was non-significant (*p* = .43); β = beta (standardised coefficient); CI = confidence interval.

Table 4.18: Total, Direct, and Indirect Effects between Auditory Orienting, Phonological Processing, and Reading Accuracy in Later Stage Readers (*n* = 70)

Model	β		95% CI, *p* value
	Auditory orienting	Phonological processing	
Direct			
Auditory orienting		0.15	[-0.14, 0.45], *p* = .31
Reading accuracy	0.15	0.82	
Indirect			
Auditory orienting		0.12	[-0.16, 0.40], *p* = .41
Reading accuracy			
Total			
Auditory orienting		0.15	[0.01, 0.53], *p* = .04
Reading accuracy	0.27	0.82	

Note. The single pathway between auditory orienting and phonological processing was non-significant (*p* = .41). β = beta (standardised coefficient); CI = confidence interval.

Table 4.19: Total, Direct, and Indirect Effects between Auditory Executive, Phonological Processing, and Reading Accuracy in Later Stage Readers (*n* = 70)

Model	β		95% CI, *p* value
	Auditory executive	Phonological processing	
Direct			
Auditory executive		0.12	[-0.26, 0.34], *p* = .78
Reading accuracy	0.04	0.82	
Indirect			
Auditory executive		0.09	[-0.20, 0.39], *p* = .54
Reading accuracy			
Total			
Auditory executive		0.12	[-0.14, 0.41], *p* = .33
Reading accuracy	0.13	0.82	

Note. The single pathway between auditory executive attention and phonological processing was non-significant (*p* = .54); β = beta (standardised coefficient); CI = confidence interval.

In contrast to visual alerting and visual executive attention, Figure 4.7 illustrates a significant, negative, indirect effect in the relationship between visual orienting and reading accuracy via phonological processing. This suggests that a larger visual orienting effect is associated with poorer phonological processing, and lower reading accuracy for later stage readers. This mediating effect was further supported by the non-zero value in the 95% bias-corrected bootstrap confidence interval (95% CI [-0.74, -0.04], with a point estimate of -0.39, *p* = .03). The direct effect of visual orienting on reading accuracy (95% CI [-0.16, 0.55], with a point estimate of 0.19, p = .29), was positive and non-significant. Finally, the total effect (95% CI [-0.45, 0.06], with a point estimate of -0.20, p = .13) was negative and non-significant.

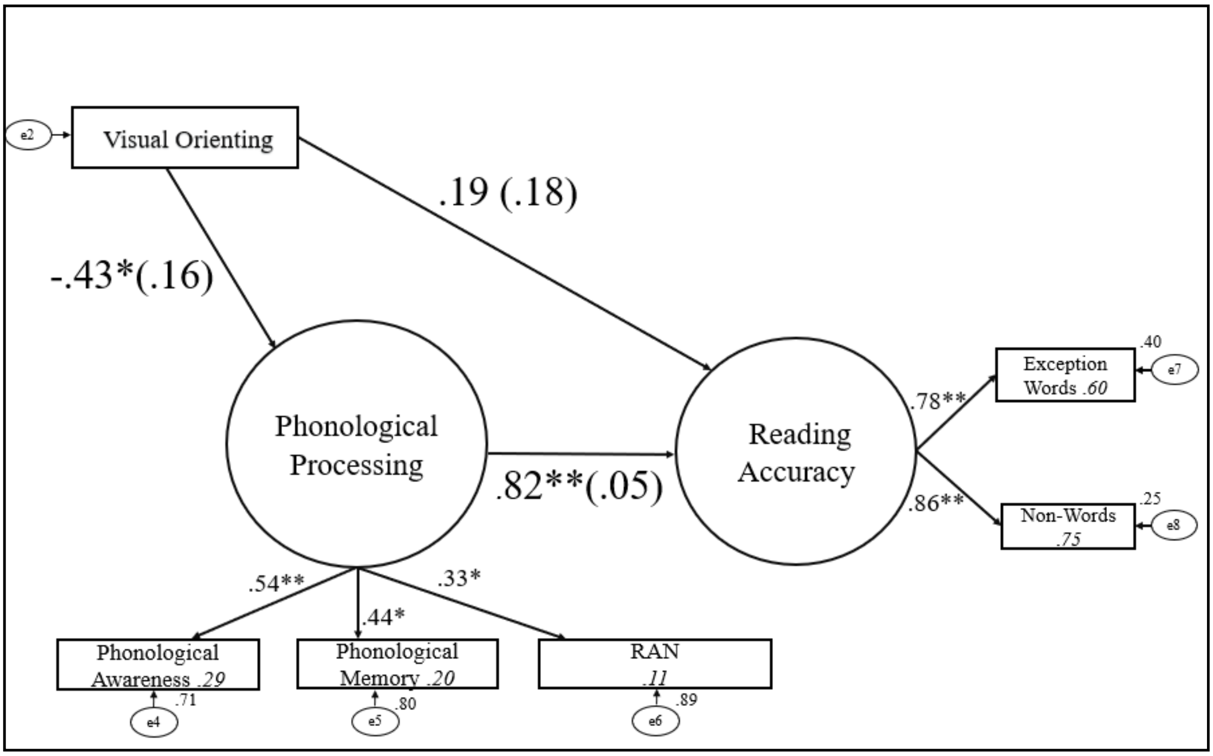


Figure 4.7. The relationship between visual orienting and reading accuracy through phonological processing in later stage readers (n = 70).Visual alerting and visual executive attention were also assessed in this model, but for ease of illustration, and given its significance, only visual orienting is illustrated. *Correlation was significant ($p < .05$) at the .05 level (2-tailed). **Correlation was strong and significant ($p < .001$) at the .05 level (2-tailed). The single pathway between visual orienting and phonological processing was significant (p = .01). Standard errors are provided in parentheses. RAN = rapid automatised naming.

Reading speed. Figure 4.8 illustrates the hypothesised model for the relationship between attention, phonological processing, and reading speed that was assessed for both stages of reading. The fit of the measurement model component of the model in Figure 4.8 (i.e., the latent constructs of phonological processing and reading speed) was initially tested, separately, for each of the two groups of readers ─ early stage reading group and later stage reading group.

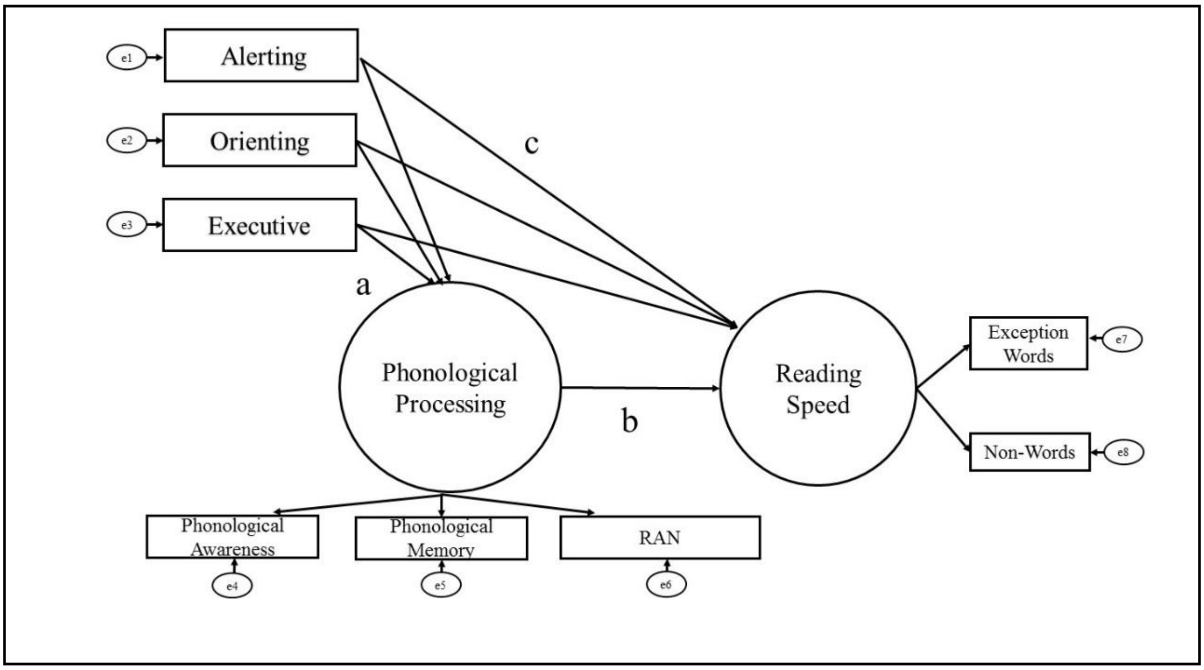


Figure 4.8. Hypothesised two factor model of the relationship between attention (visual and auditory attention assessed separately), phonological processing, and reading speed for both early (n = 72) and later (n = 70) stage readers. RAN = rapid automatised naming.

Table 4.20 provides the fit indices for the test of group measurement (Models 1─4) and structural (Models 5─6) invariance in the relationship between attention, phonological processing, and reading speed across early and later stage readers. The table shows acceptable fit indices. Model invariance across group was assessed by conducting a series of invariance tests according to Bengt Muthén (personal communication, 2018) and Muthén and Muthén (2008). Moreover, since exception word reading speed data for early stage readers had a non-normal distribution, MLR was used as the estimation method. As such, invariance was determined using the Satorra-Bentler scaled chi-square method (Satorra & Bentler, 2010). Table 4.21 further shows the mathematical calculation of this invariance testing. The chi-square difference for Model 1 versus Model 2 (X^2 = 1.42, df = 2), was not statistically significant indicating that the regression slopes across groups were invariant. The chi-square difference for Model 2 versus Model 3 (X^2 = 5.66, df = 3) was not statistically significant indicating that the intercepts across both groups were equal. Finally, the chi-square difference for Model 3 versus Model 4 (X^2 = 24.92, df = 2) was statistically significant indicating that the errors across both groups were unequal. Therefore, measurement invariance for both groups of readers was confirmed at the metric (Model 2), scalar (Model 3), but not at the error (Model 4) level. Therefore, subsequent models (Models 5 and 6) for assessing structural invariance, was nested under Model 3, since this model was invariant and had better fit indices, as Table 4.20 illustrates (Marsh et al., 2009).

For structural invariance, also illustrated by Table 4.21, the chi-square difference between Model 3 versus Model 5 (X^2 = 29.62, *df* = 23) was not statistically significant, indicating that there was covariance and variance invariance across group, for a model that includes visual attention, phonological processing, and reading speed, did not differ significantly. Similarly, the chi-square difference between Model 3 versus Model 6 (X^2 = 17.30, *df* = 24) was not significantly different, indicating that there was covariance and variance invariance across group for a model that includes auditory attention, phonological processing, and reading speed. Altogether, these tests confirm measurement and structural invariance for all latent and observed variables across early and later stage readers, though, the groups may differ in the extent to which they are characterised by the latent variables, since there was no error invariance.

Table 4.20: Fit Indices of Nested Models for Attention Networks, Phonological Processing, and Reading Speed in Early (*n* = 72) and Later Stage (*n* = 70) Readers in Study 1

Model	*df*	*p*	CFI	TLI	RMSEA	SRMR	Comparison	Decision
Measurement Invariance								
Model 0. Early stage	4	.70	.98	.95	.09	.02	__	Accept[11]
Model 0. Later stage	4	.48	1.00	1.00	.00	.04	__	Accept
Model 1. Configural	11	.74	.96	.93	.11	.06	__	Accept
Model 2. Metric	13	.92	.97	.95	.09	.08	Model 1 vs. Model 2	Accept
Model 3. Scalar	16	.97	.95	.94	.10	.12	Model 2 vs. Model 3	Accept
Model 4. Error	18	.90	.87	.78	.19	.19	Model 3 vs. Model 4	Reject
Mediation Model Fit								
Visual mediation	34	.99	.93	.90	.08	.09	__	Accept
Auditory mediation	34	.91	.98	.98	.04	.08	__	Accept
Structural Invariance [12]								
Model 5. Variance-covariance (visual)	39	1.00	.93	.91	.08	.14	Model 3 vs. Model 5	Accept
Model 6. Variance-covariance (auditory)	40	.97	.97	.97	.05	.13	Model 3 vs. Model 6	Accept

Note. *df* = degrees of freedom; CFI = comparative fit index; TFI = Tucker-Lewis index; RMSEA = root mean square error of approximation; SRMR = standardised root mean square residual.

[11] The initial fit of the model was satisfactory, X^2 (5) = 18.92, *p* = 0.60, CFI = .90, TLI = .80, RMSEA = .20, and SRMR = .07, with a poor TLI. There was a small, negative residual variance for non-word reading speed which was fixed at 0. In addition, the errors for RAN and phonological processing were covaried (Muthén, 2013).

[12] To facilitate data convergence, the indicators for the Reading Speed latent construct were rescaled to be kept between 1 and 10. This was achieved by dividing the original values by 10 (Muthén, 2012). Moreover, the small, negative, non-significant residual variance for non-word reading speed (Model 5 and Model 6) and phonological awareness (Model 6) were fixed to 0 (Muthén, 2013). Finally, to improve the fit of Model 5, the errors for reading speed and RAN were covaried, as suggested by the M*plus* modification indices (MIs).

Table 4.21: Calculations of Measurement and Structural Invariance Testing for Reading Speed Using the Satorra-Bentler Scaled Chi-Square Approach

Testing for Measurement Invariance (Comparing Model 1 versus Model 2)

cd = (d0*c0 - d1*c1)/(d0 - d1)

(13*1.488 - 11 * 1.455)/(13 - 11) = 1.670

TRd = (T0*c0 - T1*c1)/cd

(20.838*1.488 - 19.684*1.455) = 2.367

TRd = 2.367/1.670 = 1.417

df = 13-11= 2

1.417 < 5.991

Testing for Scalar Invariance (Comparing Model 2 versus Model 3)

cd = (d0*c0 - d1*c1)/(d0 - d1)

(16*1.489 - 13*1.455)/(16 - 13) = 1.636

TRd = (T0*c0 - T1*c1)/cd

(26.577* 1.489 - 20.838*1.455) = 9.254

TRd = 9.254/1.636= 5.656

df = 16-13 = 3

5.656 < 7.815

Testing for Error Invariance (Comparing Model 3 versus Model 4)

cd = (d0*c0 - d1*c1)/(d0 - d1)

(18*1.597- 16* 1.489)/(18 - 16) = 2.461

TRd = (T0*c0 - T1*c1)/cd

(63.177*1.597 - 26.577*1.489) = 61.321

TRd = 61.321/2.461= 24.917

df = 18-16 = 2

24.917 > 5.991

Testing for Factor Variance-Covariance Invariance (Comparing Model 3 versus Model 5, Visual Attention)

cd = (d0*c0 - d1*c1)/(d0 - d1)

= (39*1.312 - 16* 1.489)/(39 - 16) = 1.189

TRd = (T0*c0 - T1*c1)/cd

= (57.000*1.312 - 26.577*1.489) = 35.211

TRd= 35.211/1.189= 29.614

df = 39 -16 = 23 29.614 < 35.172
Testing for Factor Variance-Covariance Invariance (Comparing Model 3 versus Model 6, Auditory Attention) **cd** = (d0*c0 - d1*c1)/(d0 - d1) = (40*1.274 - 16* 1.489)/(40 - 16) = 1.131 **TRd** = (T0*c0 - T1*c1)/cd = (46.416*1.274 - 26.577*1.489) = 19.561 **TRd**= 19.561/1.131 = 17.295 ***df*** = 40-16 = 24 17.295 < 36.415

Early stage readers: Measurement model. The hypothesised measurement model, with the results from a multiple-group CFA, for the relationship between phonological processing and reading speed for early stage readers is shown in Figure 4.9 (Phonological Processing *CR* = 0.52, Reading Speed *CR* = 0.97). There was a marginally, significant negative relationship between phonological processing and reading speed, suggesting that as phonological processing scores increase, reading speed becomes faster ($p = .06$).

Standardised parameter estimates for the measurement model are also provided in Figure 4.9, as well as the values for the squared multiple correlation for each indicator (in italics), with the highest and lowest being non-words (1.00) and RAN (.08) respectively. Given that the indices were a good fit to the data, further post-hoc modifications were not required. The relationship between factor loadings for phonological processing and reading speed in early stage readers is presented in Table 4.22. There was a strong association between the loadings of non-word and exception word reading speed, with both correlating with phonological awareness and phonological memory, but weaker associations with RAN.

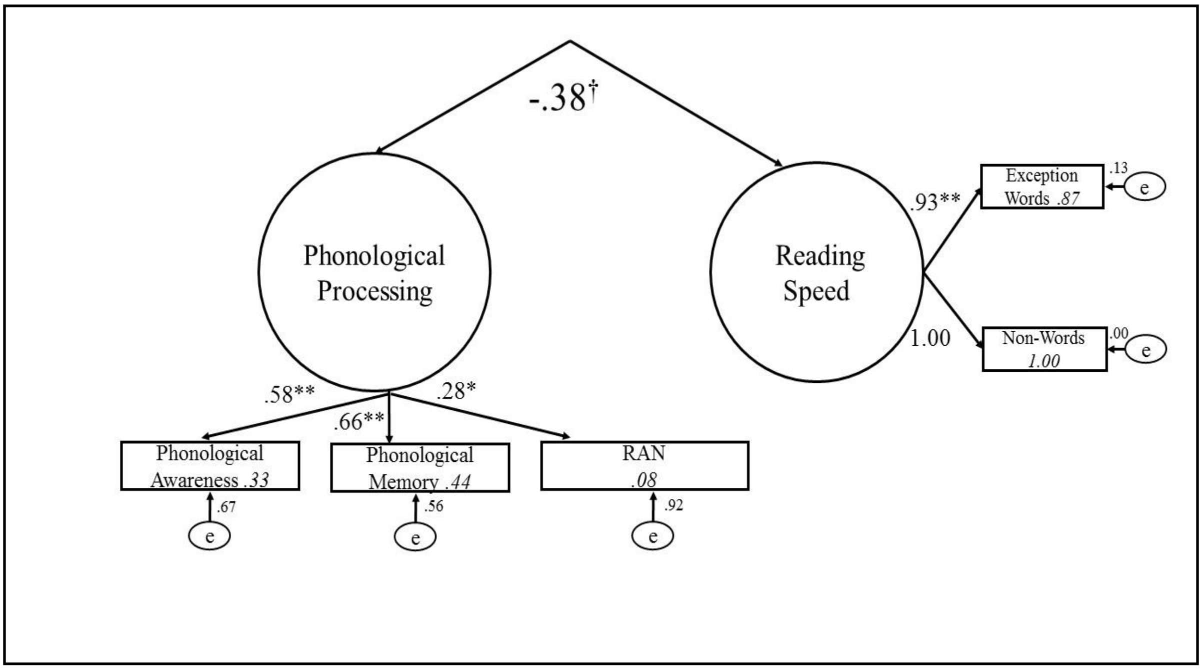


Figure 4.9. Measurement model with CFA results (standardised estimates) for the hypothesised relationship between phonological processing and reading speed in early stage readers (*n* = 72). *Correlation was significant (*p* < .05) at the .05 level (2-tailed). **Correlation was strong and significant (*p* < .001) at the .05 level (2-tailed). †Correlation was marginally significant at the *p* < .05 level. RAN = rapid automatised naming.

Table 4.22: Correlation between Factor Loadings for the Phonological Processing and Reading Speed Latent Variables in Early Stage Readers (*n* = 72)

	1	2	3	4
1. Phonological awareness				
2. Phonological memory	.38			
3. RAN	.16	.19		
4. Exception words	-.20	-.23	-.10	
5. Non-words	-.22	-.25	-.11	.93

Note. RAN = rapid automatised naming.

Early stage readers: Structural model of total, indirect, and direct effects.

Visual attention. The relationship between visual alerting and reading speed via phonological processing had non-significant indirect (95% CI [-0.21, 0.14], with a point estimate of -0.04, p = .67), and direct (95% CI [-0.47, 0.10], with a point estimate of -0.19, p = .20) effects. The total effect was significant (95% CI [-0.44, -0.01], with a point estimate of -0.22, p = .050).

The relationship between visual orienting and reading speed via phonological processing had non-significant total (95% CI [-0.21, 0.30], with a point estimate of 0.05, p = .72), indirect (95% CI [-0.35, 0.06], with a point estimate of -0.15, p = .17), and direct (95% CI [-0.06, 0.45], with a point estimate of 0.19, p = .14) effects.

The relationship between visual executive attention and reading speed via phonological processing had non-significant total (95% CI [-0.33, 0.19], with a point estimate of -0.07, p = .59), indirect (95% CI [-0.11, 0.18], with a point estimate of 0.04, p = .62), and direct (95% CI [-0.37, 0.16], with a point estimate of -0.11, p = .43) effects.

Auditory attention. The relationship between auditory alerting and reading speed via phonological processing had non-significant total (95% CI [-0.05, 0.37], with a point estimate of 0.16, p = .14), and indirect (95% CI [-0.16, 0.11], with a point estimate of -0.03, p = .71), effects, and a marginally significant direct (95% CI [-0.00, 0.37], with a point estimate of 0.18, p = .053) effect.

The relationship between auditory orienting and reading speed via phonological processing had non-significant total (95% CI [-0.32, 0.34], with a point estimate of 0.01, p = .95), and direct (95% CI [-0.50, 0.16], with a point estimate of -0.17, p = .32) effects. However, the indirect effect was marginally significant (95% CI [-0.02, 0.37], with a point estimate of 0.18, p = .07).

The relationship between auditory executive attention and reading speed via phonological processing had non-significant total (95% CI [-0.19, 0.25], with a point estimate of 0.03, p = .79), indirect (95% CI [-0.16, 0.09], with a point estimate of -0.04, p = .59), and direct (95% CI [-0.16, 0.29], with a point estimate of 0.07, p = .56) effects.

Later stage readers: Measurement model. The hypothesised measurement model, with the results from a multiple-group CFA, for the relationship between phonological processing and reading speed for later stage readers is shown in Figure 4.10 (Phonological Processing CR = 0.34, Reading Speed CR = 0.96). There was a non-significant, positive relationship between phonological processing and reading speed (p = .67). Figure 4.10 also provides the values for the squared multiple correlation for each indicator (in italics), with the highest and lowest being non-words (1.00) and RAN (.05) respectively. The relationship between factor loadings for phonological processing and reading speed in later stage readers is presented in Table 4.23. There were strong associations between loadings of non-word and exception word reading speed, with neither correlating strongly with the loadings of phonological awareness, phonological memory and RAN.

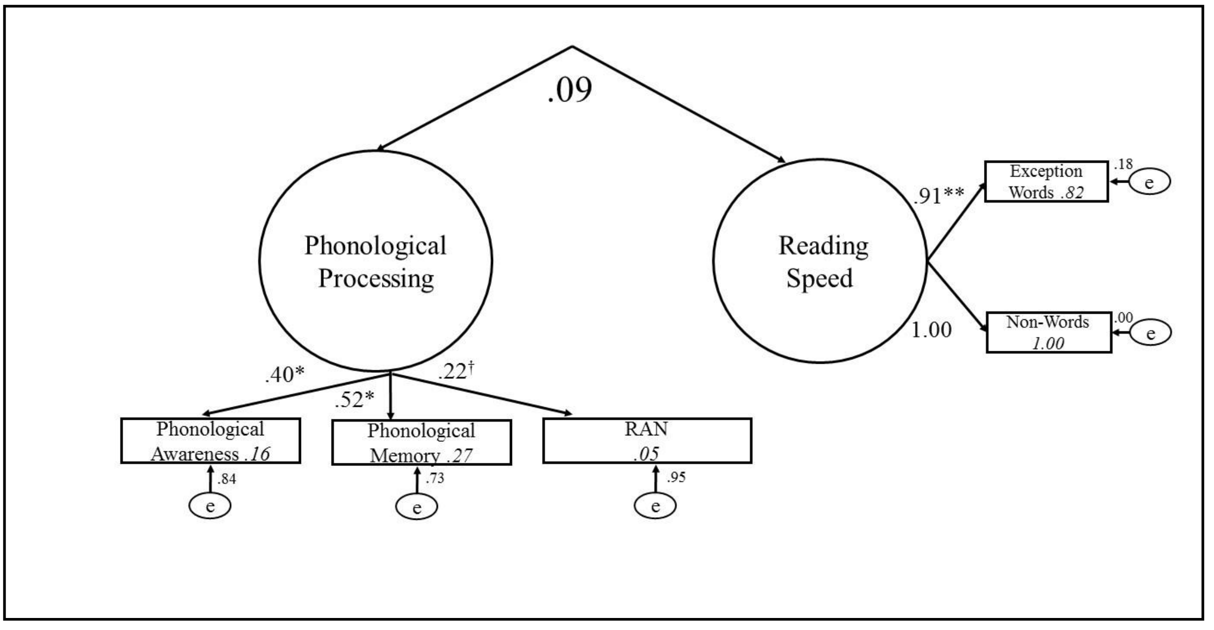


Figure 4.10. Measurement model with CFA results for the hypothesised relationship between phonological processing and reading speed in later stage readers (n = 70). *Correlation was significant (p < .05) at the .05 level (2-tailed). **Correlation was strong and significant (p < .001) at the .05 level (2-tailed). †Correlation was marginally significant at the p < .05 level. RAN = rapid automatised naming.

Table 4.23: Correlation between Factor Loadings for the Phonological Processing and Reading Speed Latent Variables in Later Stage Readers (*n* = 70)

	1	2	3	4
1. Phonological awareness				
2. Phonological memory	.21			
3. RAN	.09	.11		
4. Exception words	.03	.04	.02	
5. Non-words	.04	.05	.02	.91

Note. RAN = rapid automatised naming.

Later stage readers: Structural model of total, indirect, and direct effects.

Visual attention. The relationship between visual alerting and reading speed via phonological processing had non-significant total (95% CI [-0.07, 0.37], with a point estimate of 0.15, p = .18), indirect (95% CI [-0.27, 0.10], with a point estimate of -0.08, p = .37), and direct (95% CI [-0.04, 0.50], with a point estimate of 0.23, p = .10) effects.

The relationship between visual orienting and reading speed via phonological processing had non-significant total (95% CI [-0.03, 0.32], with a point estimate of 0.15, p = .11), indirect (95% CI [-0.07, 0.11], with a point estimate of 0.02, p = .65), and direct (95% CI [-0.08, 0.33], with a point estimate of 0.13, p = .24) effects.

The relationship between visual executive attention and reading speed via phonological processing had non-significant total (95% CI [-0.36, 0.08], with a point estimate of -0.14, p = .22), indirect (95% CI [-0.09, 0.22], with a point estimate of 0.07, p = .41), and direct (95% CI [-0.48, 0.07], with a point estimate of -0.21, p = .14) effects.

Auditory attention. The relationship between auditory alerting and reading speed via phonological processing had non-significant total (95% CI [-0.26, 0.31], with a point estimate of 0.03, p = .85), indirect (95% CI [-0.09, 0.07], with a point estimate of -0.01, p = .74), and direct (95% CI [-0.27, 0.36], with a point estimate of 0.04, p = .80) effects.

The relationship between auditory orienting and reading speed via phonological processing had non-significant total (95% CI [-0.19, 0.17], with a point estimate of -0.01, p = .93), indirect (95% CI [-0.24, 0.38], with a point estimate of

0.07, *p* = .66), and direct (95% CI [-0.42, 0.27], with a point estimate of -0.08, *p* = .66) effects.

The relationship between auditory executive attention and reading speed via phonological processing had non-significant total (95% CI [-0.13, 0.50], with a point estimate of 0.19, *p* = .25), indirect (95% CI [-0.10, 0.07], with a point estimate of -0.02, *p* = .73), and direct (95% CI [-0.16, 0.56], with a point estimate of 0.20, *p* = .28) effects.

Stage 4. Specificity and Bi-directionality of Significant SEM Relationships

Specificity of significant SEM relationships.

Early stage readers. Given the significant role of orienting in the SEM results for reading accuracy in early stage readers, Pearson's correlation analysis accompanied the primary SEM results reported in Stage 3. Of interest was the relationship between orienting and specific phonological processing skills. Moreover, it was also of interest to know whether executive functioning influenced any of the variables included in the SEM analysis. The results of the correlational analysis between visual and auditory attention, phonological processing, reading, and executive functioning for early stage readers are shown in Table 4.24. There was a significant, positive relationship between visual orienting and phonological memory (*r* = .28, *p* = .02). There was also a significant, negative relationship between auditory orienting and phonological awareness (*r* = - .30, *p* = .01). The scatterplots in Figure 4.11 further illustrate the nature of these relationships. For example, higher visual orienting difference scores were associated with higher phonological memory accuracy scores. In contrast, higher auditory orienting difference scores were associated with lower phonological awareness accuracy scores. Table 4.24 further shows a significant, negative association between visual executive attention and auditory alerting (*r* = -.29, *p* = .01) for early stage readers. All other correlations between attention networks were non-significant. Finally, there was a significant, negative relationship between executive functioning and exception word reading accuracy (*r* = -.32, *p* = .01), suggesting that as executive functioning becomes poorer (as indexed by higher executive functioning scores), word reading accuracy for exception words decreases. Finally, there was a significant, positive relationship between executive functioning and exception word reading speed (*r* = .27, *p* = .04), suggesting that as executive functioning becomes poorer, reading speed for exception words becomes slower.

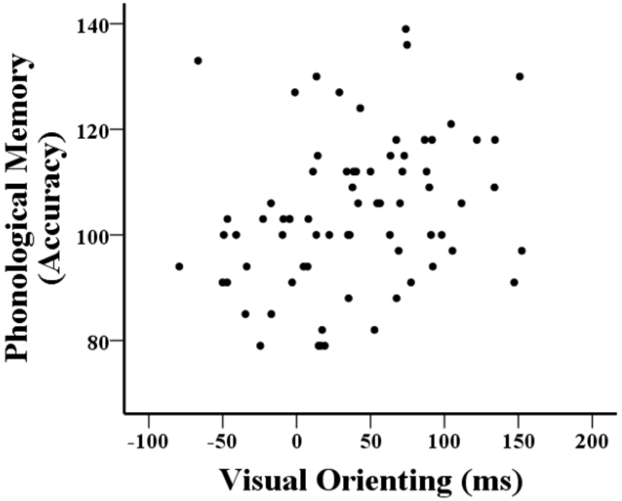
Later stage readers. The results of the correlational analysis between visual and auditory attention, phonological processing, reading, and executive functioning for later stage readers are shown in Table 4.25. There was a significant, negative relationship between visual orienting and phonological memory (r = -.24, p = .05). The relationship between visual orienting and RAN was marginally significant (r = -.22, p = .07). The scatterplots in Figure 4.12 further illustrate the nature of these relationships. The illustrations demonstrate that higher visual orienting difference scores were associated with lower phonological memory accuracy scores. Similarly, higher visual orienting difference scores were associated with lower RAN accuracy scores.

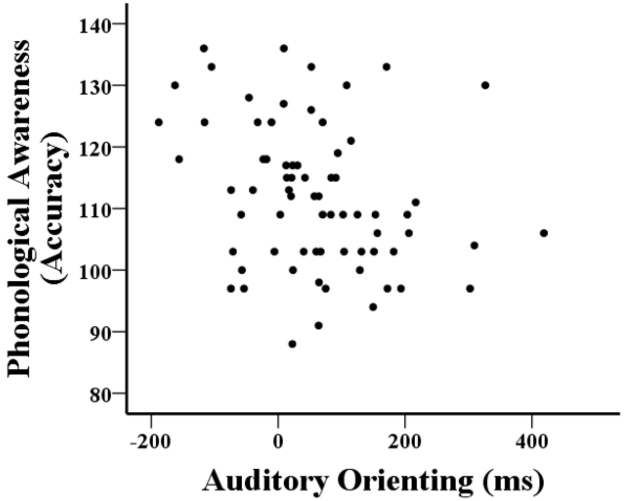
The correlational analysis further showed that there was a significant, positive relationship between auditory orienting and non-word reading accuracy (r = .28, p = .02), suggesting that higher auditory orienting difference scores were associated with higher accuracy in the reading of non-words. This finding partly explains the trend towards a significant total effect in the relationship between auditory orienting and reading accuracy in the SEM reading accuracy analysis for later stage readers. Table 4.25 further shows a significant, positive relationship between visual alerting and visual executive (r = .26, p = .03) attention, as well as a significant, positive relationship between auditory alerting and visual executive (r = .27, p = .03) attention. The results also show a significant, negative association between auditory alerting and auditory executive attention (r = -.30, p = .01). All other correlations between attention networks were non-significant.

Table 4.24: Correlation Between Visual and Auditory Attention Networks, Phonological Processing Skills, Reading, and Executive Functioning in Early Stage Readers (*n* = 72)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.Visual alerting														
2.Visual orienting	.01													
3.Visual executive	-.04	-.06												
4. Auditory alerting	- .08	.18	-.29*											
5.Auditory orienting	-.06	.02	-.15	.17										
6.Auditory executive	-.08	-.03	.13	-.04	-.02									
7.Phonological awareness	.09	.15	.12	.01	-.30*	.04								
8.Phonological memory	.02	.28*	-.17	-.04	-.20	.07	.38**							
9.RAN	.22[†]	.10	.04	.03	-.05	.01	.17	.25*						
10.RW: Accuracy	.06	.10	-.00	.14	.02	.08	.38**	.37**	.41**					
11.EW: Accuracy	.10	.16	-.07	.10	.07	.01	.34**	.32**	.30**	.76**				
12.NW: Accuracy	.12	.09	-.02	.10	-.09	.06	.48**	.34**	.45**	.83**	.65**			
13.EW: Speed	-.33**	.08	-.03	.08	.04	.05	-.07	.12	-.37**	-.40**	-.42**	-.39**		
14.NW: Speed	-.15	.18	.07	.06	-.14	.13	-.11	.16	-.45**	-.47**	-.51**	-.49**	.89**	
15.Executive functioning	-.04	-.09	.02	.04	-.15	-.06	-.21	-.03	.01	-.20	-.32*	-.18	.27*	.17

Note. *significant at the *p* < .05 level; **strong and significant at the *p* < .001 level; [†] marginally significant at the *p* < .05 level; RW = regular words; EW= exception words; NW = non-words; RAN = rapid automatised naming.





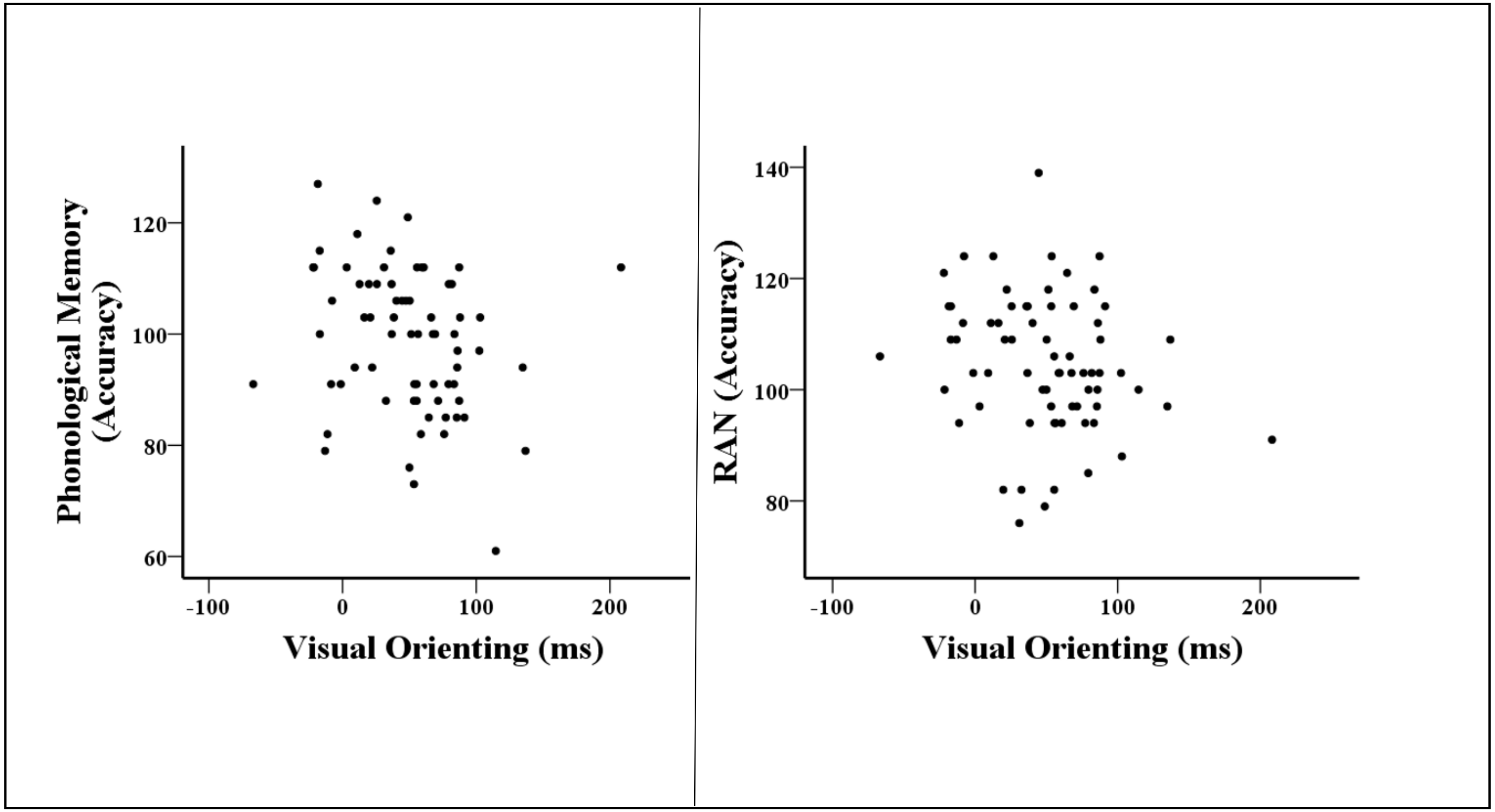
(a) (b)

Figure 4.11. Scatterplots of the correlation between (a) visual orienting (ms) and phonological memory (accuracy), and (b) auditory orienting (ms) and phonological awareness (accuracy) in early stage readers (n = 72).

Table 4.25: Correlation Between Visual and Auditory Attention Networks, Phonological Processing Skills, Reading, and Executive Functioning in Later Stage Readers (*n* = 70)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.Visual alerting														
2.Visual orienting	.07													
3.Visual executive	.26*	-.01												
4.Auditory alerting	-.17	.01	.27*											
5.Auditory orienting	-.12	.10	-.12	.03										
6.Auditory executive	.02	.09	.19	-.30*	-.14									
7.Phonological awareness	.05	-.16	.05	.09	.14	.09								
8.Phonological memory	.09	-.24*	.17	-.01	.03	.03	.22†							
9.RAN	-.17	-.22†	-.04	.07	-.07	-.16	.17	.04						
10.RW: Accuracy	.00	-.11	-.00	.08	.12	-.14	.43**	.31**	.34**					
11.EW: Accuracy	.08	-.15	-.07	.13	.14	.02	.42**	.35**	.27*	.60**				
12.NW: Accuracy	-.05	-.18	-.02	-.08	.28*	.11	.39**	.25*	.20	.61**	.63**			
13.EW: Speed	.15	.14	-.03	-.05	-.02	.17	-.18	-.15	-.52**	-.45**	-.45**	-.34**		
14.NW: Speed	.12	.16	.07	-.03	-.03	.16	-.17	-.13	-.50**	-.49**	-.42**	-.33**	.91**	
15.Executive functioning	.01	-.17	.02	.06	.08	-.08	.02	.07	.06	-.20	-.16	-.03	.03	.10

Note. *significant at the $p < .05$ level; **strong and significant at the $p < .001$ level; † marginally significant at the $p < .05$ level; RW = regular words; EW= exception words; NW = non-words; RAN = rapid automatised naming.



(a) (b)

Figure 4.12. Scatterplots of the correlation between (a) visual orienting (ms) and phonological memory (accuracy), and (b) visual orienting (ms) and RAN (accuracy) in later stage readers (n = 70).

Bi-directionality of significant SEM relationships. Given the significant (and meaningful) relationships between orienting, phonological processing, and reading accuracy for both early and later stage readers, subsequent SEM analysis was conducted to clarify this relationship, specifically between the predictor (attention) and mediating (phonological processing) variable. This was aimed at assessing if phonological processing influenced attention.

Early stage readers.

*Visual attention***.** The structural model was a good fit to the data, X^2 (23) = 26.46, p = 0.28, CFI = 0.98, TLI = 0.97, RMSEA = 0.05, and SRMR = 0.05. The relationship between phonological processing (predictor) and reading accuracy through visual attention (mediator) had non-significant indirect effects for alerting (95% CI [-0.08, 0.05], with a point estimate of -0.01, p = .66), orienting (95% CI [-0.19, 0.07], with a point estimate of -0.06, p = .37), and executive (95% CI [-0.01, 0.01], with a point estimate of 0.00, p = .98) attention. The total (95% CI [0.55, 1.04], with a point estimate of 0.80, p < .001), and direct (95% CI [0.56, 1.18], with a point estimate of 0.87, p < .001) effects were significant, suggesting that the significant relationship between phonological processing and reading accuracy was not mediated through visual alerting, visual orienting, or visual executive attention. As such, there was no evidence of a bi-directional relationship between visual orienting and phonological processing. That is, visual orienting had a significant influence on phonological processing (as shown in the main SEM analysis with visual (orienting) attention as the predictor, and phonological processing as the mediator), but phonological processing did not influence visual orienting.

Auditory attention. The structural model also provided a good fit to the data, X^2 (23) = 19.53, p = 0.67, CFI = 1.00, TLI = 1.00, RMSEA = 0.00, and SRMR = 0.05. The relationship between phonological processing (predictor) and reading accuracy via auditory attention (mediator) had non-significant indirect effects for alerting (95% CI [-0.06, 0.05], with a point estimate of -0.01, p = .75), orienting (95% CI [-0.33, 0.07], with a point estimate of -0.13, p = .21), and executive (95% CI [-0.02, 0.02], with a point estimate of 0.00, p = .90) attention. The total (95% CI [0.52, 1.02], with a point estimate of 0.77, p < .001) and direct (95% CI [0.58, 1.23], with a point estimate of 0.91, p < .001) effects were significant, suggesting that the significant relationship between phonological processing and reading accuracy was not mediated through auditory alerting, auditory orienting, or auditory executive attention. As such, there was no evidence of a bi-directional relationship between auditory (orienting) attention and phonological processing. That is, auditory orienting significantly influenced phonological processing (as shown in the main SEM analysis with auditory (orienting) attention as the predictor, and phonological processing as the mediator), but phonological processing did not influence auditory orienting.

Later Stage Readers.

*Visual attention***.** The structural model was a poor fit to the data, even after correlating error variances, as suggested by M*plus'* MIs, X^2 (19) = 32.23, p = 0.03, CFI = 0.83, TLI = 0.68, RMSEA, = 0.14 and SRMR = 0.10. Therefore, no further analysis was warranted. Although the bi-directional nature of this relationship could not be assessed, the poor fit of this model indicates that the theoretical configuration of this model was not robust, suggesting that phonological processing is not likely to predict visual attention in later stage readers.

Auditory attention. Overall, the structural model provided a satisfactory fit to the data, X^2 (17) = 22.51, p = 0.17, CFI = 0.91, TLI = 0.86, RMSEA = 0.07, and SRMR = 0.07, but note that the value for the TLI was low. The relationship between phonological processing and reading accuracy through auditory attention had non-significant indirect effects for alerting (95% CI [-0.11, 0.08], with a point estimate of -0.02, p = .75), orienting (95% CI [-0.02, 0.06], with a point estimate of 0.02, p = .34) and, executive (95% CI [-0.11, 0.08], with a point estimate of -0.01, p = .79) attention. The total (95% CI [0.89, 1.06], with a point estimate of 0.98, p < .001) and direct (95% CI [0.87, 1.11], with a point estimate of 0.99, p < .001) effects were significant, suggesting that the significant relationship between phonological processing and reading accuracy was not mediated through auditory alerting, auditory orienting, or auditory executive attention.

Summary and Discussion of Study 1

Study 1 examined the relationship between the visual and auditory attention networks, phonological processing, and reading in early stage (Years 1 and 2, aged 6 to 7 years) and later stage (Years 4 and 5, aged 9 to 10 years) readers, using a cross-sectional design. There were two aims (a) to determine if there was a group difference in the relationship between visual and auditory attention networks, phonological processing, and reading between typically developing early versus later stage readers, and, (b) to determine if there was a there was a group difference in the modality of attention that influences reading (via phonological processing or directly) between early versus later stages readers.

Aim 1: Determining group differences in the relationship between attention, phonological processing, and reading. For both stages of reading, the multiple group SEM analysis showed significant relationships between attention, phonological processing, and reading accuracy. In early stage readers, there was a significant, negative, indirect effect of auditory orienting upon reading accuracy through phonological processing, suggesting that larger auditory orienting scores are related to poorer phonological processing and in turn, lower reading accuracy. This finding supported the hypothesis of Study 1 that, during the early stages of reading, the relationship between attention and reading would be mediated through phonological processing. In addition, this finding further supports previous literature and reading models which argue that a sub-lexical or phonologically mediated route to reading is important for beginning readers (Coltheart et al., 2001; LaBerge & Samuels, 1974). The sub-lexical route provides early stage readers with the capacity to develop their mental lexicon, which is likely to facilitate more skilled, efficient reading (Maris & de Graaff Stoffers, 2009; Taft, 2013).

The hypothesis in the current study that later stage readers would adopt a more direct, unmediated route to reading was not supported by the present cross-sectional results. Instead, the results showed a significant, negative, indirect effect of visual orienting upon reading accuracy through phonological processing. This suggests that larger visual orienting scores relate to poorer phonological processing and less accurate reading. Previous findings on the role of phonological processing in more fluent reading have been mixed. One view suggests that the phonological recoding mechanism disappears as reading becomes more skilled (LaBerge & Samuels, 1974). A second view suggest that this recoding mechanism remains important (Church et al., 2008; Ziegler et al., 2014), while a third view suggests that the use of the mechanism depends on different factors such as word type, word familiarity, and skill level (Castles et al., 2018). The findings of Study 1 align with the second view and provide support for the activation-verification model of reading, which emphasises that the phonological representations of a word are fundamental to the location and activation of information in the mental lexicon (Lukatela & Turvey, 1991; Van Orden, 1987). More broadly, the adoption of a phonologically mediated pathway among later stage readers suggests that phonological processing is likely to be fundamental for more fluent reading, at least for visual orienting and for the age range (9 to 10 years) of later stage readers in the present cross-sectional study. In addition to this, there was no evidence of a bi-directional relationship between attention and phonological processing, for both early and later stage readers. This provides more robust support for the finding that attention impacts upon phonological processing, rather than the converse.

In contrast to reading accuracy, as discussed above, the multiple group SEM analysis found a significant total effect in the relationship between visual alerting and reading speed through phonological processing only for early stage readers. This simply indicates that there is a potential effect to be mediated (Hayes, 2013). However, a closer examination of the indirect (.04) and direct (.19) effects of visual alerting upon reading speed via phonological processing suggest small effect sizes, implying that although there might be some influence of visual alerting upon reading speed in early stage readers, the effect might not be meaningful. In particular, the indirect effect may not be meaningful, since the relationship between phonological processing and reading speed in early stage readers was only marginally significant. In addition to this, however, Pearson’s correlational analysis showed that, for early stage readers, there was a positive relationship between executive functioning and exception word reading speed, suggesting that poorer executive functioning is associated with slower RTs in exception word naming speed. The pattern of this correlation supports the body of research that has shown that better performance in executive functions tasks, involving inhibition and shifting, for example, are related to more efficient reading performance (Meltzer, 2007). The findings of the present study however provide further evidence that, in early stage readers, executive functioning is associated with exception word reading speed, but not with non-word reading speed, suggesting a distinction in the potential impact of executive functioning on different types of word reading speed ability.

Aim 2: Determining group difference in the modality of attention that influences reading (via phonological processing or directly) between early versus later stages readers. For auditory attention, the multiple group SEM analysis showed that auditory orienting significantly influenced reading accuracy through phonological processing in early stage readers. In contrast, for later stage readers, there were no significant indirect or direct effects of any auditory attention network upon reading accuracy. However, there was a significant total effect of auditory orienting, suggesting that there is a potential effect to be mediated by this network. But, given that the indirect and direct effects in this relationship were not significant, it is difficult to conclude, with certainty, if a meaningful mediating or direct effect was present. For visual attention, the analysis showed that visual orienting significantly influenced reading accuracy through phonological processing in later stage readers. In contrast, for early stage readers, there were no significant indirect and direct effects of any visual attention network upon reading accuracy. There was a marginally significant relationship between visual orienting and reading accuracy through phonological processing for early stage readers. However, given that zero was identified in the 95% CI interval for this latter relationship, visual orienting as predicting reading accuracy in early stages of reading was statistically non-significant, but potentially meaningful, given its large coefficient.

Together, these results support the second hypothesis of Study 1 that, in the early stages of reading, auditory attention would be more significant for reading, compared with visual attention, whereas during later stages visual attention would be more significant, compared with auditory attention. These findings suggest that attention modality, when related to the relationship with reading through phonological processing, operates differently according to stage of reading. The finding that in the early stages of reading, auditory (orienting) attention plays a dominant role, aligns with the suggestions of previous research that readers at this stage tend to rely predominantly upon the sub-lexical reading route and phonological coding skills (Ehri, 2013; Leinenger, 2014). Similarly, the finding that visual (orienting) attention was more significant for later stage readers aligns with previous views that, as reading becomes more fluent, deriving meaning from text involves a less mediated access to lexical orthographic codes (see Ehri, 2017 for different perspectives). But, unlike previous research arguing that word recognition occurs without a conversion to phonological codes (LaBerge & Samuels, 1974), the results of the current cross-sectional study provide preliminary support for the idea that although attention modality might differ between early and later readers, the mediated pathway to reading via phonological processing remains fundamental, at least for later stage readers, aged 9 to 10 years.

Chapter 5 : Results of Study 2

Chapter Overview

This chapter presents the results of Study 2, which used a longitudinal design to determine the stability of the relationship between the visual and auditory attention networks, and reading via phonological processing across early versus later stages of reading acquisition.

Aims

Study 2 aimed to assess the stability in the pattern of mediation between the attention network (T1) and phonological processing (T1) in predicting reading (T2). This study followed-up participants from Study 1 to assess the mediation hypothesis of determining whether phonological processing mediates the relationship between attention and reading at early versus later stages of reading.

Hypotheses

Study 2 hypothesised that for early stage readers, phonological processing at T1 would mediate the relationship between attention at T1 and reading at T2. However, for later stage readers, the direct pathway between attention at T1 would be a stronger predictor of reading at T2, in comparison with the indirect path through T1 phonological processing.

Analysis Plan and Rationale

Stage 1. Missing, error, and outlier data were checked or removed. Since the same RT means for the cVANT and cAANT-SL are used from Study 1, the pattern of RT and error data replicated Study 1 (see Appendix F). Then, the assumptions underlying SEM were tested for reading accuracy and reading speed measures. These assumptions included testing for univariate normality, univariate outliers, and multivariate outliers. Finally, an assessment of power of the sample size was conducted. This was implemented to determine if the sample sizes of 64 (early stage readers) and 62 (later stage readers) were robust to detect meaningful relationships between T1 attention (visual and auditory), T1 phonological processing and T2 reading (accuracy and speed), through a multiple-group SEM analysis.

Stage 2. Descriptive summaries, including means, ranges, and standard deviations of reading accuracy and speed scores were calculated. In addition, inferential statistics were conducted, including independent samples *t*-test, comparing performance across early and later stages of reading. Then, a two-way mixed design (word type and group) was conducted to determine group differences in reading speed for exception and non-words. The procedures involving follow-up analysis for ANOVA were the same as Study 1.

Stage 3. A multiple-group SEM analysis was conducted to examine the interaction between T1 attention networks, T1 phonological processing, and T2 reading. The approach to estimation, fit, and effect size interpretation was the same as Study 1. Like Study 1, the norm-referenced standard scores for the phonological processing construct, and the *z*-score transformation of raw scores for the reading accuracy construct were used. The interpretation of results from invariance testing was like Study 1. Given that the hypothesised model contained relationships between observed (T1 alerting, T1 orienting, and T1 executive attention) and latent (T1 phonological processing, T2 reading accuracy, T2 reading speed) constructs, the analysis followed a four-step procedure, as per the combined suggestions of Bengt Muthén (personal communication, 2018) and Muthén and Muthén (2008). This procedure was the same as that used in Study 1.

Stage 4. Depending on the presence of significant effects, subsequent analysis was conducted to clarify the nature of the relationship between the attention networks, phonological processing, and reading. This involved (a) determining the specific relationship between the observed variables for the visual and auditory attention networks (T1), phonological processing (T1), reading (T2), and executive functioning (T1) using Pearson's correlation, and (b) determining, through SEM analysis, if observed significant SEM relationships operated bi-directionally.

Stage 1. Missing Data, Error and Outlier Removal, Assumption Testing, and Power Analysis

The analysis did not comprise all the data from Study 1 on the basis of attrition. Instead, participants without T2 reading accuracy and T2 reading speed data were excluded. Although fewer participants were included in this follow-up study, the missing data (8 participants for early stage readers, and 8 participants for later stage readers) were accounted for by the bootstrap function of SEM. For the remaining participants in Study 2 (i.e., 64 early stage readers and 62 later stage readers), the proportion of missing data for the reading accuracy and reading speed measures were assessed to ensure that missing data did not exceed the recommended 5% for each variable. For both early and later stage readers, each variable had at least 98% of data available (range of data availability = 98.4% to 100%), and therefore imputation on missing values was not performed. Given that the reading speed task relied on analysing raw scores from an experimental task, the assumption testing for the individual analyses of this task included excluding error trials and trimming for RT outliers in the first instance. This issue does not arise if measures are generated from standardised tests, such as the CC2 (reading accuracy) tasks used in the current study.

Errors on the reading speed task, where participants failed to respond within the response period or said the wrong word (9.5% of trials among early stage readers, and 5.4% of trials among later stage readers) and RT outliers, defined as RTs less than 200 ms and scores falling 2 *SD* above or below the mean within each condition (6.4% of trials among early stage readers, and 4.3% of trials among later stage readers), were excluded when calculating the mean RT for each word type condition for each participant.

Assumption testing. The assumptions underlying SEM were tested for the T2 reading accuracy and T2 reading speed measures. These assumptions included independence, sphericity, and normality (univariate normality, univariate outliers, and multivariate outliers). When sphericity was violated, the reported results reflect the Greenhouse and Geisser corrected values.

Concerning univariate normality, T2 reading accuracy, and T2 reading speed were normally distributed. Skewness scores for these data ranged from -0.03 to 1.69 for early stage readers, and from -0.01 to 1.71 for later stage readers, well within the suggested limit of ±2 (Field, 2013; Gravetter, 2014). Similarly, kurtosis values ranged from -0.60 to 2.03 for early stages readers, and -0.01 to 4.86 for later stage readers, well within the suggested limit of ±7 (Field, 2013; Pallant, 2013).

To test for univariate outliers, T2 reading accuracy, and T2 reading speed scores were standardised to *z*-scores, within each group, through SPSS. Standardised

T2 reading speed scores for early stage readers (3.37 for exception words and 3.77 for non-words) mildly departed from the suggested ± 3.29 limit (Tabachnick, 2013). For later stage readers, scores for T2 reading speed (4.40 for exception words), fell outside the suggested ± 3.29 limit. Subsequent analysis of box plots showed that 1 outlier among early stage readers and 2 outliers among later stage readers fell within the non-critical range (i.e., 1.5 to 3 box lengths from the upper or lower edge of the box) (Iglewicz & Hoaglin, 1987). Including or excluding these outliers did not change the relationships between variables, thus these data were retained in the analysis. Finally, Study 1 has previously confirmed that there were no multivariate outliers for the predictor variables (i.e., T1 attention networks and T1 phonological processing) within the current data set.

Power analysis. The approach to assessing power in Study 1 was also applied to Study 2. This assessment was performed to examine if the sample sizes of 64 (early stage readers) and 62 (later stage readers) was sufficiently robust to detect meaningful relationships between T1 attention (visual and auditory), T1 phonological processing, and T2 reading (accuracy and speed). Given the previously established correlations between phonological processing and reading in previous research (e.g., Castles et al., 2018; Melby-Lervåg et al., 2012), the use of the bootstrapping procedure, and that the majority of the data is neither highly kurtotic nor departs greatly from normality (when it departs from the acceptable range for normality and kurtosis MLR estimation accounts for this), the stability of the parameter estimates can be trusted, as well as the power to reject models in the current study (Hoogland & Boomsma, 1998).

Stage 2. Descriptive and Inferential Statistics via SPSS.24

The T1 attention network effects and T1 phonological processing scores used in the current study for the SEM analysis are the same as Study 1 (T1). Although fewer participants were in Study 2, the pattern (e.g., means, standard deviations, ranges) of attention network effect and phonological processing data at T1 for early and later stage readers replicated Study 1 (see Appendix F). The means, ranges, and standard deviations for the T2 standardised (reading accuracy raw and *z*-scores) and T2 RT (reading speed) measures are reported in Table 5.1. A series of independent samples *t*-tests were conducted on T2 reading accuracy (number correct out of 40 trials for each word type) and T2 reading speed (mean RT for each word type) scores. For the reading speed task, a two-way mixed ANOVA was also conducted.

Reading accuracy. As Table 5.1 illustrates, the mean performance for T2 reading accuracy (*z*-score), for each word type (regular, exception, and non-words), fell within the typically developing (-1 to +1) range for both early and later stage readers.

Raw scores (total number correct). Compared with early stage readers (M = 20.86 ± 0.66), later stage readers (M = 25.56 ± 0.59) had significantly higher raw scores on the T2 exception word reading accuracy task, $t(124) = 5.31$, $p < .001$, d = .47. In contrast, there were no significant differences between groups on the T2 regular word, $t(124) = 1.31$, $p = .20$, $d = .12$, and T2 non-word, $t(124) = 1.73$, p = .09, $d = .15$, reading accuracy task.

Standardised scores. T2 reading accuracy standardised scores for regular, $t(124) = 2.57$, $p = .01$, $d = .23$, exception, $t(124) = 2.65$, $p = .01$, $d = .24$, and non-words, $t(124) = 3.68$, $p < .001$, $d = .33$, were significantly higher for early stage compared with later stage readers.

Percentage correct. The following represents the percentage correct for each word type in early stage readers: T2 regular words (M = 89.7%, SD = 12.8%), T2 exception words (M = 52.2%, SD = 13.21%), and T2 non-words (M = 77.0%, SD = 19.5%). For later stage readers, the percentage correct for each word type were, T2 regular words (M = 92.5%, SD = 11.0%), T2 exception words (M = 63.9%, SD = 11.6%), and T2 non-words (M = 82.5%, SD = 15.8%).

Reading speed. An independent samples *t*-test indicated that T2 reading speed scores for both T2 exception words, $t(103.24) = 3.92$, $p < .001$, $d = .35$, and T2 non-words, $t(124) = 3.45$, $p = .001$, $d = .29$, were significantly lower (suggesting faster reading speed) for later stage readers compared with early stage readers at T2.

Percentage error. The following represents the percentage of errors for each word type in early stage readers: T2 exception words (M = 3.8%, SD = 7.8%), and T2 non-words (M = 15.2%, SD = 15.8%). For later stage readers, the percentage of errors for each word type were: T2 exception words (M = 1.9%, SD = 4.6%), and T2 non-words (M = 9.0%, SD = 13.4%).

Group interactions in reading speed. A two-way mixed design ANOVA was conducted to determine if there was a main effect of group and an interaction between word type and group in the reading speed task. There was a main effect of word type, $F(1, 124) = 135.37$, $p < .001$, $\eta_p^2 = .52$, and group, $F(1, 124) = 13.65$, $p < .001$, $\eta_p^2 = .10$. The interaction between word type and group, $F(1,124) = 2.12$, $p = .15$, $\eta_p^2 = .02$, was not significant.

Table 5.1: Means and Standard Deviations of T2 Reading Accuracy and T2 Reading Speed Scores for Early and Later Stage Readers

	Early (*n* = 64)		Later (*n* = 62)	
Variable	*M* (min, max)	*SD*	*M* (min, max)	*SD*
T2 Reading Accuracy				
Regular raw	35.88 (15, 40)	5.10	36.98 (14, 40)	4.39
Regular *Z*	1.25 (-1.21, 3.65)	1.06	0.75 (-2.10, 2.99)	1.24
Exception raw	20.86 (6, 30)	5.28	25.56 (12, 35)	4.64
Exception *Z*	0.71 (-1.35, 2.25)	0.87	0.29 (-1.90, 2.58)	1.00
Non-Word raw	30.80 (6,40)	7.81	32.98 (10, 40)	6.32
Non-Word Z	0.90 (-1.00, 2.91)	0.91	0.26 (-1.90, 2.35)	1.06
T2 Reading Speed				
Exception words (ms)	771 (492, 1506)	217	647 (454, 1216)	129
Non-words (ms)	906 (517, 2001)	290	761 (475, 1261)	165

Note. Regular = regular words; Exception = exception words; Raw = raw score; *Z* = *z*-score; ms = milliseconds.

Stage 3. SEM Analysis via M*plus* Version 5.2

Reading accuracy. Figure 5.1 illustrates the hypothesised model for the relationship between T1 attention, T1 phonological processing, and T2 subsequent reading accuracy that was assessed for both stages of reading. The fit of the hypothesised measurement model component (i.e., T1 phonological processing and T2 reading accuracy) was initially tested, separately for each of the two groups of readers ─ early stage reading group and later stage reading group. The results of this initial fitting are presented in Table 5.2, which show a good fit to the data for early stage readers. However, to improve the fit for later stage readers, and given the suggestion by M*plus* MIs, errors for T2 non-word and T2 exception words were covaried.

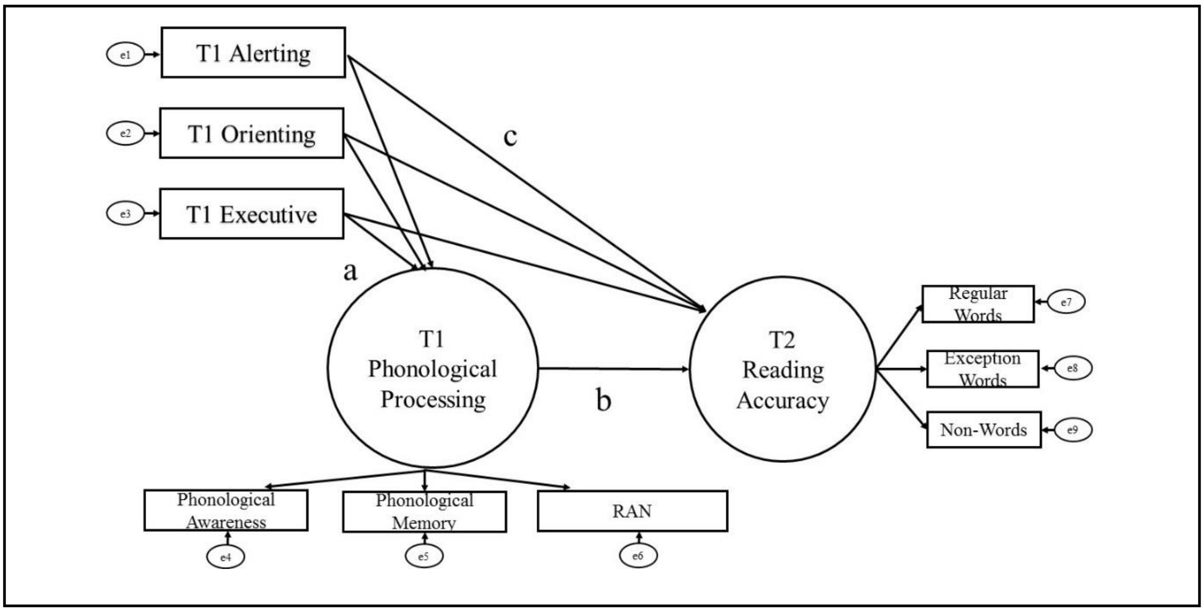


Figure 5.1. Hypothesised two factor model of the relationship between T1 attention (visual and auditory assessed separately), T1 phonological processing, and T2 subsequent reading accuracy for both early (*n* = 64) and later (*n* = 62) stage readers. T1 = time 1; T2 = time 2; RAN = rapid automatised naming.

Table 5.2 provides the fit indices for the test of group measurement (Models 1─4) and structural (Models 5─6) invariance in the relationship between T1 attention, T1 phonological processing, and T2 reading accuracy across early and later stage readers. Invariance testing was conducted using a series of tests according to Bengt Muthén (personal communication, 2018) and Muthén and Muthén (2008). These models were partially nested; the models differed in terms of their level of restrictiveness and the parameters that were constrained. Model 1, the least restrictive model, only constrained the factorial structure. Model 1 was the first step to establishing measurement invariance. Model 2 added the constraint of equal factor loadings. Model 3 added the constraint of equal item intercepts. Model 4 added the constraint of error invariance. Then, given that the observed attention variables were added to the model, the structural fit was assessed for both visual and auditory attention. Then, Model 5 (nested under Model 4) constrained factor variance-covariances across the groups for visual attention, and Model 6 (nested under Model 4) constrained factor variance-covariances across the groups for auditory attention.

As the results in Table 5.2 show, the fit indices for Model 1 were a good fit to the data. The chi-square difference for Model 1 versus Model 2 (X^2 = 2.94, *df* = 4) was not statistically significant, indicating that the regression slopes across groups were invariant. The chi-square difference for Model 2 versus Model 3 (X^2 = 6.46, *df* = 4) was not statistically significant, indicating that the intercepts across both groups were equal. Finally, the chi-square difference for Model 3 versus Model 4 (X^2 = 5.46, *df* = 4) was not statistically significant indicating, that the errors across both groups were equal. Therefore, measurement invariance across reading group was confirmed at the metric, scalar, and error levels.

For structural invariance, the chi-square difference between Model 4 versus Model 5 (X^2 = 35.91, *df* = 25) was not statistically significant, indicating that the covariance and variance for a model that included visual attention networks, phonological processing, and reading accuracy did not differ significantly across group. Similarly, the chi-square difference between Model 4 versus Model 6 was not significantly different (X^2 = 22.75, *df* = 26), indicating that the covariance and variance for a model that included auditory attention networks, phonological processing, and reading accuracy did not differ significantly across group. Altogether, these tests confirm measurement and structural invariance for all latent and observed variables across early and later stage readers.

Table 5.2: Fit Indices of Group Invariance Testing for T1 Attention Networks, T1 Phonological Processing, and T2 Reading Accuracy in Early (*n* = 64) and Later (*n* = 62) Stage Readers in Study 2

Model	X^2	*df*	*p*	CFI	TLI	RMSEA	SRMR	Comparison	Decision
Step 1-Measurement Invariance									
Model 0. Early stage	6.72	8	.57	1.00	1.00	.00	.04	__	Accept
Model 0. Later stage 1	20.87	8	.01	.85	.71	.16	.08	__	Accept
Model 0. Later stage 2	10.13	8	.26	.97	.95	.07	.06	__	Accept
Model 1. Configural	16.66	14	.27	.99	.97	.06	.05	__	Accept
Model 2. Metric	19.60	18	.36	.99	.98	.04	.08	Model 1 vs. Model 2	Accept
Model 3. Scalar	26.06	22	.25	.98	.97	.05	.10	Model 2 vs. Model 3	Accept
Model 4. Error	31.52	26	.21	.97	.96	.06	.16	Model 3 vs. Model 4	Accept
Step 2-Mediation Model Fit									
Visual mediation model	58.00	42	.05	.92	.87	.08	.08	__	Accept
Auditory mediation model	55.16	48	.22	.96	.94	.05	.08	__	Accept
Step 3-Structural Invariance									
Model 5. Variance-covariance (visual)	67.43	51	.06	.92	.90	.07	.10	Model 4 vs. Model 5	Accept
Model 6. Variance-covariance (auditory)	54.27	52	.39	.99	.98	.03	.09	Model 4 vs. Model 6	Accept

Note. X^2 = chi-square; *df* = degrees of freedom; CFI = comparative fit index; TFI = Tucker-Lewis index; RMSEA = root mean square error of approximation; SRMR = standardised root mean square residual.

For ease of presentation, the results from the multiple-group SEM analysis for the influence of T1 attention and T1 phonological processing upon T2 reading accuracy and T2 reading speed are presented separately for both early and later stage readers. Like Study 1, the results for the relationship between attention, phonological processing, and reading speed follow the presentation of the reading accuracy model.

Early stage readers: Measurement model analysis. The results from the multiple-group CFA for the relationship between T1 phonological processing and T2 reading accuracy (standardised scores) in early stage readers is shown in Figure 5.2. There was a significant, positive relationship between phonological processing at T1 and subsequent reading accuracy at T2 ($p < .001$). The size of the coefficient relating T1 phonological processing to T2 reading accuracy is like Study 1 where reading accuracy at T1 was assessed with a coefficient of .90.

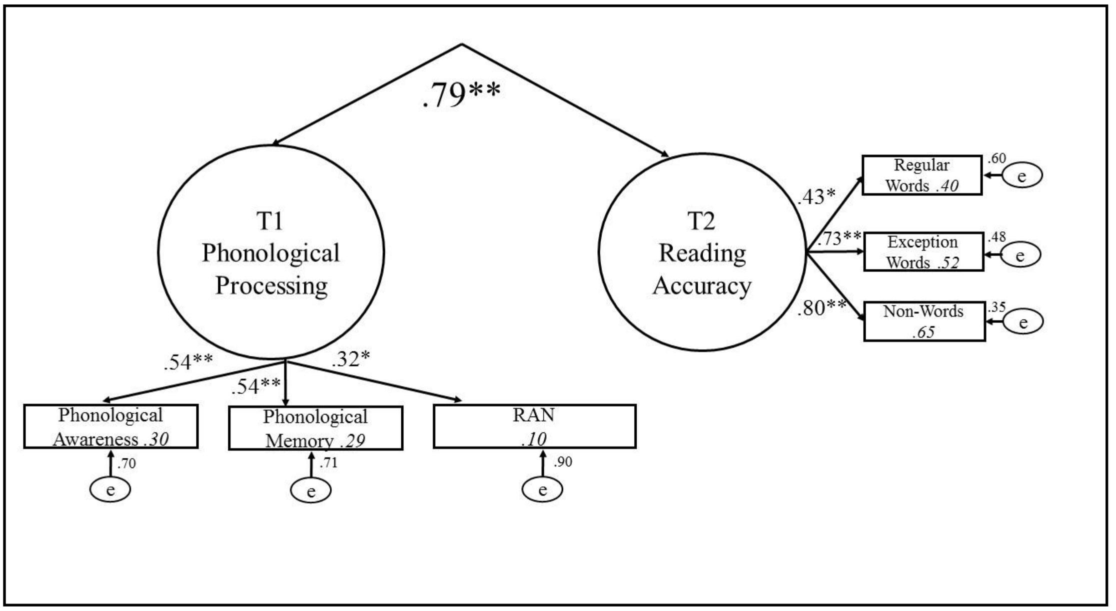


Figure 5.2. Measurement model with CFA results (standardised estimates) for the hypothesised relationship between T1 phonological processing and T2 reading accuracy in early stage readers ($n = 64$). *Correlation was significant ($p < .05$) at the .05 level (2-tailed). **Correlation was strong and significant ($p < .001$) at the .05 level (2-tailed); T1 = time 1; T2 = time 2.

Figure 5.2 also shows a weaker involvement of RAN in the latent construct of phonological processing, replicating the finding of Study 1. Given that the indices were a good fit to the data, post-hoc modifications were not required, and there were no discrepancies with the residual variances, which ranged between .35 and .90, well within the suggested ≤ 2 criterion. The relationship between factor loadings for T1 phonological processing and T2 reading accuracy in early stage readers is presented in Table 5.3. There were strong associations between loadings of regular word, exception word, and non-word reading accuracy, with all three correlating strongly with phonological awareness and phonological memory with less robust correlations with RAN. There were however weaker associations among the loadings of phonological awareness, phonological memory, and RAN.

Table 5.3: Correlation between Factor Loadings of the T1 Phonological Processing and T2 Reading Accuracy Latent Variables for Early Stage Readers (*n* = 64)

	1	2	3	4	5
1. Phonological awareness					
2. Phonological memory	.30				
3. RAN	.18	.18			
4. Regular words	.36	.35	.21		
5. Exception words	.31	.31	.18	.49	
6. Non-words	.35	.35	.21	.54	.58

Note. RAN = rapid automatised naming.

Early stage readers: Structural analysis of total, indirect, and direct effects. Tables 5.4 to 5.8 illustrate the total, indirect, and direct effects of visual alerting, visual orienting, visual executive, auditory alerting, and auditory executive attention, in their interactions with T1 phonological processing and T2 subsequent reading accuracy. The tables suggest that the total, indirect, or direct effects for the relationship between these attention networks with phonological processing and reading accuracy were not significant. However, it should be noted that the coefficient for the indirect relationship between T1 visual orienting and T2 reading accuracy through T1 phonological processing in Table 5.5 was large (.28).

Table 5.4: Total, Direct, and Indirect Effects Between T1 Visual Alerting, T1 Phonological Processing, and T2 Subsequent Reading Accuracy in Early Stage Readers (*n* = 64)

Model	β		95% CI, *p* value
	T1 Visual alerting	T1 phonological Processing	
Direct			
T1 Visual alerting		0.15	[-0.52, 0.13], *p* = .23
T2 Reading accuracy	-0.20	0.79	
Indirect			
T1 Visual alerting		0.13	[-0.17, 0.43], *p* = .41
T2 Reading accuracy			
Total			
T1 Visual alerting		0.15	[-0.34, 0.19], *p* = .60
T2 Reading accuracy	-0.07	0.79	

Note. The single pathway between T1 visual alerting and T1 phonological processing was not significant (*p* = .38); T1 = time 1; T2 = time 2; β = beta (standardised coefficient); CI = confidence interval.

Table 5.5: Total, Direct, and Indirect Effects Between T1 Visual Orienting, T1 Phonological Processing, and T2 Subsequent Reading Accuracy in Early Stage Readers (*n* = 64)

Model	β		95% CI, *p* value
	T1 Visual orienting	T1 Phonological processing	
Direct			
T1 Visual orienting		0.33	[-0.46, 0.28], *p* = .64
T2 Reading accuracy	-0.09	0.79	
Indirect			
T1 Visual orienting		0.28	[-0.07, 0.63], *p* = .12
T2 Reading accuracy			
Total			
T1 Visual orienting		0.33	[-0.06, 0.45], *p* = .14
T2 Reading accuracy	0.19	0.79	

Note. The single pathway between T1 visual orienting and T1 phonological processing was marginally significant (*p* = .051); T1 = time 1; T2 = time 2; β = beta (standardised coefficient); CI = confidence interval.

Table 5.6: Total, Direct, and Indirect Effects Between T1 Visual Executive, T1 Phonological Processing, and T2 Subsequent Reading Accuracy in Early Stage Readers (*n* = 64)

Model	β		95% CI, *p* value
	T1 Visual executive	T1 Phonological processing	
Direct			
T1 Visual executive		0.00	[-0.52, 0.11], *p* = .20
T2 Reading accuracy	-0.21	0.79	
Indirect			
T1 Visual executive		0.00	[-0.29, 0.29], *p* = .99
T2 Reading accuracy			
Total			
T1 Visual executive		0.00	[-0.46, 0.06], *p* = .12
T2 Reading accuracy	-0.20	0.79	

Note. The single pathway between T1 visual executive attention and T1 phonological processing was not significant (*p* = .99); T1 = time 1; T2 = time 2; β = beta (standardised coefficient); CI = confidence interval.

Table 5.7: Total, Direct, and Indirect Effects Between T1 Auditory Alerting, T1 Phonological Processing, and T2 Subsequent Reading Accuracy in Early Stage Readers (*n* = 64)

Model	β		95% CI, *p* value
	T1 Auditory alerting	T1 Phonological processing	
Direct			
T1 Auditory alerting		0.13	[-0.20, 0.36], *p* = .58
T2 Reading accuracy	0.08	0.79	
Indirect			
T1 Auditory alerting		0.11	[-0.17, 0.38], *p* = .45
T2 Reading accuracy			
Total			[-0.08, 0.45], *p* = .17
T1 Auditory alerting		0.13	
T2 Reading accuracy	0.19	0.79	

Note. The single pathway between T1 auditory alerting and T1 phonological processing was not significant (*p* = .43); T1 = time 1; T2 = time 2; β = beta (standardised coefficient); CI = confidence interval.

Table 5.8: Total, Direct, and Indirect Effects Between T1 Auditory Executive, T1 Phonological Processing, and T2 Subsequent Reading Accuracy in Early Stage Readers (*n* = 64)

Model	β		95% CI, *p* value
	T1 Auditory executive	T1 Phonological processing	
Direct			
T1 Auditory executive		0.15	[-0.37, 0.20], *p* = .56
T2 Reading accuracy	-0.09	0.79	
Indirect			
T1 Auditory executive		0.12	[-0.15, 0.39], *p* = .38
T2 Reading accuracy			
Total			
T1 Auditory executive		0.15	[-0.23, 0.30], *p* = .79
T2 Reading accuracy	0.04	0.79	

Note. The single pathway between auditory executive attention and phonological processing was not significant (*p* = .36); T1 = time 1; T2 = time 2; β = beta (standardised coefficient); CI = confidence interval.

Figure 5.3 illustrates the relationship between T1 auditory orienting and T2 subsequent reading accuracy through T1 phonological processing in early stage readers. The indirect effect was significant (95% CI [-0.71, -0.001], with a point estimate of -.36, *p* = .049). Like the findings of Study 1, this suggests that a larger auditory orienting effect is associated with poorer phonological processing, and thus lower reading accuracy in early stage readers. The direct (95% CI [-0.02, 0.71], with a point estimate of 0.35, *p* = .06) effect was positive and marginally significant, suggesting that a larger orienting effect score is directly associated with higher reading accuracy scores. The total effect (95% CI [-0.28, 0.26], with a point estimate of -0.01, *p* = .95) was non-significant.

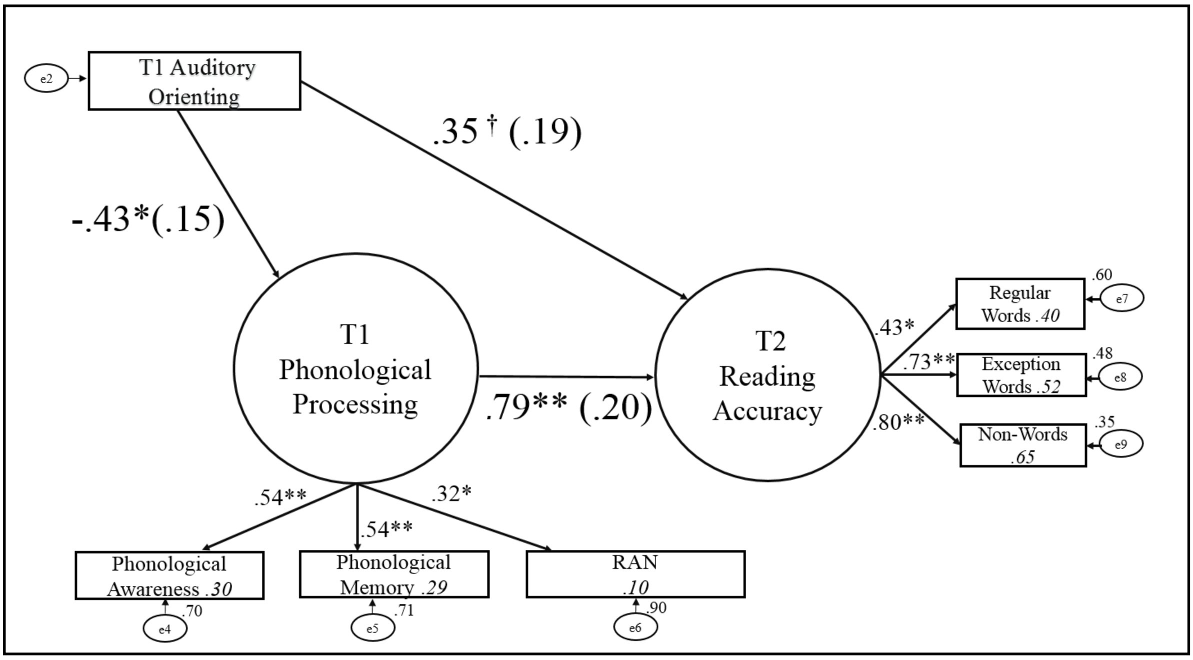


Figure 5.3. The relationship between T1 auditory orienting and T2 subsequent reading accuracy via T1 phonological processing in early stage readers (n = 64). Auditory alerting and auditory executive attention were also assessed in this model, but for ease of illustration, and given its significance only auditory orienting is illustrated. **Correlation was strong and significant ($p < .001$) at the .05 level (2-tailed). *Correlation was significant ($p < .05$) at the .05 level (2-tailed). † Correlation was marginally significant at the .05 level. The single pathway from T1 auditory orienting to T1 phonological processing was significant (p = .01). T1 = time 1; T2 = time 2; RAN = rapid automatised naming. Standard errors are provided in parentheses.

Later stage readers: Measurement model analysis. The hypothesised measurement model, with the results from a multiple-group CFA, for the relationship between T1 phonological processing and T2 subsequent reading accuracy for later stage readers, is shown in Figure 5.4. There was a significant, positive relationship between T1 phonological processing and subsequent reading accuracy at T2 (p = .03). The size of the coefficient relating phonological processing to reading accuracy was lower than Study 1, where reading accuracy at T1 was assessed with a coefficient of .99. Of note however is, unlike Study 1, the measurement model (as initially hypothesised) presented in Figure 5.1 was a good fit to the data. Previously, in Study 1, the regular words indicator was removed as its inclusion produced multicollinearity. There was however a weaker involvement of T2 regular words in the latent construct of reading accuracy, compared with T2 exception words and T2 non-words, as Figure 5.4 illustrates. Figure 5.4 further shows a weaker involvement of RAN in the latent construct of phonological processing, compared with phonological awareness and phonological memory. This pattern replicates the findings of Study 1.

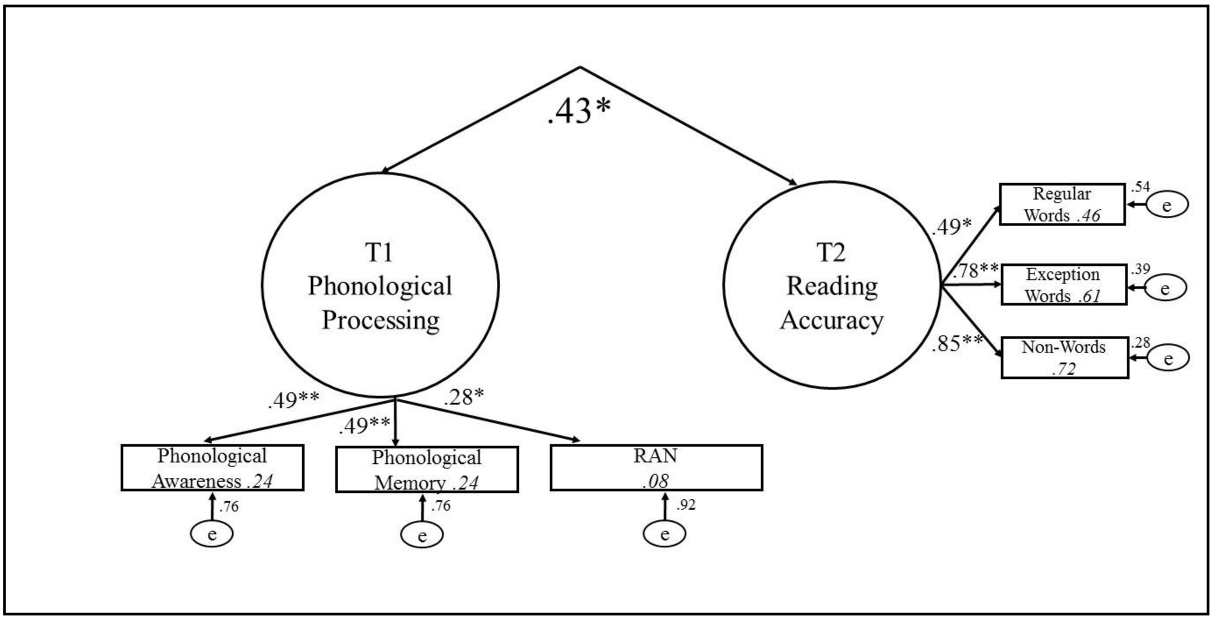


Figure 5.4. Measurement model with CFA results (standardised estimates) for the hypothesised relationship between T1 phonological processing and T2 reading accuracy in later stage readers (n = 62). *Correlation was significant ($p < .05$) at the .05 level (2-tailed). **Correlation was strong and significant ($p < .001$) at the .05 level (2-tailed). T1 = time 1; T2 = time 2; RAN = rapid automatised naming.

Figure 5.4 further provides the values for the squared multiple correlation for each indicator (in italics), with the highest and lowest being non-words (.72) and RAN (.08), respectively. Given that the indices were a good fit to the data, post-hoc modifications were not required, and there were no discrepancies with the residual variances, which ranged between .28 and .92, well within the suggested ≤ 2 criterion.

The relationship between factor loadings for T1 phonological processing and T2 reading accuracy in later stage readers is presented in Table 5.9. There were strong associations between loadings of regular word, exception word and non-word reading accuracy, with primarily the regular word reading accuracy loading correlating strongly with phonological awareness and phonological memory. There were weaker correlations between exception words and non-words and the loadings that assess the T1 phonological processing latent construct.

Table 5.9: Correlation between Factor Loadings for the Phonological Processing (T1) and Reading Accuracy (T2) Latent Variables in Later Stage Readers (*n* = 62)

	1	2	3	4	5
1. Phonological awareness					
2. Phonological memory	.24				
3. RAN	.14	.14			
4. Regular words	.36	.36	.21		
5. Exception words	.16	.16	.10	.56	
6. Non-words	.18	.18	.10	.61	.66

Note. RAN = rapid automatised naming.

***Later stage readers: Structural analysis of total, indirect, and direct effects*.** Tables 5.10 to 5.12 illustrate the total, indirect, and direct effects of T1 visual alerting, T1 auditory alerting, and T1 auditory executive attention in their interactions with T1 phonological processing and T2 subsequent reading accuracy. The tables suggest that the total, indirect, or direct effects for the relationship between these attention variables with phonological processing and reading accuracy were not significant.

Table 5.10: Total, Direct, and Indirect Effects Between T1 Visual Alerting, T1 Phonological Processing, and T2 Subsequent Reading Accuracy in Later Stage Readers (*n* = 62)

Model	β		95% CI, *p* value
	T1 Visual alerting	T1 Phonological processing	
Direct			
T1 Visual alerting		-0.04	[-0.43, 0.27], *p* = .64
T2 Reading accuracy	-0.08	0.43	
Indirect			
T1 Visual alerting		-0.04	[-0.42, 0.33], *p* = .84
T2 Reading accuracy			
Total			
T1 Visual alerting		-0.04	[-0.37, 0.13], *p* = .34
T2 Reading accuracy	-0.12	0.43	

Note. The single pathway between T1 visual alerting and T1 phonological processing was not significant (*p* = .84); T1 = time 1; T2 = time 2; β = beta (standardised coefficient); CI = confidence interval.

Table 5.11: Total, Direct, and Indirect Effects Between T1 Auditory Alerting, T1 Phonological Processing, and T2 Subsequent Reading Accuracy in Later Stage Readers (*n* = 62)

Model	β		95% CI, *p* value
	T1 Auditory alerting	T1 Phonological processing	
Direct			
T1 Auditory alerting		0.42	[-0.58, 0.32], *p* = .57
T2 Reading accuracy	-0.13	0.43	
Indirect			
T1 Auditory alerting		0.32	[-0.12, 0.75], *p* = .15
T2 Reading accuracy			
Total			
T1 Auditory alerting		0.42	[-0.08, 0.45], *p* = .17
T2 Reading accuracy	0.19	0.43	

Note. The single pathway between T1 auditory alerting and T1 phonological processing was significant (*p* = .03); T1 = time 1; T2 = time 2; β = beta (standardised coefficient); CI = confidence interval.

Table 5.12: Total, Direct, and Indirect Effects Between T1 Auditory Executive, T1 Phonological Processing, and T2 Subsequent Reading Accuracy in Later Stage Readers (*n* = 62)

Model	β		95% CI, *p* value
	T1 Auditory executive	T1 Phonological processing	
Direct			
T1 Auditory executive		0.24	[-0.58, 0.14], *p* = .23
T2 Reading accuracy	-0.22	0.43	
Indirect			
T1 Auditory executive		0.18	[-0.17, 0.53], *p* = .31
T2 Reading accuracy			
Total			
T1 Auditory executive		0.24	[-0.31, 0.23], *p* = .78
T2 Reading accuracy	-0.04	0.43	

Note. The single pathway between T1 auditory executive attention and T1 phonological processing was not significant (*p* = .23); T1 = time 1; T2 = time 2; β = beta (standardised coefficient); CI = confidence interval.

Figure 5.5 illustrates the relationship between T1 visual orienting and T2 subsequent reading accuracy through T1 phonological processing in later stage readers. The total effect (95% CI [-0.51, -0.03], with a point estimate of -0.27, *p* = .03) was significant. However, the indirect (95% CI [-0.82, 0.25], with a point estimate of -0.29, *p* = .30) and direct (95% CI [-0.51, 0.55], with a point estimate of 0.02, *p* = .95) effects were not significant.

Similarly, Figure 5.6 illustrates the relationship between T1 visual executive attention and T2 subsequent reading accuracy through T1 phonological processing in later stage readers. The total effect (95% CI [0.09, 0.60], with a point estimate of 0.34, *p* = .01) was significant. However, the indirect (95% CI [-0.26, 1.17], with a point estimate of 0.46, *p* = .21) and direct (95% CI [-0.82, 0.59], with a point estimate of -0.12, *p* = .75) effects were not significant.

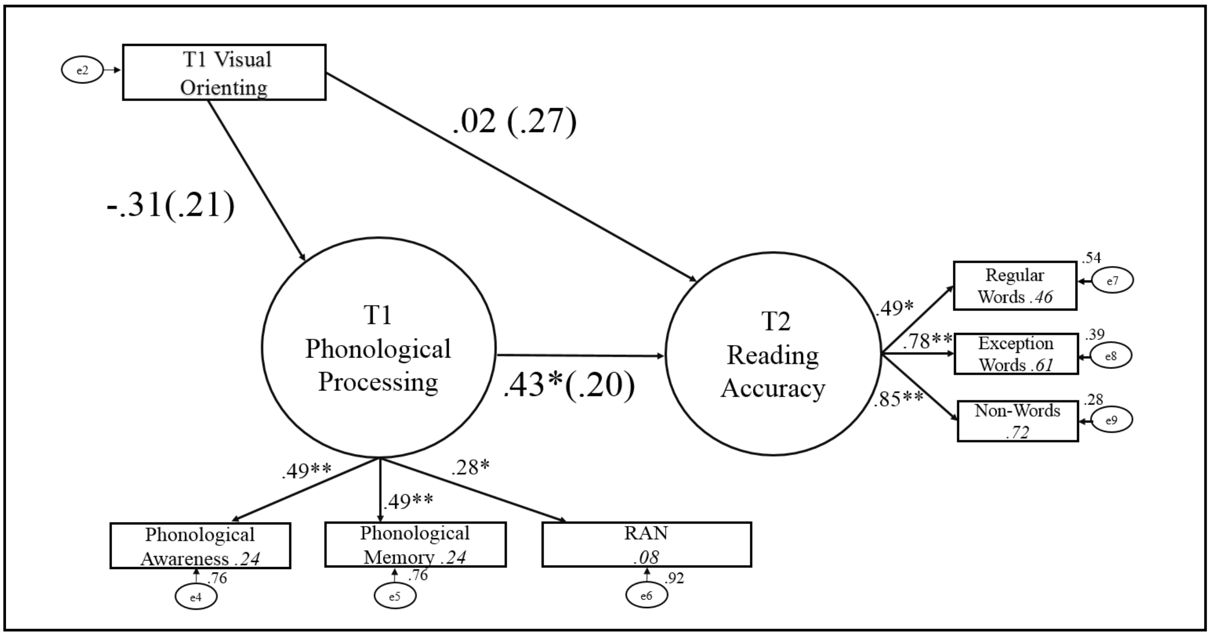


Figure 5.5. The relationship between T1 visual orienting and T2 subsequent reading accuracy via T1 phonological processing in later stage readers (n = 62). Visual alerting and visual executive attention were also assessed in this model, but for ease of illustration, and given its significant total effect, only visual orienting is illustrated. **Correlation was strong and significant (p < .001) at the .05 level (2-tailed). *Correlation was significant (p < .05) at the .05 level (2-tailed). The single pathway from T1 visual orienting to T1 phonological processing was not significant (p = .14). T1 = time 1; T2 = time 2; RAN = rapid automatised naming. Standard errors are provided in parentheses.

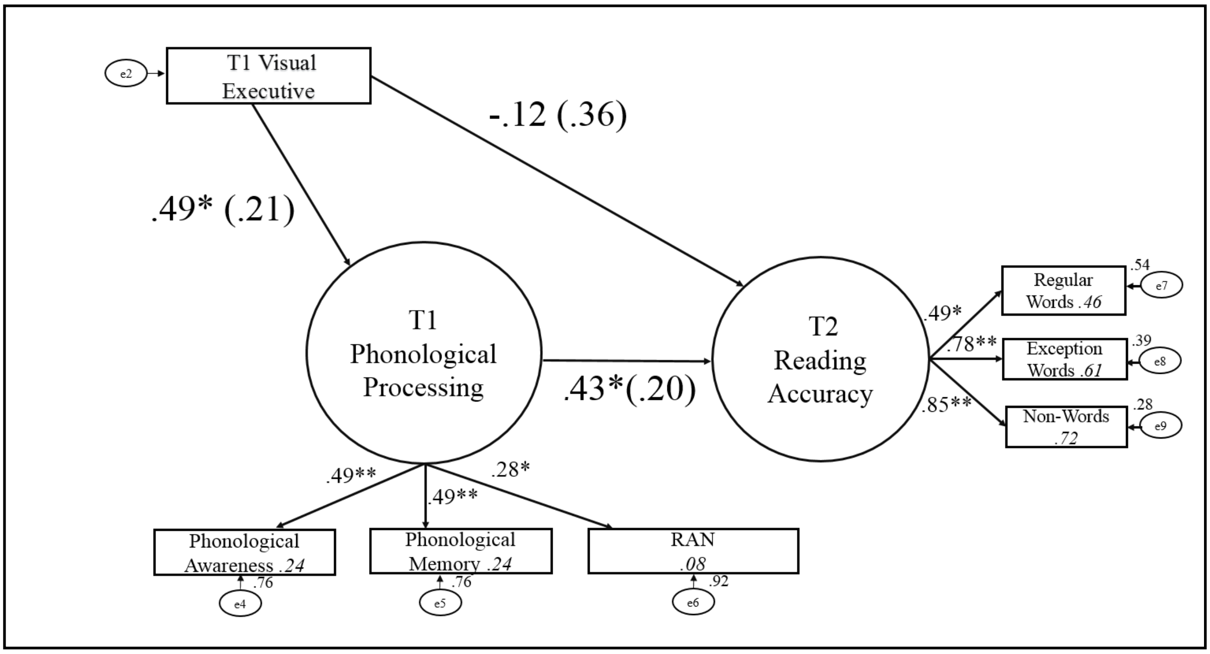


Figure 5.6. The relationship between T1 visual executive attention and T2 subsequent reading accuracy via T1 phonological processing in later stage readers (*n* = 62).Visual alerting and visual orienting were also assessed in this model, but for ease of illustration, and given its significant total effect, only visual executive attention is illustrated. **Correlation was strong and significant ($p < .001$) at the .05 level (2-tailed). *Correlation was significant ($p < .05$) at the .05 level (2-tailed). The single pathway from T1 visual executive attention to T1 phonological processing was significant ($p = .02$). T1 = time 1; T2 = time 2; RAN = rapid automatised naming. Standard errors are provided in parentheses.

The pattern of relationship for visual orienting and visual executive (i.e., significant total effects, but non-significant, large indirect effects) attention as described in the previous paragraphs is not unusual. The significant total effect suggests that both visual orienting and visual executive attention at T1 are likely to be related with subsequent reading accuracy at T2 for later stage readers. But, the non-significance of the direct and indirect effects indicates that the current data may not be able to provide an estimate of these effects that are distinguishable from zero. However, given the large effect sizes of the indirect effects for both visual orienting and visual executive attention, this suggests that the possible mediating effects are meaningful. In fact, with these outcomes (i.e., non-significant large effects), it is suggested that the indirect effect is most meaningfully interpreted by considering the path coefficients, as well as, how precisely these coefficients have been estimated (using standard errors or 95% CIs) before considering *p*-values (Stata discussion board, 2014).

Thus, in Figure 5.5, the negative, indirect effect in the relationship between visual orienting and reading accuracy via phonological processing had a large coefficient (-.29), suggesting that a larger visual orienting score is related to poorer phonological processing scores, and poorer reading accuracy. In contrast, the direct effect between T1 visual orienting and T2 reading accuracy had a smaller coefficient (.02), compared with the indirect effect, suggesting that a direct relationship between T1 visual orienting and later reading accuracy is not likely. This finding aligns with the negative, indirect effect of visual orienting upon reading accuracy through phonological processing observed for later stage readers in Study 1.

Similarly, in Figure 5.6, the positive, indirect effect in the relationship between T1 visual executive attention and T2 reading accuracy via T1 phonological processing had a large coefficient (.46), suggesting that a larger visual executive effect is related with higher phonological processing scores, and more accurate reading. The direct effect between T1 visual executive attention and T2 reading accuracy had a smaller coefficient (-.12), compared with the indirect effect, suggesting that a direct relationship between T1 visual executive attention and T2 reading accuracy is not likely.

Figure 5.7 illustrates the relationship between T1 auditory orienting and T2 subsequent reading accuracy via T1 phonological processing for later stage readers. The direct (95% CI [0.02 to 0.65], with a point estimate of 0.34, $p = .04$) and total (95% CI [0.01 to 0.53], with a point estimate of 0.27, $p = .04$) effects were positive and significant. Together, this suggests that a larger auditory orienting effect is directly associated with higher reading accuracy scores for later stage readers. The indirect effect was negative and not significant (95% CI [-0.36 to 0.23], with a point estimate of -0.07, $p = .66$).

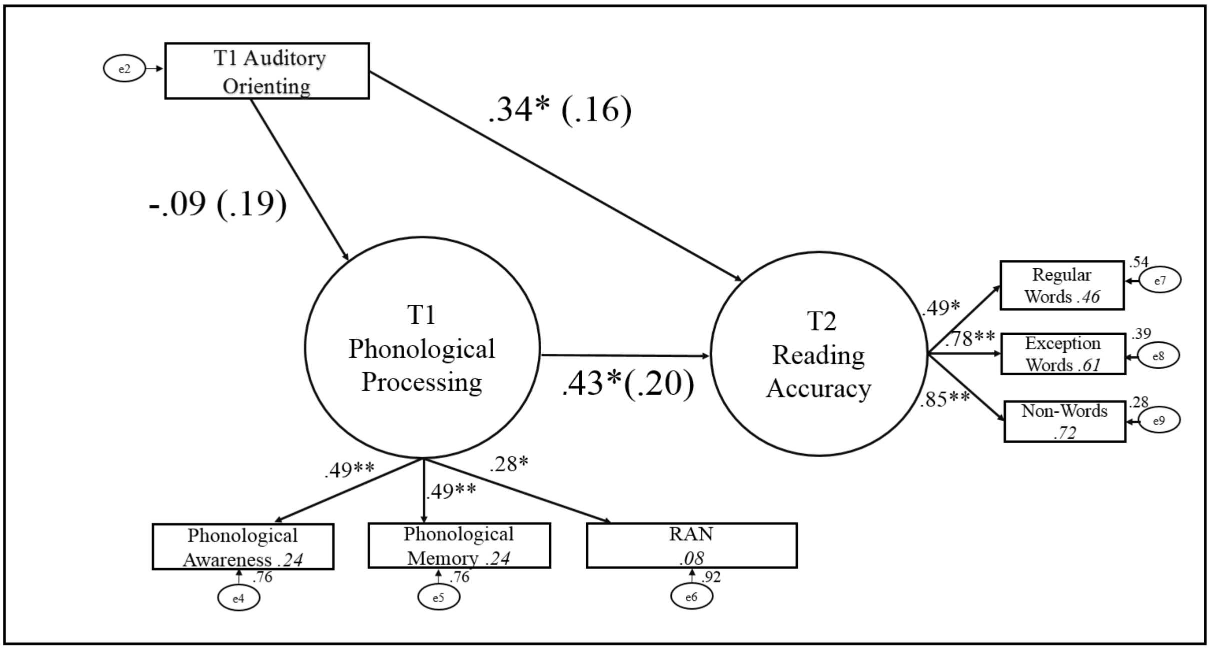


Figure 5.7. The relationship between T1 auditory orienting and T2 subsequent reading accuracy through T1 phonological processing in later stage readers (n = 62). Auditory alerting and auditory executive attention were also assessed in this model, but for ease of illustration, and given its significance, only auditory orienting is illustrated. **Correlation was strong and significant (p < .001) at the .05 level (2-tailed). *Correlation was significant (p < .05) at the .05 level (2-tailed). The single pathway between T1 auditory orienting and T1 phonological processing was not significant (p = .65). T1 = time 1; T2 = time 2; RAN = rapid automatised naming. Standard errors are provided in parentheses.

Reading speed. Figure 5.8 illustrates the hypothesised model for the relationship between T1 attention, T1 phonological processing, and T2 subsequent reading speed that was assessed for both stages of reading.

Table 5.13 provides the fit indices for the test of group measurement (Models 1─4) and structural (Models 5─6) invariance in the relationship between T1 attention, T1 phonological processing, and T2 reading speed across early and later stage readers. The fit of the hypothesised measurement model component (i.e., T1 phonological processing and T2 reading speed) in Figure 5.8 was initially tested separately for each of the two groups of readers ─ early stage reading group and later stage reading group. The results of this initial fitting are also presented in Table 5.13.

Model invariance across the two groups of readers was then assessed by conducting a series of invariance tests according to Bengt Muthén (personal communication, 2018) and Muthén and Muthén (2008). As the results in Table 5.13 show, the indices for Model 1 were a good fit to the data. The chi-square difference for Model 1 versus Model 2 (X^2 = 2.09 *df* = 3) was not statistically significant, indicating that the regression slopes across groups were invariant. The chi-square difference for Model 2 versus Model 3 (X^2 = 9.24, *df* = 3) was statistically significant at the $p < 0.05$ level, but statistically non-significant at the $p < 0.01$ level, indicating that there were some differences in the intercepts across groups. Therefore, although there was no full scalar invariance across both groups of readers, there was also no evidence of complete non-equivalence. This is called *partial scalar invariance* (Milfont & Fischer, 2010). Given the strict criteria for invariance, the degree of acceptable variance depends on the proportion of invariant parameters (Bollen, 1989a).

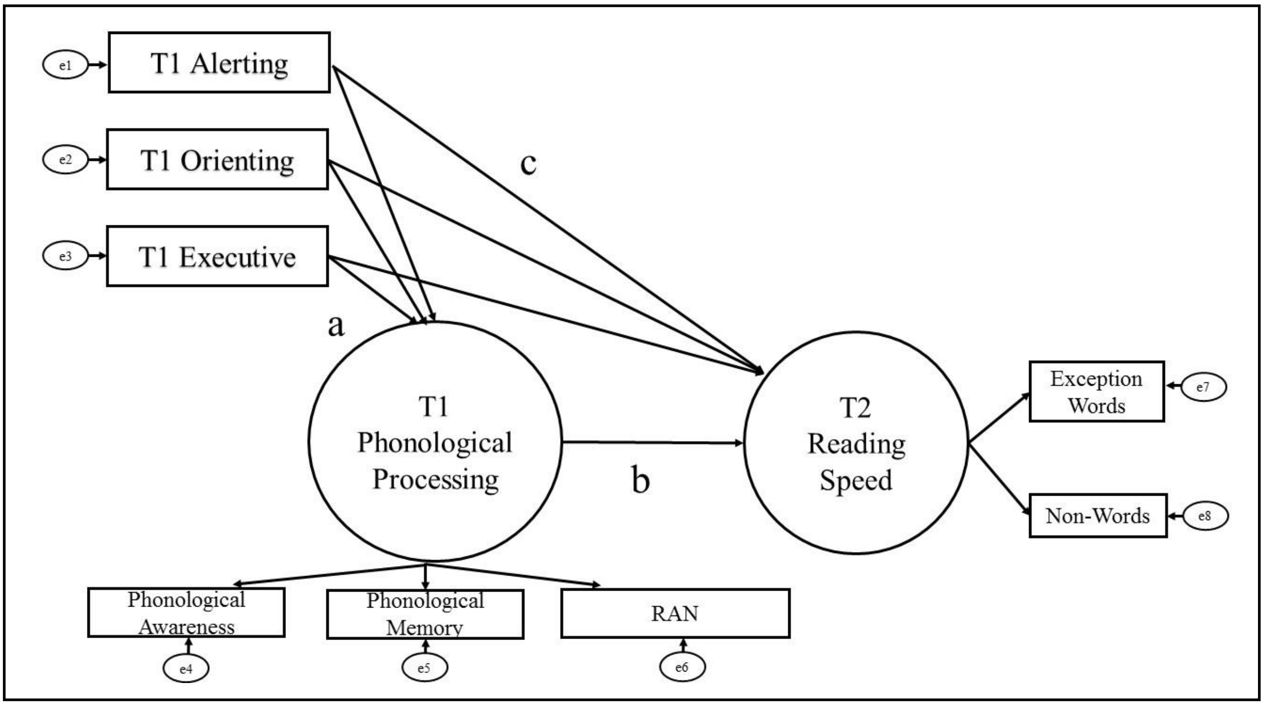


Figure 5.8. Hypothesised two factor model of the relationship between T1 alerting, orienting, and executive attention (visual and auditory assessed separately), T1 phonological processing, and T2 subsequent reading speed for both early (n = 64) and later (n = 62) stage readers.

To examine the extent of partial scalar invariance, in the case of the current study, a modification was required for Model 3, through relaxing some non-invariant intercepts across both groups. The choice of which intercepts to relax was determined by the reported MIs of M*plus* for Model 3. Generally, the value of the MI for a parameter equates to the expected decrease in the chi-square value if this parameter were to be relaxed (Byrne, 2012; Muthén & Muthén, 2008). If the value of the MI for a specific intercept was found to be greater than 3.84 (with $df = 1$), it would be statistically significant, and thus it would be appropriate to be relaxed. The M*plus* results for Model 3 showed that the intercept for RAN was statistically significant (MI = 10.97). Therefore, the intercept for this item was relaxed, thus creating Model 3P. As Table 5.13 illustrates, the chi-square difference for Model 2 versus Model 3P ($X^2 = 0.33$, $df = 2$) was not statistically significant indicating that the intercepts were now invariant across groups. Finally, the chi-square difference for Model 3P versus Model 4 ($X^2 = 12.06$, $df = 2$) was statistically significant at the $p < .05$ level as well as at the $p < .01$ level, suggesting no full or partial error invariance, indicating that differences exist in the errors across groups.

Given that there was no error invariance, structural invariance was conducted with Model 3P as a point of comparison (Milfont & Fischer, 2010). To assess structural invariance, the complete model including the observed variables of attention was fit for both reading groups. These results showed acceptable fit indices as illustrated in Table 5.13. This was followed by the constraining of factor variances and covariances as suggested by Muthén and Muthén (2008). The chi-square difference between Model 3P versus Model 5 ($X^2 = 35.66$, $df = 23$) was statistically significant at the $p < 0.05$ level, but statistically non-significant at the $p < 0.01$ level, indicating that there may be some differences in the covariance and variance, for a model that included visual attention networks, phonological processing, and reading speed, across group. In contrast, the chi-square difference ($X^2 = 29.98$, $df = 25$) between Model 3P versus Model 6 was not statistically significant at the $p < 0.05$ level, suggesting covariance and variance invariance, for a model that included auditory attention networks, phonological processing, and reading speed, across early and later stage readers. Therefore, for the relationship between T1 attention (visual and auditory), T1 phonological processing, and T2 reading speed, partial structural invariance (covariance and variance) was identified for visual attention, but full structural invariance was identified for auditory attention. Altogether, these tests have generally confirmed measurement and structural invariance across early and later stage readers. However, the groups may differ in the extent to which the latent variables, as well as the structural pathways are characterised, since there was no error invariance and only partial structural invariance for the model involving visual attention networks.

Early stage readers: Measurement model analysis. The hypothesised measurement model with the results from a multiple-group CFA in the relationship between T1 phonological processing and T2 subsequent reading speed for early stage readers is shown in Figure 5.9. There was a significant, negative relationship between phonological processing and subsequent reading speed at T2 (p < .001). That is, those early stage readers with stronger phonological processing at T1 were faster at speeded word naming at T2. Given that the indices were a good fit to the data, post-hoc modifications were not required, and there were no discrepancies with the residual variances, which ranged between .09 and .85, well within the suggested ≤ 2 criterion.

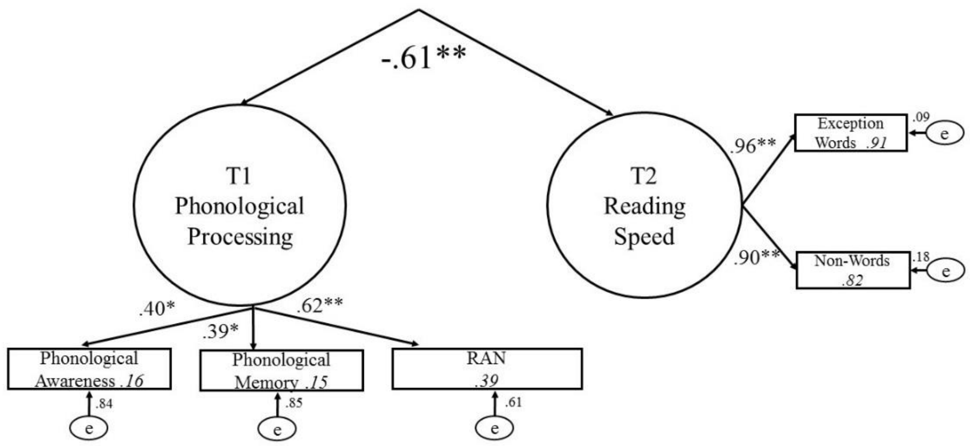


Figure 5.9. Measurement model with CFA results (standardised estimates) for the hypothesised relationship between T1 phonological processing and T2 reading speed for early stage readers (n = 64). **Correlation was strong and significant (p < .001) at the .05 level (2-tailed). *Correlation was significant (p < .05) at the .05 level (2-tailed). T1 = time 1; T2 = time 2; RAN = rapid automatised naming.

Table 5.13: Fit Indices of Group Invariance Testing for T1 Attention Networks, T1 Phonological Processing, and T2 Reading Speed in Early (*n* = 64) and Later (*n* = 62) Stage Readers in Study 2

Model	X^2	df	*p*	CFI	TLI	RMSEA	SRMR	Comparison	Decision
Step 1-Measurement Invariance									
Model 0. Early stage	6.58	4	.16	.97	.94	.10	.05	__	Accept
Model 0. Later stage	5.59	4	.23	.99	.97	.08	.05	__	Accept
Model 1. Configural	12.16	8	.14	.98	.96	.09	.05	__	Accept
Model 2. Metric	14.25	11	.22	.99	.98	.07	.07	Model 1 vs. Model 2	Accept
Model 3. Partial scalar	23.49	14	.05	.96	.94	.10	.09	Model 2 vs. Model 3	Reject
Model 3P. Full scalar	14.58	13	.33	.99	.99	.04	.07	Model 2 vs. Model 3P	Accept
Model 4. Error	26.64	15	.03	.95	.93	.11	.19	Model 3P vs. Model 4	Reject
Step 2-Mediation Model Fit									
Visual mediation model	36.95	31	.21	.98	.96	.06	.07	__	Accept
Auditory mediation model	30.36	31	.50	1.00	1.00	.00	.07	__	Accept
Step 3-Structural Invariance									
Model 5.Variance-covariance (visual)	50.24	36	.06	.94	.92	.08	.12	Model 3P vs. Model 5	Accept (Partial)[13]
Model 6.Variance-covariance (auditory)	44.56	38	.22	.97	.96	.05	.09	Model 3P vs. Model 6	Accept

Note. X^2 = chi-square; *df* = degrees of freedom; CFI = comparative fit index; TFI = Tucker-Lewis index; RMSEA = root mean square error of approximation; SRMR = standardised root mean square residual.

[13] Two initial models to test structural invariance were run through M*plus*. However, M*plus* provided warning messages regarding issues with the standard errors for the first, X^2 (38) = 61.48, *p* = 0.01, CFI = 0.91, TLI = 0.88, RMSEA = 0.10, and SRMR= 0.12, and second, X^2 (27) = 57.26, *p* = 0.02, CFI = 0.92, TLI = 0.90, RMSEA = 0.09, and SRMR= 0.12, models. Therefore, based on M*plus*' MIs, the final model as reported in this table involves relaxing the RAN intercept for later stage readers and co-varying the errors for exception word reading speed and phonological awareness for early stage readers.

The relationship between factor loadings for T1 phonological processing and T2 reading speed for early stage readers is presented in Table 5.14. There was a strong association between the loadings of exception word and non-word reading speed, with these loadings correlating moderately, but consistently with phonological awareness, phonological memory and RAN. There were small to moderate correlations for loadings that assess the phonological processing latent construct.

Table 5.14: Correlation between Factor Loadings for the T1 Phonological Processing and T2 Subsequent Reading Speed Latent Variables in Early Stage Readers (*n* = 64)

	1	2	3	4
1. Phonological awareness				
2. Phonological memory	.26			
3. RAN	.23	.25		
4. Exception words	-.24	-.26	-.32	
5. Non-words	-.28	-.30	-.27	.87

Note. RAN = rapid automatised naming.

Early stage readers: Structural analysis of total, indirect, and direct effects. Tables 5.15 to 5.19 illustrate the total, indirect, and direct effects of T1 visual alerting, T1 visual orienting, T1 visual executive, T1 auditory alerting, and T1 auditory executive attention, in their interactions with T1 phonological processing and T2 subsequent reading speed. The data from these tables suggest that the total, indirect or direct effects for the relationship between these attention variables, phonological processing, and reading speed were not significant. However, it should be noted that the single pathway between T1 visual orienting and T1 phonological processing was significant (p = .050), and the coefficient for the indirect relationship between T1 visual orienting and T2 reading speed through T1 phonological processing was large (-.26), as Table 5.16 illustrates.

Table 5.15: Total, Direct, and Indirect Effects between T1 Visual Alerting, T1 Phonological Processing, and T2 Subsequent Reading Speed in Early Stage Readers (*n* = 64)

Model	β		95% CI, *p* value
	T1 Visual alerting	T1 Phonological processing	
Direct			
T1 Visual alerting		0.27	[-0.11, 0.55], *p* = .19
T2 Reading speed	0.22	-0.61	
Indirect			
T1 Visual alerting		-0.22	[-0.53, 0.01], *p* = .18
T2 Reading speed			
Total			
T1 Visual alerting		0.27	[-0.25, 0.26], *p* = .96
T2 Reading speed	0.01	-0.61	

Note. The single pathway between T1 visual alerting and T1 phonological processing was non-significant ($p = .10$); T1 = time 1; T2 = time 2; β = beta (standardised coefficient); CI = confidence interval.

Table 5.16: Total, Direct, and Indirect Effects between T1 Visual Orienting, T1 Phonological Processing, and T2 Subsequent Reading Speed in Early Stage Readers (*n* = 64)

Model	β		95% CI, *p* value
	T1 Visual orienting	T1 Phonological processing	
Direct			
T1 Visual orienting		0.33	[-0.17, 0.51], *p* = .34
T2 Reading speed	0.17	-0.61	
Indirect			
T1 Visual orienting		-0.26	[-0.58, 0.07], *p* = .12
T2 Reading speed			
Total			
T1 Visual orienting		0.33	[-0.34, 0.16], *p* = .48
T2 Reading speed	-0.09	-0.61	

Note. The single pathway between T1 visual orienting and T1 phonological processing was significant ($p = .050$); T1 = time 1; T2 = time 2; β = beta (standardised coefficient); CI = confidence interval.

Table 5.17: Total, Direct, and Indirect Effects between T1 Visual Executive, T1 Phonological Processing, and T2 Subsequent Reading Speed in Early Stage Readers (*n* = 64)

Model	β		95% CI, *p* value
	T1 Visual executive	T1 Phonological processing	
Direct			
T1 Visual executive		0.06	[-0.30, 0.29], *p* = .98
T2 Reading speed	-0.00	-0.61	
Indirect			
T1 Visual executive		-0.05	[-0.32, 0.22], *p* = .74
T2 Reading speed			
Total			
T1 Visual executive		0.06	[-0.31, 0.21], *p* = .71
T2 Reading speed	-0.05	-0.61	

Note. The single pathway between T1 visual executive attention and T1 phonological processing was non-significant ($p = .73$); T1 = time 1; T2 = time 2; β = beta (standardised coefficient); CI = confidence interval.

Table 5.18: Total, Direct, and Indirect Effects between T1 Auditory Alerting, T1 Phonological Processing, and T2 Subsequent Reading Speed in Early Stage Readers (*n* = 64)

Model	β		95% CI, *p* value
	T1 Auditory Alerting	T1 Phonological processing	
Direct			[-0.22, 0.38], *p* = .60
T1 Auditory alerting		0.11	
T2 Reading speed	0.08	-0. 61	
Indirect			[-0.33, 0.17], *p* = .53
T1 Auditory alerting		-0.08	
T2 Reading speed			
Total			[-0.27, 0.27], *p* = .99
T1 Auditory alerting		0.11	
T2 Reading speed	0.00	-0. 61	

Note. The single pathway between T1 auditory alerting and T1 phonological processing was non-significant ($p = .52$); T1 = time 1; T2 = time 2; β = beta (standardised coefficient); CI = confidence interval.

Table 5.19: Total, Direct, and Indirect Effects between T1 Auditory Executive, T1 Phonological Processing, and T2 Subsequent Reading Speed in Early Stage Readers (*n* = 64)

Model	β		95% CI, *p* value
	T1 Auditory executive	T1 Phonological processing	
Direct			
T1 Auditory executive		0.08	[-0.18, 0.39], *p* = .48
T2 Reading speed	0.10	-0. 61	
Indirect			
T1 Auditory executive		-0.06	[-0.30, 0.18], *p* = .63
T2 Reading speed			
Total			
T1 Auditory executive		0.08	[-0.22, 0.30], *p* = .75
T2 Reading speed	0.04	-0. 61	

Note. The single pathway between T1 auditory executive attention and T1 phonological processing was non-significant (*p* = .62); T1 = time 1; T2 = time 2; β = beta (standardised coefficient); CI = confidence interval.

Figure 5.10 illustrates the relationship between T1 auditory orienting and T2 subsequent reading speed through T1 phonological processing in early stage readers. The direct effect was negative and non-significant (95% CI [-0.51, 0.20], with a point estimate of -0.15, *p* = .40). The total (95% CI [-0.13, 0.38], with a point estimate of 0.12, *p* = .34) effect was positive and non-significant. However, the indirect effect was negative and marginally significant (95% CI [-0.04, 0.59], with a point estimate of 0.28, *p* = .09). This suggests that a larger auditory orienting effect is associated with poorer phonological processing, and thus slower reading speed in early stage readers.

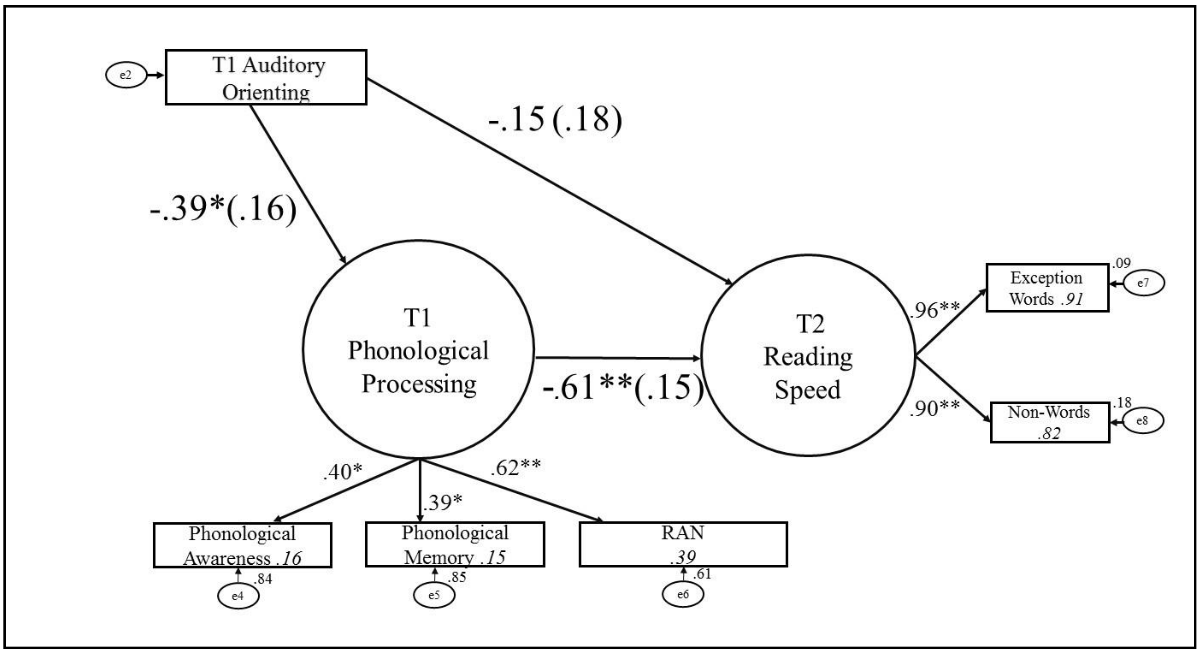


Figure 5.10. The relationship between T1 auditory orienting and T2 subsequent reading speed via T1 phonological processing in early stage readers (n = 64). Auditory alerting and auditory executive attention were also assessed in this model, but for ease of illustration, and given its marginal significance, only auditory orienting is illustrated. **Correlation was strong and significant (p < .001) at the .05 level (2-tailed). *Correlation was significant (p < .05) at the .05 level (2-tailed). The single pathway between T1 auditory orienting and T1 phonological processing was significant (p = .02). T1 = time 1; T2 = time 2; RAN = rapid automatised naming. Standard errors are provided in parentheses.

Later stage readers: Measurement model analysis. The hypothesised measurement model, with the results from a multiple-group CFA, in the relationship between T1 phonological processing, and T2 subsequent reading speed, for later stage readers is shown in Figure 5.11. There was a significant, negative relationship between phonological processing at T1 and subsequent reading speed at T2 (p < .001), suggesting that later stage readers with stronger phonological processing at T1 were faster at speeded word naming at T2; the size of this association was markedly greater than that of early stage readers (-.61) in the current longitudinal study. Figure 5.11 also provides the values for the squared multiple correlation for each indicator (in italics), with the highest and lowest being non-words (.95) phonological awareness (.07), respectively. Given that the indices were a good fit to the data, post-hoc modifications were not required, and there were no discrepancies with the residual variances, which ranged between .05 and .93, well within the suggested ≤ 2 criterion.

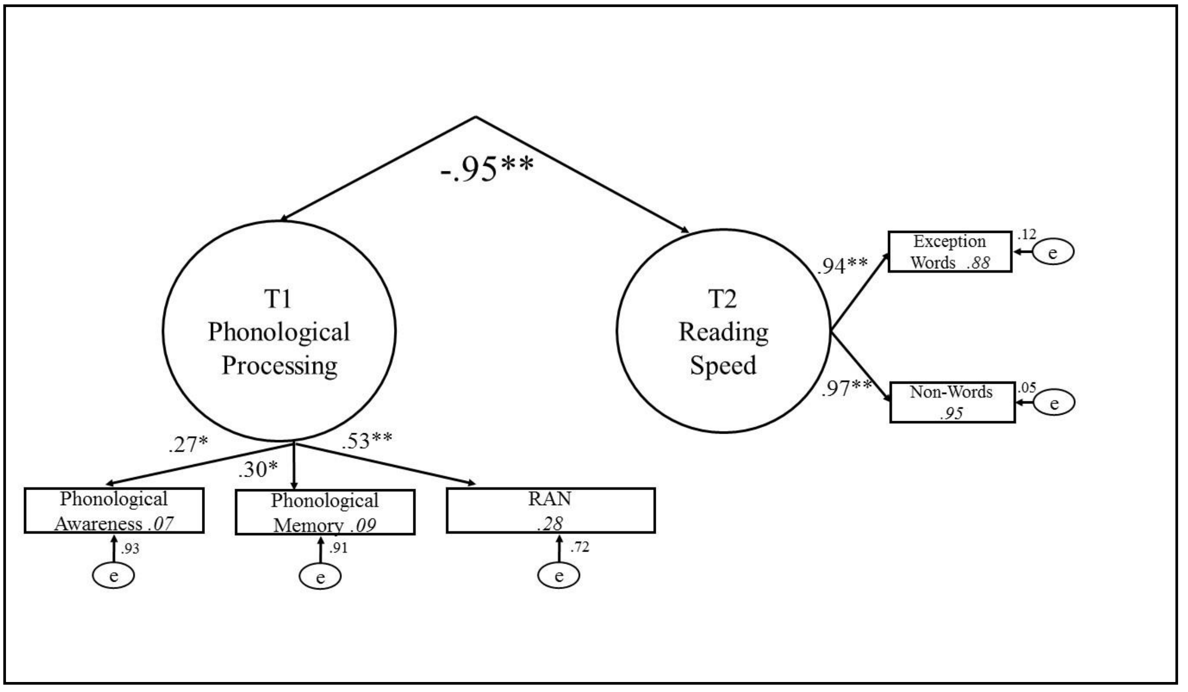


Figure 5.11. Measurement model with CFA results (standardised estimates) for the hypothesised relationship between T1 phonological processing and T2 reading speed in later stage readers (n = 62). **Correlation was strong and significant (p < .001) at the .05 level (2-tailed). *Correlation was significant (p < .05) at the .05 level (2-tailed). T1 = time 1; T2 = time 2; RAN = rapid automatised naming.

The relationship between factor loadings for T1 phonological processing and T2 reading speed in later stage readers is presented in Table 5.20. There were strong associations between the loadings of exception word and non-word reading speed, with these loadings showing a stronger correlation with RAN, compared with phonological awareness and phonological memory. There were weak correlations between phonological awareness, phonological memory and RAN. A weak correlation is especially evident between phonological awareness and phonological memory.

Table 5.20: Correlation between Factor Loadings for the T1 Phonological Processing and T2 Subsequent Reading Speed Latent Variables in Later Stage Readers (*n* = 62)

	1	2	3	4
1. Phonological awareness				
2. Phonological memory	.06			
3. RAN	.13	.14		
4. Exception words	-.20	-.22	-.51	
5. Non-words	-.21	-.23	-.52	.92

Note. RAN = rapid automatised naming

Later stage readers: Structural analysis of total, indirect, and direct effects. Tables 5.21 to 5.25 illustrate the total, indirect, and direct effects of T1 visual alerting, T1 visual executive, T1 auditory alerting, T1 auditory orienting, T1 auditory executive attention, and subsequent reading speed at T2 through T1 phonological processing. The data from these tables suggest that the total, indirect, or direct effects for the relationship between these attention variables, phonological processing, and reading speed were not significant. However, it should be considered that, in Table 5.21, the coefficient for the total effect in the relationship between T1 visual alerting, T1 phonological processing, and T2 reading speed was positive and marginally significant (p = .06). This suggests that higher visual alerting at T1 could relate with slower speeded word naming at T2 in later stage readers.

Table 5.21: Total, Direct, and Indirect Effects between T1 Visual Alerting, T1 Phonological Processing, and T2 Subsequent Reading Speed in Later Stage Readers (*n* = 62)

Model	β		95% CI, *p* value
	T1 Visual alerting	T1 Phonological processing	
Direct			
T1 Visual alerting		-0.08	[-0.26, 0.55], p = .49
T2 Reading speed	0.14	-0.95	
Indirect			
T1 Visual alerting		0.10	[-0.37, 0.56], p = .69
T2 Reading speed			
Total			
T1 Visual alerting		-0.08	[-0.01, 0.48], p = .06
T2 Reading speed	0.24	-0.95	

Note. The single pathway between T1 visual alerting and T1 phonological processing was non-significant (p = .70); T1 = time 1; T2 = time 2; β = beta (standardised coefficient); CI = confidence interval.

Table 5.22: Total, Direct, and Indirect Effects between T1 Visual Executive, T1 Phonological Processing, and T2 Subsequent Reading Speed in Later Stage Readers (*n* = 62)

Model	β		95% CI, *p* value
	T1 Visual executive	T1 Phonological processing	
Direct			
T1 Visual executive		0.30	[-0.28, 0.70], *p* = .40
T2 Reading speed	0.21	-0.95	
Indirect			
T1 Visual executive		-0.34	[-0.88, 0.21], *p* = .22
T2 Reading speed			
Total			
T1 Visual executive		0.30	[-0.40, 0.14], *p* = .35
T2 Reading speed	-0.13	-0.95	

Note. The single pathway between T1 visual executive attention and T1 phonological processing was not significant ($p = .18$); T1 = time 1; T2 = time 2; β = beta (standardised coefficient); CI = confidence interval.

Table 5.23: Total, Direct, and Indirect Effects between T1 Auditory Alerting, T1 Phonological Processing, and T2 Subsequent Reading Speed in Later Stage Readers (*n* = 62)

Model	β		95% CI, *p* value
	T1 Auditory alerting	T1 Phonological processing	
Direct			
T1 Auditory alerting		0.32	[-0.21, 0.67], *p* = .30
T2 Reading speed	0.23	-0.95	
Indirect			
T1 Auditory alerting		-0.33	[-0.82, 0.17], *p* = .20
T2 Reading speed			
Total			
T1 Auditory alerting		0.32	[-0.36, .17], *p* = .48
T2 Reading speed	-0.10	-0.95	

Note. The single pathway between T1 auditory alerting and T1 phonological processing was not significant ($p = .16$); T1 = time 1; T2 = time 2; β = beta (standardised coefficient); CI = confidence interval.

Table 5.24: Total, Direct, and Indirect Effects between T1 Auditory Orienting, T1 Phonological Processing, and T2 Subsequent Reading Speed in Later Stage Readers (*n* = 62)

Model	β		95% CI, *p* value
	T1 Auditory orienting	T1 Phonological processing	
Direct			
T1 Auditory orienting		-0.15	[-0.53, 0.21], *p* = .40
T2 Reading speed	-0.16	-0.95	
Indirect			
T1 Auditory orienting		0.15	[-0.28, 0.58], *p* = .50
T2 Reading speed			
Total			
T1 Auditory orienting		-0.15	[-0.26, 0.24], *p* = .93
T2 Reading speed	-0.01	-0.95	

Note. The single pathway between T1 auditory orienting and T1 phonological processing was not significant ($p = .49$); T1 = time 1; T2 = time 2; β = beta (standardised coefficient); CI = confidence interval.

Table 5.25: Total, Direct, and Indirect Effects between T1 Auditory Executive, T1 Phonological Processing, and T2 Subsequent Reading Speed in Later Stage Readers (*n* = 62)

Model	β		95% CI, *p* value
	T1 Auditory executive	T1 Phonological processing	
Direct			
T1 Auditory executive		0.08	[-0.10, 0.74], *p* = .13
T2 Reading speed	0.32	-0.95	
Indirect			
T1 Auditory executive		0.08	[-0.56, 0.40], *p* = .74
T2 Reading speed			
Total			
T1 Auditory executive		0.08	[-0.01, 0.49], *p* = .06
T2 Reading speed	0.24	-0.95	

Note. The single pathway between T1 auditory executive attention and T1 phonological processing was not significant ($p = .74$); T1 = time 1; T2 = time 2; β = beta (standardised coefficient); CI = confidence interval.

Figure 5.12 illustrates the relationship between T1 visual orienting and T2 reading speed through T1 phonological processing for later stage readers. The direct (95% CI [-0.78, 0.12], with a point estimate of -0.33, *p* = .15) and total (95% CI [-0.05, 0.42], with a point estimate of 0.19, *p* = .13) effects were not significant. However, the indirect effect was negative and significant (95% CI [0.01, -1.03], with a point estimate of -0.52, *p* = .04), suggesting that larger visual orienting scores are related to lower phonological processing scores and slower reading speed in later stage readers.

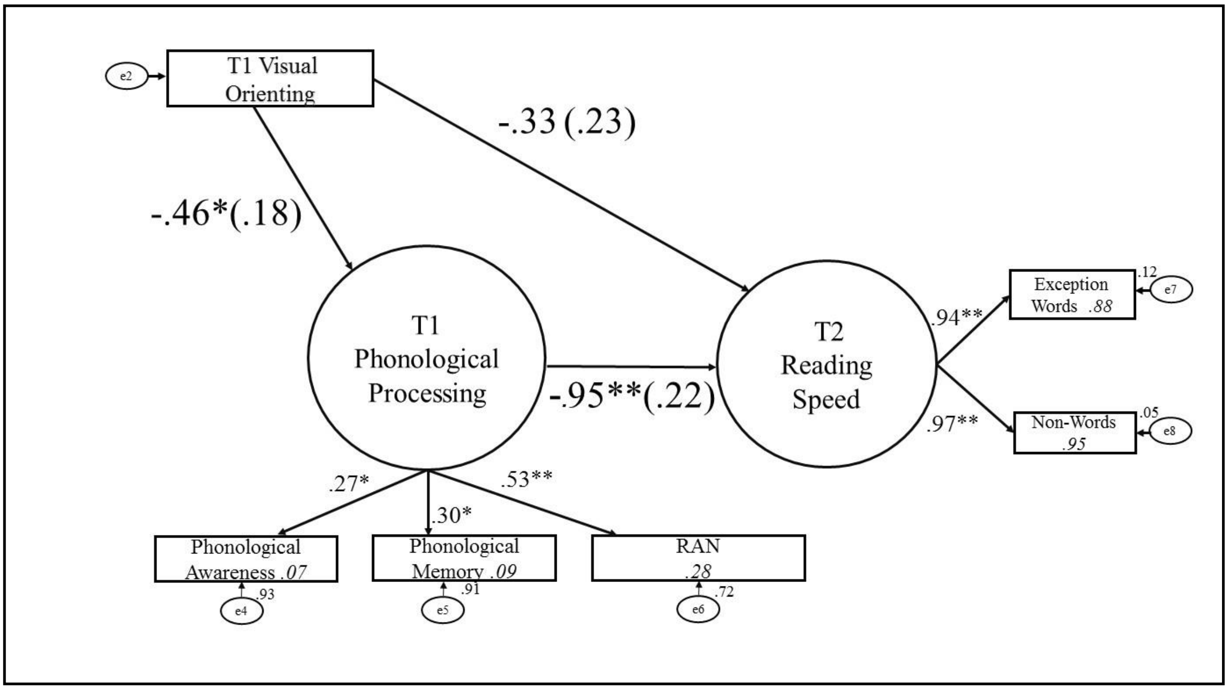


Figure 5.12. The relationship between T1 visual orienting and T2 subsequent reading speed via T1 phonological processing for later stage readers (*n* = 62). Visual alerting and visual executive attention were also assessed in this model, but for ease of illustration, and given its significance, only visual orienting is illustrated. **Correlation was strong and significant (*p* < .001) at the .05 level (2-tailed). *Correlation was significant (*p* < .05) at the .05 level (2-tailed). The single pathway between T1 visual orienting and T1 phonological processing was significant (*p* = .01). T1 = time 1; T2 = time 2; RAN = rapid automatised naming. Standard errors are provided in parentheses.

Stage 4. Specificity and Bi-directionality of Significant SEM Relationships

Specificity of significant SEM relationships. Pearson's correlation analysis accompanied the primary SEM results reported in Stage 3. Note that the pattern of the correlations for both early and later stage readers that were presented in Study 1 were replicated in Study 2 with fewer participants. Therefore, these findings from Study 1 applied to Study 2. Therefore, it was of interest in the current study to determine (a) whether T1 executive functioning influenced the reading accuracy (standardised) and reading speed scores at T2, and (b) the correlations between T1 visual and auditory attention, T2 reading accuracy and T2 reading speed. Table 5.26 presents the results of this correlational analysis for early stage readers, whereas Table 5.27 presents these results for later stage readers.

***Early stage readers*.** Table 5.26 showed significant, negative correlations between T1 executive functioning and T2 regular word (r = -.36, p = .01), T2 exception word (r = -.38, p = .004), and T2 non-word (r = -.27, p = .04) reading accuracy. This suggests that poorer executive functioning (as indicated by higher scores) relates to less accurate reading. The negative correlation between T1 visual executive attention and T2 regular word reading accuracy was marginally significant (r = -.23, p = .07), suggesting that higher visual executive attention scores are related to less accurate regular word reading.

***Later stage readers*.** Table 5.27 shows a significant, negative correlation between T1 visual orienting and T2 regular word reading accuracy (r = -.28, p = .03), suggesting that larger orienting scores are related with lower reading accuracy of regular words. This finding also aligns with the significant, negative total effect of T1 visual orienting upon T2 reading accuracy in the SEM analysis for later stage readers that was reported at Stage 3. There was also a significant, positive relationship between T1 visual executive attention and T2 regular word reading accuracy (r = .34, p = .01), suggesting that larger visual executive attention scores are associated with higher reading accuracy. This finding also aligns with the significant, positive total effect of T1 visual executive attention upon T2 reading accuracy in the SEM analysis for later stage readers that was reported at Stage 3.

Table 5.26: Correlation between Visual and Auditory Attention Networks (T1), Executive Functioning (T1), and T2 Reading Accuracy and Speed in Early Stage Readers (*n* = 64)

	1	2	3	4	5	6	7	8	9	10	11
1.Visual alerting											
2.Visual orienting	.01										
3.Visual executive	-.04	-.05									
4.Auditory alerting	-.05	.18	-.27*								
5.Auditory orienting	-.06	.01	-.15	.16							
6. Auditory executive	-.05	.01	.12	-.03	-.02						
7.RW: Accuracy	-.08	.21	-.23†	.11	.03	.02					
8.EW: Accuracy	.01	.14	-.19	.18	-.00	.01	.66**				
9.NW: Accuracy	.02	.16	-.03	.14	.03	.04	.54**	.61**			
10.EW: Speed	-.00	-.09	-.04	.03	.10	.06	-.49**	-.44**	-.40**		
11.NW: Speed	.10	-.02	.11	-.18	.03	-.01	-.39**	-.40**	-.31*	.85**	
12.Executive functioning	-.05	-.06	.06	.03	-.15	-.04	-.36**	-.38**	-.27*	.10	.11

Note. *Correlation was significant at the $p < .05$ level; ** correlation was strong and significant at the $p < .001$ level; † correlation approached significance at the $p < .05$ level; RW = regular words; EW= exception words; NW = non-words.

Table 5.27 also shows a significant, positive relationship between T1 auditory orienting and T2 non-word reading accuracy (r = .33, p = .01), suggesting that larger auditory orienting scores are related to more accurate reading of non-words. It is possible that this finding either supports or clarifies the nature of the significant, positive, direct effect of T1 auditory orienting upon T2 reading accuracy identified in the SEM analysis for later stage readers. T1 auditory executive attention was significantly and positively related to non-word reading speed (r = .26, p = .04), and marginally related to exception word reading speed (r = .23, p = .08). Therefore, higher auditory executive attention scores are likely to be related with slower RTs on word naming tasks. There were no significant correlations between T1 executive functioning and T2 reading accuracy and T2 reading speed in later stage readers.

Bi-directionality of Significant SEM Relationships. Given the notable relationships between attention and reading via phonological processing in early (auditory attention) and later (visual attention) stage readers, subsequent SEM analysis was conducted to clarify these relationships. This was aimed at assessing if phonological processing influenced attention. The results presented below were derived from a multiple-group SEM analysis, and was conducted separately for accuracy and speed, and by attention modality.

Early stage readers: Auditory attention (reading accuracy). The bi-directional model for the relationship between T1 phonological processing (predictor) and T2 reading accuracy through T1 auditory attention (mediator) was a good fit to the data, X^2 (52) = 51.21, p = 0.51, CFI = 1.00, TLI = 1.00, RMSEA = 0.00, and SRMR = 0.09. There were non-significant indirect effects for alerting (95% CI [-0.05, 0.05], with a point estimate of -0.00, p = .95), orienting (95% CI [-0.37, 0.09], with a point estimate of -0.14, p = .23), and executive (-0.06 to 0.04, with a point estimate of -0.01, p = .71) attention. The total (95% CI [0.37, 1.02], with a point estimate of 0.70, p < .001), and direct (0.44 to 1.26, with a point estimate of 0.85, p < .001) effects were significant.

Table 5.27: Correlation between Visual and Auditory Attention Networks (T1), Executive Functioning (T1) and, T2 Reading Accuracy and Speed in Later Stage Readers (*n* = 62)

	1	2	3	4	5	6	7	8	9	10	11
1.Visual alerting											
2.Visual orienting	.08										
3.Visual executive	.28*	-.05									
4. Auditory alerting	.18	-.06	.28*								
5.Auditory orienting	-.17	.16	-.11	.08							
6. Auditory executive	.06	.11	.23	-.26*	-.11						
7.RW: Accuracy	-.04	-.28*	.34**	.12	.01	.12					
8.EW: Accuracy	.03	.01	.06	.20	.21	-.16	.49**				
9.NW: Accuracy	-.07	-.21	-.03	.19	.33*	-.15	.60**	.64**			
10.EW: Speed	.21	.18	.01	-.10	-.05	.23†	-.38**	-.29**	-.32**		
11.NW: Speed	.21	.21	-.10	-.19	-.03	.26*	-.47**	-.36**	-.35*	.92**	
12.Executive functioning	-04	-.20	-.23	.08	.17	-.08	-.19	-.02	.00	.09	.10

Note. *Correlation was significant at the $p < .05$ level; ** correlation was strong and significant at the $p < .001$ level; † correlation approached significance at the $p < .05$ level; RW = regular words; EW= exception words; NW = non-words.

Early stage readers: Auditory attention (reading speed.) The bi-directional model for the relationship between T1 phonological processing (predictor) and T2 reading speed through T1 auditory attention (mediator) was a good fit to the data, X^2 (39) = 52.74, p = 0.07, CFI = 0.94, TLI = 0.92, RMSEA = 0.08, and SRMR = 0.08. There were non-significant indirect effects for alerting (95% CI [-0.00, 0.00], with a point estimate of 0.00, p = .99), orienting (95% CI [-0.10, 0.19], with a point estimate of 0.05, p = .55), and executive (-0.04 to 0.06, with a point estimate of 0.01, p = .69) attention. The total (95% CI [-0.86, -0.21], with a point estimate of -0.53, p = .001), and the direct (-0.98 to -0.20, with a point estimate of -0.59, p = .003) effects were significant.

Summary of bi-directionality analysis for early stage readers. Together, for reading accuracy and speed, these findings suggest that the significant relationship between T1 phonological processing and T2 reading accuracy/speed was not mediated through T1 auditory alerting, orienting, or executive attention. As such, there is no evidence of a bi-directional relationship between T1 auditory orienting and T1 phonological processing. That is, T1 auditory orienting significantly influenced T1 phonological processing (as shown in the current longitudinal study when auditory orienting was the predictor and phonological processing was the mediator), but T1 phonological processing does not influence T1 auditory orienting.

Later stage readers: Visual attention (reading accuracy). The bi-directional model provided a good fit to the data, X^2 (50) = 61.99, p = 0.12, CFI = 0.94, TLI = 0.91, RMSEA = 0.06, and SRMR = 0.11. The relationship between T1 phonological processing (predictor) and T2 reading accuracy through T1 visual attention (mediator) had non-significant indirect effects for alerting (95% CI [-0.12, 0.05], with a point estimate of -0.03, p = .46), orienting (95% CI [-0.03, 0.09], with a point estimate of 0.03, p = .31), and executive (95% CI [-0.13, 0.20], with a point estimate of 0.03, p = .69) attention. The total (95% CI [0.34, 0.82], with a point estimate of 0.58, p < .001) and direct (95% CI [0.21, 0.89], with a point estimate of 0.55, p = .002) effects were significant.

Later stage readers: Visual attention (reading speed). The bi-directional model provided a good fit to the data, X^2 (36) = 50.72, p = 0.05, CFI = 0.94, TLI = 0.91, RMSEA = 0.08, and SRMR = 0.08. The relationship between T1 phonological processing (predictor) and T2 reading speed through T2 visual attention (mediator) had non-significant indirect effects for alerting (95% CI [-0.07, 0.07], with a point estimate of -0.00, p = .97), orienting (95% CI [-0.10, 0.16], with a point estimate of 0.03, p = .63), and executive (95% CI [-0.07, 0.08], with a point estimate of 0.01, p = .91) attention. The total (95% CI [-0.97, -0.43], with a point estimate of -0.70, p < .001) and direct (95% CI [-1.11, -0.35], with a point estimate of -0.73, p < .001) effects were significant.

Summary of bi-directionality analysis for later stage readers. Together, for reading accuracy and speed, these findings suggest that the significant relationship between T1 phonological processing and T2 reading accuracy/speed was not mediated through T1 visual alerting, orienting, or executive attention. As such, there is no evidence that T1 phonological processing influenced visual attention.

Summary and Discussion of Study 2

The aim of Study 2 was to assess the stability in the pattern of mediation between T1 attention and T1 phonological processing in predicting T2 reading between early versus later stage readers using a longitudinal design.

Reading accuracy. The primary multiple-group SEM analysis of Study 2 showed significant relationships between T1 attention (predictor), T1 phonological processing (mediator), and T2 reading accuracy for early and later stage readers. In early stage readers, there was a significant, negative, indirect effect of T1 auditory orienting attention upon T2 reading accuracy through T1 phonological processing, suggesting that larger auditory orienting scores are related to poorer phonological processing and in turn, lower reading accuracy. While the coefficient for the indirect effect in the relationship between T1 visual orienting and T2 reading accuracy through T1 phonological processing was statistically non-significant, it was large, and potentially meaningful. The longitudinal results of Study 2 for early stage readers therefore support the hypothesis of a mediated route to reading, which also replicate the cross-sectional findings in Study 1. Moreover, the finding that T1 attention predicts later reading accuracy at T2 via T1 phonological processing is consistent with previous longitudinal designs that have assessed the relationship between attention and decoding via phonological awareness in beginning readers (e.g., Dice & Schwanenflugel, 2012; van de Sande et al., 2013). Thus, given the finding of a phonologically mediated access to word recognition, the present results confirm the fundamental role of phonological processing at very early stages of reading, and that better phonological skills enable more accurate reading (Melby-Lervåg et al., 2012).

For later stage readers, the total effects of T1 visual orienting attention and T1 visual executive attention, in the relationship with T1 phonological processing and T2 reading accuracy, was significant. This finding suggests that there was an effect of visual orienting attention and visual executive attention that might be mediated by phonological processing. Such a possibility is likely, since the indirect effects for each of these attention networks (compared with their direct effects) through phonological processing had a large effect size. On the one hand, the pattern of the meaningful indirect effect of visual orienting replicates the findings for later stage readers in Study 1, where a larger visual orienting effect was significantly associated with lower phonological processing and in turn, lower reading accuracy. On the other hand, the finding that visual executive attention has become important for subsequent reading accuracy extends the findings of Study 1, but also supports previous research that shows the important role of executive attention to reading (Besner et al., 2016). The idea is that executive attention functions as a gatekeeping mechanism that regulates information processing to prioritise relevant information (Fernandez-Duque et al., 2000; Yap & Balota, 2015). However, given the mediated relationship of T1 visual orienting and T1 visual executive attention via T1 phonological processing, the present longitudinal results for visual attention do not support the hypothesis of a direct relationship between attention and reading for later stage readers.

Nevertheless, the role of auditory attention for later stage readers has presented a special case that supports the hypothesis of an unmediated relationship between attention and reading for later stage readers. The analysis showed that there was a significant, positive, direct effect of T1 auditory orienting upon T2 reading accuracy, suggesting that larger auditory orienting scores are directly related to higher reading accuracy. This finding offers a potential solution to the debate on whether or not a phonologically mediated route is adopted among more fluent readers (Goswami et al., 2001; Grainger et al., 2012; Jared & O'Donnell, 2017). That is, when considering attention modality, the role of phonological processing in word recognition accuracy among later stage readers is clarified. Further details of a reconciliation to this debate is discussed in greater detail in the General Discussion. Finally, like Study 1, there was no evidence of a bi-directional relationship between attention and phonological processing in their influence upon reading accuracy, in the participants that were followed up in this longitudinal study. This provides more robust support for the finding that attention impacts upon phonological processing, rather than the converse.

Reading speed. Study 2 showed an indirect relationship between T1 attention and T2 reading speed via T1 phonological processing. For early stage readers, the relationship between T1 auditory orienting, T1 phonological processing, and T2 reading speed was marginally significant, suggesting that larger auditory orienting scores relate to lower phonological processing, and in turn slower word (exception and non-word) reading speed. For later stage readers, the relationship between T1 visual orienting, T1 phonological processing, and T2 reading speed was significant, suggesting that higher visual orienting scores, relate to lower phonological processing and in turn slower word (exception and non-word) reading speed. Together, the pattern of these findings suggests that for reading speed, the early impact of phonological processing skills influences later reading speed for both early and more fluent stages of reading. Moreover, like reading accuracy in Study 1 and Study 2, the modality of attention for the indirect effect of T1 attention upon T2 reading speed via T1 phonological processing seems to be dependent upon stage of reading. In addition, there was no evidence of a bi-directional relationship between attention and phonological processing, in their influence upon reading speed. This provides more robust support for the finding that attention impacts upon phonological processing, rather than the converse.

Interactions between attention networks and executive functioning. Finally, for early stage readers, there were no significant relationships between the attention networks that were observed as significant in the SEM analysis with other attention networks or executive functioning. This suggests that the impact of T1 orienting attention upon T2 reading accuracy or speed, through T1 phonological processing, is not likely to be influenced by other attention networks or executive functioning, at least for the current sample. Therefore, this finding provides more robust evidence to support the claim that attention, and particularly, orienting attention has a unique contribution to reading accuracy, above and beyond the influence of interactions with other attention networks, and potentially executive functioning. This latter proposition regarding executive function is also supported by a previous meta-analysis of longitudinal datasets revealing that reading achievement was influenced by attention skills controlling for skills related to executive functioning (Duncan et al., 2007). In contrast, for later stage readers, the correlational analysis showed a significant, positive relationship between visual alerting and visual executive attention, as well as between auditory alerting and visual executive attention, suggesting that as visual/auditory alerting increases, there is also an increase in the visual executive attention score (indicating less efficiency to inhibit information). This finding implies that the significant, positive total effect observed in the relationship between visual executive attention, phonological processing, and reading in later stage readers might be influenced by visual and auditory alerting attention. Although previous perspectives have identified independent attention networks (e.g., Fan et al., 2002; Rueda et al., 2004), it is unsurprising that there are interactions between networks, which is likely to influence later stage reading accuracy. In fact, more recent studies have identified a strategic interaction between alerting and executive attention (Weinbach & Henik, 2011, 2012, 2013). Further details of this strategic relationship and what it might indicate about reading at more fluent stages are discussed in greater detail in the General Discussion.

Chapter 6 : Results of Study 3

Chapter Overview

This chapter provides the results of the final study, which examined, quasi-experimentally, group differences between typically developing and disordered reading populations (children with DD) in the relationship between the visual and auditory attention networks, phonological processing, and reading.

Aims

The aims of Study 3 were:

a) To determine group differences in the relationship between visual and auditory attention networks, phonological processing, and reading in children with DD (aged 9 to 10 years) compared with their RA (aged 6 to 7 years) and CA (aged 9 to 10 years) matched controls. RA and CA matched controls were drawn from a subset of Study 1 participants.
b) To determine if there was a group difference in the modality of attention that influences reading (via phonological processing or directly) between children with DD and their typically DD matched controls.

Hypotheses. Study 3 predicted that the strength and modality of the hypothesised mediation pathway would vary as a function of group (same as that predicted for Study 1). As a reminder, Study 1 hypothesised that (a) in the early stages of reading (RA matched controls in Study 3), phonological processing would mediate the relationship between attention and reading, but the during later stages of reading (CA matched controls in Study 3), the mediated pathway would diminish and the direct pathway from attention to reading would be strengthened and; (b) in the early stages of reading, auditory attention would be more important for reading, compared with visual attention, but during later stages of reading, the visual attention would be more important, compared with auditory attention. In addition to this, it was further predicted that children with DD would present with a similar pattern of mediation as their RA matched controls, although, it was expected that they would perform less efficiently on the measures of attention, and more poorly on the measures of phonological processing, and reading. As well, it was hypothesised that for children with DD, auditory attention would be more significant for reading compared with visual attention.

Analysis Plan and Rationale

Stage 1. Children with DD and their typically developing RA and CA matched controls were matched and the procedures involved in this matching process are reported. Then, missing, error, and outlier data were checked or removed. Then, the assumptions underlying repeated measures ANOVA and SEM were tested. The same assumptions as Study 1 were applied to Study 3. Finally, an assessment of power of the sample size was conducted. This was aimed at determining if the sample sizes of 50 participants in each of the three groups (RA matched controls, children with DD and CA matched controls) were robust to detect meaningful relationships between attention, phonological processing, and reading through SEM.

Stage 2. Descriptive summaries, including means, ranges, and standard deviations of standardised test measures (i.e., screening measures, visual and auditory attention network effects, phonological processing scores, reading accuracy and speed scores, and executive functioning scores) were analysed. In addition, inferential statistics were conducted, including one-way ANOVAs for scores on phonological processing, reading accuracy (number correct out of 40 trials for each word type), and executive functioning (scores calculated based on Likert type scale), comparing performance across reading ability groups. The Kruskal-Wallis test was used to compare group differences for reading speed scores. Post-hoc test for significant group differences in the ANOVAs and the Kruskal-Wallis test was conducted using Tukey's HSD and the Dunn's test, respectively.

For each ANT test in each group, two-way repeated measures ANOVA were used to test for effects of cue type (no cue, double cue, central cue, spatial cue), congruency (neutral, congruent, incongruent), and their interaction, on mean RT and error rates. This was conducted to confirm that any observed influence of attention upon both phonological processing and reading in the SEM analysis emerged from a genuine attention network effect in each group. Then, for each ANT test, a three-way mixed (cue, congruency, and group) design ANOVA was then conducted to identify group differences in ANT performance. Finally, a two-way mixed design (word type and group) was conducted to determine group differences in reading speed for exception and non-words. Information regarding follow-up analysis for attention network ANOVAs, interactions, alpha level, and effect size was the same as Study 1.

Stage 3. Information regarding estimation method, invariance testing, effect size calculation, interpretation of fit indices, and reliability composites, which was presented in Study 1 regarding the SEM analysis, was also applied to Study 3. However, in contrast to Studies 1 and 2, single-indicator SEM models were used in the current study. Single indicator models have only one indicator that most reliably measures each latent construct of interest. Prior to presenting the SEM results, a brief justification for using single-indicator SEM is presented.

Stage 4. Depending on the presence of significant effects, subsequent analysis was conducted to clarify the nature of the relationship between the attention networks, phonological processing, and reading. This involved (a) determining the specific relationship between the observed variables for the visual and auditory attention networks and phonological processing, reading and executive functioning using Pearson’s correlation, and (b) determining, through SEM analysis, if observed significant SEM relationships operated bi-directionally.

Stage 1. Matching Participants, Missing Data, Error and Outlier Removal, Assumption Testing, and Power Analysis

Data from children with DD were compared with the datasets of RA and CA matched typically developing controls from Study 1. The reading (regular word, non-word, and exception word reading accuracy) ages for both children with DD and RA matched controls were calculated. Then, matching of children with DD to RA and CA matched controls was done using case-by-case matching. Reading age was the same for children with DD (M = 7.5 years, SD = .33 years, IQ = 109) and RA (M = 7.5 years, SD = .39 years, IQ = 105) matched controls, and IQ was in a similar range. CA matched controls (M = 10 years, SD = .35, IQ = 111) had a similar mean chronological age to children with DD (M = 10.1 years, SD = .26). All participants scored within the average and above average range on the test of intelligence and were free from any uncorrected visual and auditory deficits.

The proportion of missing data for all variables, which were included in the analysis of the relationship between attention, phonological processing, and reading, was assessed to ensure that missing data did not exceed 5% for each experimental variable. For all groups, each variable had at least 96% of data available (range of data availability = 96.0% to 100%). Given that the missing values used in the final analysis accounted for less than the recommended 5%, missing data were not imputed (Tabachnick & Fidell, 2007).

Given that the cVANT, cAANT-SL, and the reading speed task relied on analysing raw scores from an experimental task, the assumption testing for the individual analyses of these tasks included excluding error trials and trimming for RT outliers in the first instance. This issue does not arise if measures are generated from standardised tests, such as the CTOPP (phonological processing), CC2 (reading accuracy), and BRIEF (executive functioning) tasks used in the current study.Given that the RA and CA matched controls were drawn from a subset of the participants in Study 1, the same means were used for attention network and reading speed data.

Moreover, the same approach to calculating the attention network effects and reading speed scores in Study 1 (i.e., excluding errors, trimming RT outliers) was used in the current study. Exclusion criteria for errors and outliers, and RT mean calculation approach were the same as Study 1. Errors (9.6% of trials among children with DD for the cVANT, as well as, 18.0% of trials among children with DD for the cAANT-SL) and RT outliers (4.9% of trials among children with DD for the cVANT, as well as, 3.7% of trials among children with DD for the cAANT-SL), were excluded when calculating the mean RT for each condition for each child with DD. Data pooling and analysis for the cAANT-SL and cVANT, as well as the alpha level and reports of effect sizes were the same as Study 1. Similarly, for the reading speed task, errors and outliers were defined in the same way as Study 1. Errors (27.7% of trials among children with DD) and RT outliers (6.3% of trials among children with DD) were excluded when calculating the mean RT for each word type. The pattern of the error percentages for RA and CA matched controls replicate those in the original study (i.e., Study 1).

Assumption testing. Concerning univariate normality, distributional properties for the attention, phonological processing, reading accuracy, reading speed (for RA matched controls and children with DD), and executive functioning scores were normally distributed. Non-standardised skewness scores for these variables ranged between -0.01 to 2.06 for RA matched controls and 0.04 to 2.04 for children with DD. Similarly, kurtosis values ranged from 0.10 to 5.74 for RA matched controls and 0.22 to 4.57 for children with DD. Conversely, although CA matched controls had normal distributions for attention, phonological processing, and reading accuracy scores (skewness ranged from 0.06 to 1.16 with kurtosis values ranging from 0.01 to 4.46), their reading speed scores were skewed (2.51 for exception word reading speed and 2.73 for non-word reading speed, with high kurtosis values (6.72 for exception word reading speed and 7.71 for non-word reading speed).

In the case of accounting for univariate and multivariate outliers, standardised visual alerting (-4.05) and exception word reading speed (4.10) scores for RA matched controls fell outside of the suggested ±3.29 limit (Tabachnick, 2013). For readers with DD, one exception word reading speed score (3.90) fell outside the limit. Finally, for CA matched controls, auditory alerting (4.00), exception word reading speed (3.53), and non-word reading speed (4.14) scores fell outside the suggested limit. Subsequent analysis of box plots showed that these outliers (1 participant with DD and 5 RA matched controls) fell within the non-extreme range (i.e., 1.5 to 3 box lengths from the upper or lower point of the box). Including or excluding these outliers did not change the relationships between variables, thus these data were retained in the analysis.

In the case of multivariate outliers (performed separately for RA matched controls, children with DD, and CA matched controls), the lowest probability value for RA matched controls (p = .02), children with DD (p = .01), and CA matched controls (p = .01) was greater than .001, indicating that multivariate outliers were not present in the current data set.

Power analysis. A power analysis was performed to examine if the sample sizes of 50 RA matched controls, 50 children with DD, and 50 CA matched controls were robust to detect a meaningful relationship between attention (visual and auditory, separate models), phonological processing, and reading (accuracy and speed, separate models). The proposed structural equation model has six free parameters (a disturbance for each of the two endogenous variables, a variance for the exogenous variable, and three path coefficients). According to Markus (2012), 50 in each group (a participant/parameter ratio of 8.3 for each group) will yield reliable parameter estimates for the multiple-group analysis. According to G*Power, at an alpha-level of .05, 150 participants (50 in each group) will provide an 80% chance of capturing a ‘moderate’ (f = .25) group effect. The current sample sized is 150, thus meets this requirement.

Stage 2. Descriptive and Inferential Statistics via SPSS.24

The means, ranges, and standard deviations for the standardised and RT measures for each reading ability group are reported in Table 6.1. This includes the TONI-4 IQ standardised scores, the standardised Woodcock-Johnson WI and PC scores, the CTOPP phonological processing scores (standardised), the CC2 reading accuracy (z-score), and the BRIEF executive functioning scores. Mean performance for each phonological processing subtest fell within a typically developing range (90–110) for both RA and CA matched control readers. Children with DD as a group (with 22 participants scoring below the average, ranging between 73–88) had average phonological awareness skills, but below average phonological memory and RAN skills. Mean performance on the reading accuracy, for each word type, fell within the typically developing range (-1 to +1) for both RA and CA matched controls, but within the below average range (-2 to -1) for children with DD.RT data for the cVANT, cAANT-SL and reading speed tasks are also presented in Table 6.1.

Phonological processing (standard scores).

Phonological awareness. There was a statistically significant difference between groups, $F(2,147) = 45.65$, $p < .001$, $\eta_p^2 = .38$, for phonological awareness accuracy scores. A Tukey post hoc test revealed that phonological awareness scores were statistically significantly higher for RA matched controls ($M = 109.32 \pm 9.13$, $p < .001$) and CA matched controls ($M = 107.56 \pm 11.87$, $p < .001$), compared to children with DD ($M = 90.92 \pm 10.84$). There was no statistically significant difference between the RA and CA matched control groups ($p = .69$).

Phonological memory. There was a statistically significant difference between groups, $F(2,147) = 28.12$, $p < .001$, $\eta_p^2 = .28$, for phonological memory accuracy scores. A Tukey post hoc test revealed that phonological memory scores were statistically significantly higher for RA matched controls ($M = 101.62 \pm 13.45$, $p < .001$) and CA matched controls ($M = 99.40 \pm 12.02$, $p < .001$) compared to children with DD ($M = 84.34 \pm 11.38$). There was no statistically significant difference between the RA and CA matched control groups ($p = .64$).

Table 6.1: Means and Standard Deviations of Attention Network Effects, Phonological Processing, Reading, and Executive Functioning for each Reading Ability Group

	RA Matched (*n* = 50)		DD (*n* = 50)		CA Matched (*n* = 50)	
	M (min, max)	*SD*	*M* (min, max)	*SD*	*M* (min, max)	*SD*
Screening						
IQ	105.66 (90, 130)	9.31	109.10 (86, 130)	5.52	111.22 (86,138)	11.77
WI	112.20 (85,145)	15.93	68.10 (60, 78)	4.36	116.68 (86, 141)	15.74
PC	107.90 (88,131)	9.91	89.08 (77,99)	5.65	109.26 (85, 140)	14.87
Phon. Processing						
Phon. aware SS	109.32 (91, 133)	9.13	90.92 (73,109)	10.84	107.56 (82, 127)	11.87
Phon. aware raw	26.24 (17,44)	6.61	17.16 (11,29)	4.03	22.48 (14, 29)	3.98
Phon. memory SS	101.62 (79, 139)	13.45	84.34 (64, 106)	11.38	99.40 (73,127)	12.02
Phon. memory raw	20.52 (13,33)	4.50	14.78 (8, 22)	3.79	19.74 (11, 29)	4.00
RAN SS	100.54 (67, 139)	13.41	86.40 (64, 106)	9.30	105.70 (76, 139)	13.02
RAN raw	20.00 (9,31)	4.15	15.47 (8, 22)	3.10	22.06 (12, 33)	4.19
Word Reading Accuracy						
Regular Z	0.28 (-1.29, 2.53)	0.85	-1.25 (-2.79, 1.45)	0.92	0.64 (-2.33, 2.99)	1.14
Regular raw	26.74 (4, 39)	9.18	27.26 (2,39)	8.29	36.84 (18,40)	4.03
Exception Z	0.21 (-1.54, 1.83)	0.91	-1.30 (-2.40, 0.74)	0.68	0.14 (-2.03, 2.07)	1.01
Exception raw	13.94 (1, 23)	5.92	16.26 (3, 28)	4.92	24.56 (12, 35)	5.12
Non-word Z	0.45 (-1.06, 2.29)	0.78	-1.33 (-2.83, 0.41)	0.66	0.26 (-1.69, 2.35)	1.07
Non- word raw	20.46 (2, 38)	10.03	17.62 (1, 36)	8.51	32.68 (16, 40)	5.91
cVANT Effects						
Alerting	58 (-191, 115)	61	36 (-80, 209)	54	35 (-18, 133)	30
Orienting	36 (-47, 151)	47	46 (-78, 158)	49	40 (-32, 110)	36
Executive	93 (-11,188)	45	65 (-24, 166)	47	56 (-17, 142)	34
cAANT-SL Effects						

Alerting	-5 (-295, 200)	108	0 (-316, 225)	109	32 (-152, 375)	86
Orienting	71 (-206, 419)	114	73 (-139, 414)	105	24 (-137, 218)	71
Executive	149 (-187, 466)	130	106 (-97, 371)	108	90 (-79, 275)	80
Reading Speed						
Exception RT (ms)	971 (593, 2443)	351	1142 (584, 3364)	570	667 (470, 1304)	180
Non-word RT (ms)	1224 (656, 2457)	471	1751 (674, 3824)	897	833 (512, 2315)	357
Exec. functioning	53.78 (32,73)	9.00	63.24 (39,85)	10.18	51.17 (39,63)	5.96

Note. IQ = Intelligence Quotient; WI = Word Identification; PC = Passage Comprehension; Phon. aware = phonological awareness; SS = standard score; raw = raw score; Phon. memory = phonological memory; Regular = regular words; Exception = exception words; Z = z-score; Exec. Functioning = executive functioning; ms = milliseconds.

RAN. There was a statistically significant difference between groups, $F(2,147) = 31.84$, $p < .001$, $\eta_p^2 = .31$, for RAN accuracy scores. A Tukey post hoc test revealed that RAN scores were statistically significantly higher for RA matched controls ($M = 100.54 \pm 13.41$, $p < .001$) and CA matched controls ($M = 105.70 \pm 13.02$, $p < .001$) compared to children with DD ($M = 86.40 \pm 9.30$). There was no statistically significant difference between the RA and CA matched control groups ($p = .09$).

Reading accuracy.

Regular words (standardised scores). There was a statistically significant difference between groups, $F(2,147) = 52.66$, $p < .001$, $\eta_p^2 = .42$, for regular word reading accuracy. A Tukey post hoc test revealed that regular word reading accuracy standardised scores were statistically significantly higher for RA matched controls ($M = 0.28 \pm 0.85$, $p < .001$) and CA matched controls ($M = 0.64 \pm 1.14$, $p < .001$) compared to children with DD ($M = -1.25 \pm 0.92$). There was no statistically significant difference between the RA and CA matched control groups ($p = .16$).

Exception words (standardised scores). There was a statistically significant difference between groups, $F(2,147) = 47.47$, $p < .001$, $\eta_p^2 = .39$, for exception word reading accuracy. A Tukey post hoc test revealed that exception word reading accuracy standardised scores were statistically significantly higher for RA matched controls ($M = 0.21 \pm 0.91$, $p < .001$) and CA matched controls ($M = 0.14 \pm 1.01$, $p < .001$) compared to children with DD ($M = -1.30 \pm 0.68$). There was no statistically significant difference between the RA and CA matched control groups ($p = .91$).

Non-words (standardised scores). There was a statistically significant difference between groups, $F(2,147) = 65.11$, $p < .001$, $\eta_p^2 = .47$, for non-word reading accuracy. A Tukey post hoc test revealed that non-word reading accuracy standardised scores were statistically significantly higher for RA matched controls ($M = 0.45 \pm 0.78$, $p < .001$) and CA matched controls ($M = 0.26 \pm 1.07$, $p < .001$) compared to children with DD ($M = -1.33 \pm 0.66$). There was no statistically significant difference between the RA and CA matched control groups ($p = .51$).

Percentage correct (raw scores). The following represents the percentage correct for each word type in RA matched controls: regular words (M = 66.9%, SD = 23.0%), exception words (M = 34.9%, SD = 14.8%), and non-words (M = 51.2%, SD

= 25.1%). For children with DD, the percentage correct for each word type were as follows: regular words (*M* = 68.2%, *SD* = 20.7%), exception words (*M* = 40.7%, *SD* = 12.3%), and non-words (*M* = 44.1%, *SD* = 21.3%). For CA matched controls, the percentage correct for each word type were as follows: regular words (*M* = 92.1%, *SD* = 10.1%), exception words (*M* = 61.4%, *SD* = 12.8%), and non-words (*M* = 81.7%, *SD* = 14.8%).

Executive functioning. Higher scores for executive functioning on the BRIEF indicate greater degrees of executive dysfunction. Scores at or above 65 are clinically significant (elevated range). As Table 6.1 illustrates, mean performance for executive functioning fell within the non-elevated range for all groups. There was a statistically significant difference between groups, $F(2,123) = 23.24$, $p < .001$, $\eta_p^2 = .27$. A Tukey post hoc test revealed that executive functioning scores were statistically significantly lower for RA matched controls ($M = 53.78 \pm 9.00$, $p < .001$) and CA matched controls ($M = 51.17 \pm 5.96$, $p < .001$) compared to children with DD ($M = 63.24 \pm 10.18$). There was no statistically significant difference between the RA and CA matched control groups ($p = .40$).

Visual attention. Table 6.2 provides the mean RTs in each condition for the cVANT, along with marginal means for RA matched controls, children with DD, and CA matched controls. Two-way repeated measures ANOVA for the cVANT showed a main effect of cue for RA matched controls, $F(3, 147) = 36.99$, $p < .001$, $\eta_p^2 = .43$, children with DD, $F(3, 147) = 39.51$, $p < .001$, $\eta_p^2 = .45$, and CA matched controls, $F(3, 147) = 70.00$, $p < .001$, $\eta_p^2 = .59$. There was also a main effect of congruency for RA matched controls, $F(2, 98) = 118.04$, $p < .001$, $\eta_p^2 = .71$, children with DD, $F(2, 98) = 103.69$, $p < .001$, $\eta_p^2 = .68$, and CA matched controls, $F(2, 98) = 97.89$, $p < .001$, $\eta_p^2 = .67$. The cue by congruency interaction was not significant for RA matched controls, $F(6, 294) = 1.65$, $p = .13$, $\eta_p^2 = .03$, children with DD, $F(4.76, 233.41) = 2.01$, $p = .08$, $\eta_p^2 = .04$, and CA matched controls, $F(4.75, 232.61) = 1.55$, $p = .16$, $\eta_p^2 = .03$.

Table 6.2: Mean RT in Milliseconds and Standard Deviations for the cVANT for RA Matched Controls (*n* = 50), Children with DD (*n* = 50), and CA Matched Controls (*n* = 50)

	Cue Type				
Congruency Type	No Cue	Double	Central	Spatial	Total Mean
RA Matched					
Neutral	861 (99)	790 (119)	818 (124)	775 (114)	811 (104)
Congruent	871 (91)	799 (119)	817 (113)	790 (113)	819 (98)
Incongruent	941 (97)	910 (132)	917 (94)	880 (124)	912 (98)
Total Mean	891 (86)	833 (111)	851 (98)	815 (106)	
Children with DD					
Neutral	741 (103)	704 (104)	701 (118)	663 (102)	702 (98)
Congruent	776 (113)	721 (113)	735 (126)	686 (112)	730 (105)
Incongruent	813 (106)	801 (115)	808 (110)	757 (115)	795 (100)
Total Mean	777 (94)	741 (101)	748 (109)	702 (102)	
CA Matched					
Neutral	672 (112)	635 (111)	628 (109)	595 (108)	632 (103)
Congruent	688 (121)	639 (106)	657 (127)	609 (103)	648 (110)
Incongruent	736 (122)	710 (118)	709 (105)	661 (118)	704 (110)
Total Mean	699 (112)	661 (105)	664 (109)	621 (105)	

Note. RT difference between the no cue and double cue conditions = alerting effect; RT difference between the central and spatial cue conditions = orienting effect; RT difference between incongruent and congruent conditions = executive effect; RA = reading aged; DD = developmental dyslexia; CA = chronological age.

Planned contrasts between the no cue and double cue conditions revealed significant visual alerting benefits, with an advantage for the double cue condition for RA matched controls (58 ms), $F(1, 49) = 44.19$, $p < .001$, $\eta_p^2 = .47$, children with DD (36 ms), $F(1, 49) = 20.84$, $p < .001$, $\eta_p^2 = .30$, and CA matched controls (38 ms), $F(1, 49) = 74.40$, $p < .001$, $\eta_p^2 = .60$.

A contrast between the central cue and spatial cue conditions showed significant visual spatial-orienting benefits for the spatial cue condition for RA matched controls (36 ms), $F(1, 49) = 29.41$, $p < .001$, $\eta_p^2 = .38$, children with DD (46 ms), $F(1, 49) = 43.95$, $p < .001$, $\eta_p^2 = .47$, and CA matched controls (43 ms), $F(1, 49) = 70.98$, $p < .001$, $\eta_p^2 = .59$.

Finally, a contrast between the incongruent and congruent flanker conditions revealed that visual executive control benefits were significant for RA matched controls (93 ms), $F(1, 49) = 209.33$, $p < .001$, $\eta_p^2 = .81$, children with DD (65 ms), $F(1, 49) = 96.15$, $p < .001$, $\eta_p^2 = .66$, and CA matched controls (56 ms), $F(1, 49) = 137.99$, $p < .001$, $\eta_p^2 = .74$.

Group interactions in the cVANT. A three-way mixed design ANOVA, including cue, congruency, and group, was conducted for the cVANT. There was a main effect of group, $F(2, 147) = 43.98$, $p < .001$, $\eta_p^2 = .37$. There was no significant interaction between cue and group, $F(6, 441) = 1.59$, $p = .15$, $\eta_p^2 = .02$. In contrast, the interaction between congruency and group was significant, $F(4, 294) = 5.47$, $p < .001$, $\eta_p^2 = .07$. The interaction between cue, congruency, and group was not significant, $F(12, 882) = 0.73$, $p = .72$, $\eta_p^2 = .01$.

Least significant difference contrasts showed that RA matched controls (M = 848 ms ± 14 ms) had a significantly slower overall mean RT across levels of cue and congruency, compared with children with DD (M = 742 ms ± 14 ms, $p < .001$) and CA matched controls (M = 662 ms ± 14 ms, $p < .001$). There was a significant difference in RT between children with DD and CA matched controls ($p < .001$). To examine the congruency by group interaction, simple effect analysis was used to compare different levels of group (RA matched vs. children with DD vs. CA matched controls) for each level of congruency. The analysis showed a significantly greater RT for RA matched controls, relative to CA matched controls, in the neutral condition ($p = .05$). However, this difference disappeared in the congruent ($p = .18$) and incongruent ($p = .68$) conditions.

Error analysis in the cVANT.

RA matched controls. Table 6.3 provides the mean error percentage data for each reading ability group for the cVANT. The analysis of errors found no main effect of cue, $F(3, 147) = 0.70$, $p = .56$, $\eta_p^2 = .01$, but of congruency, $F(2, 98) = 12.58$, $p < .001$, $\eta_p^2 = .20$, for RA matched controls. The cue by congruency interaction was not significant, $F(6, 294) = 0.63$, $p = .71$, $\eta_p^2 = .01$. Follow-up contrasts showed that there were significantly more errors in the incongruent (M = 12.7% ± 1.5%) compared with the congruent (M = 7.4% ± 1.1%, $p < .001$) and neutral (M = 8.7% ± 1.1%, $p = .002$) conditions. The errors between neutral and congruent conditions did not significantly differ ($p = .15$).

Children with DD. The analysis of errors for the cVANT found a main effect of cue, $F(3, 147) = 4.29$, $p = .01$, $\eta_p^2 = .08$, and congruency, $F(2, 98) = 11.02$, $p < .001$, $\eta_p^2 = .18$, for children with DD. There were significantly more errors in the no cue (M = 12.0% ± 1.4%) compared with the double cue (M = 9.8% ± 1.3%, $p = .03$) and spatial cue (M = 8.6% ± 1.2%, $p = .004$) conditions. The difference in errors between the no cue and central cue (*M* = 10.0% ± 1.2%) condition was marginally significant (p = .06). Errors in the double cue condition were not significantly different from the errors in the central (p = .78) and spatial (p = .19) cue conditions. Finally, errors between central and spatial cue conditions did not significantly differ (p = .12). There were significantly more errors in the incongruent (*M* = 12.4% ± 1.4%) compared with the congruent (*M* = 7.4% ± 1.3%, $p < .001$) condition. There were significantly more errors in the congruent compared with the neutral (*M* = 10.5% ± 1.3%, p = .004) condition. Finally, the difference in errors between the incongruent and neutral conditions did not significantly differ (p = .09). The cue by congruency interaction for errors in the cVANT was significant in children with DD, $F(6, 294) = 3.65$, $p = .002$, $\eta_p^2 = .07$. Simple effect analysis showed that there were significantly more errors if incongruent targets were not preceded by a cue (*M* = 18. 2% ± 2.6%), compared with a double (*M* = 11.5% ± 1.7%, p = .02), central (*M* = 10.0% ± 1.4%, p = .002), and spatial (*M* = 10.0% ± 1.8%, p = .004) cue.

Table 6.3: Mean Error Percentage Data and Standard Deviations for the cVANT for RA Matched Controls (*n* = 50), Children with DD (*n* = 50), and CA Matched Controls (*n* = 50)

	Cue Type				
Congruency Type	No Cue	Double	Central	Spatial	Total Mean
RA Matched					
Neutral	9.3 (9.9)	7.2 (8.1)	9.7 (11.1)	8.5 (10.4)	8.7 (7.7)
Congruent	7.7 (10.2)	7.5 (10.9)	8.5 (9.7)	5.8 (12.2)	7.4 (7.9)
Incongruent	12.8 (11.9)	13.5 (15.7)	12.2 (13.7)	12.2 (11.7)	12.7 (10.2)
Total Mean	9.9 (7.9)	9.4 (8.4)	10.1 (9.6)	8.8 (8.4)	
Children with DD					
Neutral	10.2 (10.7)	10.8 (11.8)	11.3 (10.9)	9.5 (11.5)	10.5 (9.2)
Congruent	7.7 (10.2)	7.0 (9.9)	8.7 (12.7)	6.2 (9.5)	7.4 (8.9)
Incongruent	18.2 (18.0)	11.5 (12.1)	10.0 (10.0)	10.0 (12.8)	12.4 (9.8)
Total Mean	12.0 (10.1)	9.8 (9.2)	10.0 (8.7)	8.6 (8.6)	
CA Matched					
Neutral	5.2 (6.7)	3.3 (5.8)	2.8 (5.7)	3.0 (5.0)	3.6 (4.5)
Congruent	3.0 (5.8)	2.5 (4.8)	2.7 (4.6)	2.0 (4.9)	2.5 (3.5)
Incongruent	5.0 (6.3)	4.0 (7.4)	4.2 (6.8)	6.0 (8.9)	4.7 (5.2)
Total Mean	4.4 (5.0)	3.3 (4.3)	3.2 (4.4)	3.7 (4.3)	

Note. RA = reading age; DD = developmental dyslexia; CA = chronological age.

CA matched controls. The analysis of errors for the cVANT found no main effect of cue, $F(3, 147) = 1.98$, $p = .12$, $\eta_p^2 = .04$, but a main effect of congruency, $F(2, 98) = 8.41$, $p < .001$, $\eta_p^2 = .15$, for the CA matched controls. The cue by congruency interaction was not significant, $F(6, 294) = 1.26$, $p = .28$, $\eta_p^2 = .03$. There were significantly more errors in the incongruent ($M = 4.7\% \pm 0.7\%$) compared with the congruent ($M = 2.5\% \pm 0.5\%$, $p = .002$) and neutral ($M = 3.6\% \pm 0.6\%$, $p = .04$) conditions. There were significantly more errors in the congruent compared with the neutral condition ($p = .04$).

Group differences in visual attention network effects. The visual attention network effect scores for each reading ability group are provided in Table 6.1. A one-way ANOVA was conducted to determine group differences in visual alerting, visual orienting, and visual executive attention network effects. The analysis showed that there was a statistically significant difference between groups in visual alerting, $F(2,147) = 3.05$, $p = .05$, $\eta_p^2 = .04$. A Tukey post hoc test revealed that visual alerting effect scores were marginally significantly ($p = .07$) higher for RA matched controls ($M = 58$ ms $\pm$ 9 ms), compared with children with DD ($M = 36$ ms $\pm$ 8 ms). There was no statistically significant difference between the RA and CA matched ($M = 35$ ms $\pm$ 4 ms) control groups ($p = .11$), or between children with DD and the CA matched controls ($p = .97$). For visual orienting effect scores, the analysis showed that there was no statistically significant difference between groups, $F(2,147) = 0.64$, $p = .05$, $\eta_p^2 = .01$.

For visual executive attention, the ANOVA showed that there was a statistically significant difference between groups, $F(2,147) = 10.15$, $p < .001$, $\eta_p^2 = .12$. A Tukey post hoc test revealed that visual executive effect scores were significantly higher for RA matched controls ($M = 93$ ms $\pm$ 6 ms), compared with CA matched controls ($M = 56$ ms $\pm$ 5 ms, $p < .001$), and children with DD ($M = 65$ ms $\pm$ 7 ms, $p = .004$). There was no statistically significant difference between children with DD and CA matched controls ($p = .51$).

Auditory attention. Table 6.4 provides the mean RTs in each condition of the cAANT-SL, along with marginal means, for RA matched controls, children with DD and CA matched controls. Two-way repeated measures ANOVA for the cAANT-SL showed a main effect of cue for RA matched controls, $F(3, 147) = 7.06$, $p < .001$, $\eta_p^2 = .13$, children with DD, $F(3, 147) = 10.88$, $p < .001$, $\eta_p^2 = .18$, and CA matched controls, $F(3, 147) = 6.18$, $p = .001$, $\eta_p^2 = .11$. There was also a main effect of congruency for RA matched controls, $F(2, 98) = 96.08$, $p < .001$, $\eta_p^2 = .67$, children with DD, $F(2, 98) = 85.35$, $p < .001$, $\eta_p^2 = .64$, and CA matched controls, $F(2, 98) = 105.00$, $p < .001$, $\eta_p^2 = .68$.

Table 6.4: Mean RT in Milliseconds and Standard Errors for the cAANT-SL for RA Matched Controls (*n* = 50), Children with DD (*n* = 50), and CA Matched Controls (*n* = 50)

	Cue Type				
Congruency Type	No Cue	Double	Central	Spatial	Total Mean
RA Matched					
Neutral	1099 (20)	1140 (27)	1147 (28)	1097 (29)	1121 (23)
Congruent	1207 (23)	1207 (34)	1232 (28)	1159 (28)	1201 (25)
Incongruent	1381 (30)	1355 (38)	1376 (36)	1286 (39)	1350 (31)
Total Mean	1229 (22)	1234 (28)	1252 (27)	1181 (29)	
Children with DD					
Neutral	985 (25)	1014 (30)	992 (29)	955 (27)	987 (24)
Congruent	1068 (26)	1075 (30)	1080 (30)	1029 (27)	1063 (25)
Incongruent	1211 (34)	1179 (33)	1208 (37)	1077 (39)	1169 (32)
Total Mean	1089 (25)	1089 (28)	1093 (29)	1020 (28)	
CA Matched					
Neutral	911 (22)	904 (29)	896 (27)	874 (25)	896 (24)
Congruent	995 (28)	966 (31)	980 (30)	956 (32)	974 (29)
Incongruent	1103 (32)	1044 (38)	1069 (38)	1040 (39)	1064 (34)
Total Mean	1003 (26)	971 (31)	981 (30)	957 (31)	

Note. RT difference between the no cue and double cue conditions = alerting effect; RT difference between the central and spatial cue conditions = orienting effect; RT difference between incongruent and congruent conditions = executive effect; RA = reading age; DD = developmental dyslexia; CA = chronological age.

Planned contrasts between the no cue and double cue conditions revealed significant auditory alerting benefits, with an advantage for the double cue condition for CA matched controls (32 ms), $F(1, 49) = 6.74$, $p = .01$, $\eta_p^2 = .12$. In contrast, there was no RT advantage for the double cue condition relative to the no cue condition, for both RA matched controls (-5 ms, the no cue condition was faster), $F(1, 49) = 0.06$, $p = .81$, $\eta_p^2 < .001$, and children with DD (0 ms), $F(1, 49) = 0.002$, $p = .96$, $\eta_p^2 < .001$.

A contrast between the central cue and spatial cue conditions showed significant auditory spatial-orienting benefits for the spatial cue condition for RA matched controls (71 ms), $F(1, 49) = 18.49$, $p < .001$, $\eta_p^2 = .28$, children with DD (73 ms), $F(1, 49) = 24.20$, $p < .001$, $\eta_p^2 = .33$, and CA matched controls (24 ms), $F(1, 49) = 5.99$, $p = .02$, $\eta_p^2 = .11$.

Finally, a contrast between the incongruent and congruent flanker conditions revealed that auditory executive control benefits were significant for RA matched controls (149 ms), $F(1, 49) = 62.48$, $p < .001$, $\eta_p^2 = .57$, children with DD (106 ms), $F(1, 49) = 47.65$, $p < .001$, $\eta_p^2 = .49$, and CA matched controls (90 ms), $F(1, 49) = 62.64$, $p < .001$, $\eta_p^2 = .56$.

Cue by congruency interaction in the cAANT-SL (children with DD). The cue by congruency interaction was not significant for RA matched controls, $F(6, 294) = 1.51$, $p = .18$, $\eta_p^2 = .03$, and CA matched controls, $F(4.88, 239.25) = 0.96$, $p = .16$, $\eta_p^2 = .02$. In contrast, the interaction was significant for children with DD, $F(6, 294) = 3.30$, $p = .004$, $\eta_p^2 = .06$. Simple effect analysis for the cAANT-SL cue by congruency interaction showed that the main effect of cue was significant in the neutral, $F\ (3, 147) = 2.81$, $p = .04$, $\eta_p^2 = .05$, and incongruent, $F(3, 147) = 11.53$, $p < .001$, $\eta_p^2 = .19$ conditions, but marginally significant in the congruent condition, $F(3, 147) = 2.64$, $p = .052$, $\eta_p^2 = .05$.

Least significant difference contrasts showed that RTs were significantly faster when neutral targets were preceded by a spatial cue (M = 955 ms ± 27 ms), compared with double cue conditions (M = 1014 ms ± 29 ms, $p = .003$), and marginally faster when preceded by central cue conditions (M = 992 ms ± 29 ms, $p = .07$). Similarly, in the congruent condition, RTs were significantly faster when congruent targets were preceded by a spatial cue (M = 1029 ms ± 27 ms), compared with no cue (M = 1068 ms ± 26 ms, $p = .04$), double cue (M = 1075 ms ± 30 ms, $p = .04$), central cue (M = 1080 ms ± 30 ms, $p = .01$) conditions. Finally, a similar pattern for the incongruent conditions was observed, showing that RTs were significantly faster when incongruent targets were preceded by a spatial cue (M = 1077 ms ± 39 ms), compared with no cue (M = 1212 ms ± 34 ms, $p < .001$), double cue (M = 1179 ms ± 33 ms, $p = .001$), central cue (M = 1208 ms ± 37 ms, $p < .001$) conditions. In each congruency condition, no other comparisons between cue conditions differed significantly ($p > .05$). Together, these results illustrate that across all levels of congruency, RTs were significantly reduced when a spatial cue precedes a target. A spatial cue is especially advantageous when distracting (congruent or incongruent) information is presented.

Group interactions in the cAANT-SL. A three-way mixed design ANOVA, including cue, congruency, and group was conducted for the cAANT-SL. There was a main effect of group, $F(2, 147) = 21.49$, $p < .001$, $\eta_p^2 = .23$. The interaction between cue and group, $F(6, 441) = 2.17$, $p = .05$, $\eta_p^2 = .03$, and between congruency and group, $F(4, 294) = 3.20$, $p = .01$, $\eta_p^2 = .04$, was significant. The interaction between cue, congruency, and group, $F(12,882) = 0.81$, $p = .64$, $\eta_p^2 = .01$, was not significant.

Least significant difference contrasts showed that RA matched controls (M = 1224 ms ± 27 ms) had a significantly slower overall mean RT across levels of cue and congruency, compared with children with DD (M = 1073 ms ± 26 ms, $p < .001$) and CA matched controls (M = 978 ms ± 26 ms, $p < .001$). There was a significant difference in RT between children with DD and CA matched controls ($p = .01$).

Cue and group interaction in the cAANT-SL. To examine the interaction between cue and group, simple effect analysis was used to compare different levels of group (RA matched vs. children with DD vs. CA matched controls) for each level of cue. The analysis showed that the interaction between cue and group was not significant between the RA matched controls and children with DD, $F(3,288) = 0.41$, $p = .74$, $\eta_p^2 = .00$, but significant between RA matched controls and CA matched controls, $F(3, 288) = 3.05$, $p = .03$, $\eta_p^2 = .03$, and between the CA matched controls and children with DD, $F(3, 294) = 3.61$, $p = .01$, $\eta_p^2 = .04$.

RA matched controls and CA matched controls. Least significant difference contrasts showed a significantly greater RT for RA matched controls, relative to CA matched controls, when targets were not cued ($p = .002$). However, this difference disappeared when targets were cued (double cue, $p = .22$; central cue, $p = .13$; spatial cue, $p = .37$).

CA matched controls and children with DD. Least significant difference contrasts showed a significantly greater RT for children with DD, relative to CA matched controls, when targets were preceded by no cue ($p = .02$), double cue ($p = .01$), and central cue ($p = .01$) conditions. However, this difference disappeared when targets were preceded by spatial cue conditions ($p = .13$). This finding highlights the important role of spatial cues to the reduction in RT for children with DD.

Congruency and group interaction in the cAANT-SL. To examine the interaction between congruency and group, simple effect analysis was used to compare different levels of group (RA matched vs. children with DD vs. CA matched controls) for each level of congruency (neutral vs. congruent vs. incongruent). The analysis showed a significantly greater RT for children with DD, relative to the CA matched controls, when targets were presented in the incongruent condition ($p < .001$). However, this difference disappeared in the neutral ($p = .48$) and congruent ($p = .34$) conditions. There was a significantly greater RT for RA matched controls, relative to the CA matched controls, in the neutral condition ($p = .05$). However, this difference disappeared in the congruent ($p = .13$) and incongruent ($p = .23$) conditions.

Error analysis in the cAANT-SL.

RA matched controls. Table 6.5 provides the mean error percentage data for each reading ability group for the cAANT-SL. The analysis of errors found a main effect of cue, $F(3, 147) = 27.49$, $p < .001$, $\eta_p^2 = .36$, and congruency, $F(2, 98) = 32.75$, $p < .001$, $\eta_p^2 = .41$, for RA matched controls. The cue by congruency interaction was not significant, $F(6, 294) = 1.05$, $p = .39$, $\eta_p^2 = .02$. Follow-up contrasts showed that there were significantly ($p < .001$) more errors in the double cue (M = 23.8% ± 2.5%), central cue (M = 26.8% ± 2.4%) and spatial cue (M = 18.2% ± 1.7%) conditions, compared with the no cue condition (M = 11.8% ± 1.3%). There were significantly more errors in the double cue ($p = .005$) and central cue ($p < .001$) conditions, compared with the spatial cue condition. The difference in errors between the double and central cue conditions was marginally significant ($p = .06$). There were significantly ($p < .001$) more errors in the incongruent (M = 26.8% ± 2.0%), compared with the congruent (M = 15.9% ± 1.8%) and neutral (M = 17.8% ± 2.0%) conditions. The difference in errors between the neutral and congruent conditions was marginally significant ($p = .06$).

Children with DD. The analysis of errors for the cAANT-SL found a main effect of cue, $F(3, 147) = 25.39$, $p < .001$, $\eta_p^2 = .34$, and congruency, $F(2, 98) = 23.78$, $p < .001$, $\eta_p^2 = .33$, for children with DD. The cue by congruency interaction was not significant, $F(6, 294) = 0.64$, $p = .70$, $\eta_p^2 = .01$. Follow-up contrasts showed that there were significantly fewer errors in the no cue condition (M = 13.2% ± 1.9%) compared with the double cue (M = 21.6% ± 2.4%, $p < .001$), central cue (M = 22.3% ± 2.1%, $p < .001$) and spatial cue (M = 15.5% ± 2.0%, $p = .01$) conditions. Errors did not significantly differ between the double cue and central cue conditions

(p = .61), but there were more errors in the double cue conditions compared with the spatial cue condition (p < .001). Finally, there were significantly more errors in the central compared with the spatial cue condition (p < .001). There were significantly more errors in the incongruent (M = 23.4% ± 2.3%) compared with the congruent (M = 15.0% ± 2.0%, p < .001) and neutral (M = 16.0% ± 2.1%, p < .001) conditions. Errors between the neutral and congruent conditions did not significantly differ (p = .28).

Table 6.5: Mean Error Percentage Data and Standard Deviations for the cAANT-SL for RA Matched Controls (*n* = 50), Children with DD (*n* = 50), and CA Matched Controls (*n* = 50)

	Cue Type				
Congruency Type	No Cue	Double	Central	Spatial	Total Mean
RA Matched					
Neutral	8.8 (10.4)	23.0 (20.8)	25.5 (21.3)	13.9 (13.2)	17.8 (13.9)
Congruent	7.5 (10.2)	19.4 (22.2)	22.6 (17.3)	13.9 (13.5)	15.9 (12.5)
Incongruent	19.2 (14.9)	29.1 (19.4)	32.3 (20.4)	26.7 (17.5)	26.8 (14.2)
Total Mean	11.8 (9.3)	23.8 (17.8)	26.8 (19.4)	18.2 (14.5)	
Children with DD					
Neutral	11.2 (15.1)	18.8 (20.5)	18.3 (17.1)	12.2 (14.2)	16.0 (14.6)
Congruent	10.3 (13.4)	19.0 (18.6)	26.5 (16.9)	12.5 (15.9)	15.0 (14.1)
Incongruent	18.2 (18.0)	27.0 (20.7)	12.2 (14.2)	21.8 (19.3)	23.4 (15.9)
Total Mean	13.2 (13.7)	21.6 (17.1)	22.3 (14.8)	15.5 (13.9)	
CA Matched					
Neutral	4.0 (10.8)	6.3 (12.2)	7.5 (13.2)	3.7 (6.6)	5.4 (8.3)
Congruent	2.7 (8.9)	5.5 (11.2)	7.2 (9.7)	3.2 (6.3)	4.6 (6.8)
Incongruent	10.2 (14.8)	10.0 (13.0)	12.7 (14.8)	8.3 (11.5)	10.3 (10.5)
Total Mean	5.6 (10.4)	7.3 (10.4)	9.1 (10.8)	5.1 (7.0)	

Note. RA = reading age; DD = developmental dyslexia; CA = chronological age.

CA matched controls. The analysis of errors for the cAANT-SL found a main effect of cue, $F(3, 147) = 3.72$, $p = .01$, $\eta_p^2 = .07$, and congruency, $F(2, 98) = 24.93$, $p < .001$, $\eta_p^2 = .34$, for CA matched controls. The cue by congruency interaction was not significant, $F(6, 294) = 0.56$, $p = .76$, $\eta_p^2 = .01$. There were significantly fewer errors in the no cue (M = 5.6% ± 1.5%) compared with the central cue (M = 9.1% ± 1.5%, p = .05) conditions. However, there were no significant differences in errors between the no cue condition, compared with the double (M = 7.3% ± 1.5%, p = .29) and spatial cue (*M* = 5.1% ± 1.0%, *p* = .69) conditions. Errors in the double cue condition were significantly fewer than the central cue condition (*p* = .03), and marginally greater than in the spatial (*p* = .06) cue condition. Finally, there were significantly more errors in the central compared with spatial cue conditions (*p* = .002).

There were significantly more errors in the incongruent (*M* = 10.3% ± 1.5%) compared with the congruent (*M* = 4.6% ± 1.0%, *p* < .001) and neutral (*M* = 5.4% ± 1.2%, *p* < .001) conditions. The difference in errors between the neutral and congruent conditions did not significantly differ (*p* = .15).

Group differences in auditory attention network effects. The auditory attention network effect scores for each reading ability group are provided in Table 6.1. A one-way ANOVA was conducted to determine group differences in auditory alerting, auditory orienting, and auditory executive attention network effects. The analysis showed that there was no statistically significant difference between groups in auditory alerting, $F(2,147) = 1.85$, $p = .16$, $\eta_p^2 = .02$.

For auditory orienting, the analysis showed that there was a statistically significant difference between groups in the auditory orienting effect score, $F(2,147) = 3.82$, $p = .02$, $\eta_p^2 = .05$. A Tukey post hoc test revealed that auditory orienting effect scores were significantly higher for children with DD (*M* = 73 ms ± 15 ms), compared with CA matched controls (*M* = 24 ms ± 10 ms). The difference between RA matched controls (*M* = 71 ms ± 16 ms) and CA matched controls was marginally significant (*p* = .06). There was no statistically significant difference between children with DD and RA matched controls (*p* = .99).

For auditory executive attention, the ANOVA showed a statistically significant difference between groups, $F(2,147) = 3.86$, $p = .02$, $\eta_p^2 = .05$. A Tukey post hoc test revealed that auditory executive effect scores were significantly higher for RA matched controls (*M* = 149 ms ± 19 ms), compared with CA matched controls (*M* = 90 ms ± 11 ms, *p* = .02). There was no statistically significant difference between children with DD (*M* = 106 ms ± 15 ms) and CA matched controls (*p* = .74), or between children with DD and RA matched controls (*p* = .13).

Reading speed.

Exception words. There was a statistically significant difference between groups, $\chi^2(2) = 56.84$, $p < .001$, $\eta_p^2 = .39$, in the reading speed of exception words. Pairwise comparisons revealed that exception word reading speed scores were statistically significantly lower for CA matched controls (*Mean Rank* = 38 ms), compared to children with DD (*Mean Rank* = 98 ms, $p < .001$) and RA matched controls (*Mean Rank* = 89 ms, $p < .001$). There was no statistically significant difference between RA matched controls and children with DD ($p = .90$).

Non-words. There was a statistically significant difference between groups, $\chi^2(2) = 55.35$, $p < .001$, $\eta_p^2 = .39$, in the reading speed of non-words. Pairwise comparisons revealed that non-word reading speed scores were statistically significantly lower for CA matched controls (*Mean Rank* = 38 ms), compared to children with DD (*Mean Rank* = 99 ms $p < .001$) and RA matched controls (*Mean Rank* = 80 ms, $p < .001$). There was no statistically significant difference between RA matched controls and children with DD ($p = .09$).

Error percentage. The following represents the error percentage for each word type in children with DD: exception words (*M* = 15.8%, *SD* = 17.1%) and non-words (*M* = 43.8%, *SD* = 21.8%). Error percentages for RA matched controls (exception words, *M* = 16.6%, *SD* = 23.0%; non-words, *M* = 35.1%, *SD* = 25.9%) and CA matched controls (exception words, *M* = 5.2%, *SD* = 9.4%; non-words, *M* = 16.0%, *SD* = 20.0%) were similar to the larger group of early and later stage readers, respectively in Study 1.

Group interactions in the reading speed task. A two-way mixed design ANOVA was conducted to determine if there was a main effect of group and an interaction between word type and group in the reading speed task. There was a main effect of word type, $F(1, 140) = 98.97$, $p < .001$, $\eta_p^2 = .41$, and group, $F(2, 140) = 26.91$, $p < .001$, $\eta_p^2 = .28$. The interaction between word type and group, $F(2, 140) = 14.89$, $p < .001$, $\eta_p^2 = .18$, was significant.

Main effect of group. Least significant difference contrasts showed significant group differences between RA matched controls and children with DD ($p < .001$), with RA matched controls (*M* = 1098 ms ± 66 ms) showing a faster overall mean RT across word type, compared with children with DD (*M* = 1447 ms ± 66 ms). Similarly, least significant difference contrasts showed significant RT differences between RA matched controls and CA matched controls ($p = .001$), with RA matched controls showing a greater overall mean RT across word type, compared with CA (*M* = 750 ms ± 64 ms) matched controls. There was also a significant difference ($p < .001$) between children with DD and CA matched controls, with faster RTs for CA matched controls

Word type and group interaction. Table 6.1 shows that although the reading speed of children with DD was significantly slower compared to RA and CA matched controls for both word types, the difference in reading speed between children with DD and each of their matched control group was larger for non-words, compared with exception words. A similar pattern was exhibited when comparing RA and CA matched controls.

Stage 3. SEM Analysis via M*plus* Version 5.2

Though using multiple measures of the same construct, as did Studies 1 and 2, increases the validity and reliability of measures, single-indicator models offer an opportunity to advance more precise (and equally valid and reliable) theories about cognitive process (Hayduk & Littvay, 2012). Although some researchers (e.g., Muthén, 2010) advocate the use of path analysis or multiple regression with single indicator variables, others (e.g., Hayduk & Littvay, 2012) argue that more reliable results are achieved through the single-indicator SEM approach. This is because single indicator latent modelling involves fixing measurement error and reliability information for each latent variable, thus providing less biased estimates, compared with multiple regression and path analysis (Byrne, 2012).

Ultimately, the central reason for using the single-indicator SEM approach in Study 3 is that measurement error variances, when fixed, provide more specific theoretical models, thereby advancing the examination and assessment of theory (Hayduk & Littvay, 2012). In this way, single indicator SEM models use the most appropriate indicator for each latent construct, and “most appropriate” means the indicator that most clearly reflects the cognitive process in the population of interest (Hayduk & Littvay, 2012). Moreover, using the single indicator SEM approach requires knowledge of an indicator’s reliability information, which can be obtained from previously normed data (Hayduk & Littvay, 2012; Munck, 1979). Having this knowledge facilitates fixing the measurement error variance of the construct. In the current study, reliability information about the phonological processing, and reading accuracy constructs are known to the researcher. Therefore, only these constructs are defined by single indicators. Munck's formula (with α reflecting the internal consistency reliability estimate of the indicator) was used to specify values of the regression coefficients, $(\lambda) = SD(X)\sqrt{(\alpha)}$, and the measurement error variances, $Var(X)\ (1 - \alpha)$, associated with each single indicator latent variable (Munck, 1979).

Selecting the most appropriate indicators. For RA matched controls, phonological awareness was selected as the most reliable indicator of phonological processing, as it had the highest Cronbach's α (.92)[14] for children aged 7. For the CA matched control group, RAN was selected as the most reliable indicator of phonological processing, as it had the highest Cronbach's α (.93)[15] for children aged 10 (Wagner et al., 1999). Finally, phonological awareness was selected as the most reliable indicator of phonological processing for children with DD.[16] For all groups, regular word reading was selected as a reliable indicator of word reading accuracy (split half reliability of .85, as reported in the Method in Chapter 3). In contrast, for the reading speed task, both exception and non-word reading speed[17] were used to not limit the analysis to reading scores that assess either the lexical or sub-lexical pathway, respectively.

Model fit and invariance testing in single indicator models. Fit statistics are not always provided for single indicator measurement models, because they are not considered as genuine measurement models. Given that the models in Study 3 (particularly for phonological processing and reading accuracy) were single indicator models, fit statistics were not provided when a single group analysis was conducted for each reading ability group.[18] This means that the model was just-identified, and therefore had zero degrees of freedom. This can sometimes happen from fixing measurement errors, which produces a model that fits the data with high levels of precision (Muthén, 2018b). But, it also indicates that there is a possibility that other models are likely to also fit the data perfectly. Consequently, given that degrees of

[14] For children aged 7, the internal consistency reliability Cronbach's score had an alpha of .86 for phonological memory and, alternate-form reliability for the RAN composite was .87.
[15] For children aged 10, the internal consistency reliability Cronbach's score had alphas of .92 and .84 for phonological awareness and phonological memory, respectively.
[16] Although these children have a mean chronological age of 10 years old, previous research has consistently found phonological awareness to be the most reliable and strongest predictor of reading in children with DD (Castles et al., 2018; Melby-Lervåg et al., 2012).
[17] Reading speed for regular words is not included in the word naming reading speed task.
[18] When the grouping factor was used, the initial configural model test resulted in an extremely poor fit, although, the values for factor loadings in the model were high (≥ .90). As well, when a multiple-group analysis was attempted using a path analysis approach, the model again was just identified, with no fit statistics.

freedom are not calculated, one disadvantage of this result is that a multiple-group approach, including the assessment of invariance, is currently not testable within the single indicator SEM framework, at least when the model is just-identified (Muthén, 2018a). Therefore, since the reading accuracy models in the Study 3 were just-identified for each reading ability group, single group analysis was conducted. Moreover, since fit statistics are not reported, the suggested criteria to judge the acceptability of single indicator SEM models is based on the lower order components of the model, including the values of path coefficients and the value of indirect, direct, and total effects (Tomarken & Waller, 2003). Moreover, if the M*plus* output is returned with a warning message, then the model may not be suitable for the data. If, however, the analysis yields no warning, then the data can be interpreted and taken to indicate no empirical problems with the hypothesised models (Hayduk & Littvay, 2012). Ultimately, however, the interpretation of the data in Study 3 will rely on previous theoretical information about the relationships and estimates between variables, as well as the findings from Studies 1 and 2 in the current thesis. Tables 6.6 to 6.8 illustrate the coefficients (i.e., SD√α and Var (1-α)) that were used to specify the single indicator latent variables for RA matched controls, children with DD, and CA matched controls, respectively.

Table 6.6: Single Indicator Coefficients for RA Matched Controls (*n* = 50)

Variable	α	1-α	SD	Variance (SD^2)	λ = SD√α	Error = Var (1-α)
Phonological processing	0.92	0.08	9.13	83.41	8.76	6.67
Reading accuracy	0.85	0.15	0.85	0.73	0.78	0.11

Note. Phonological processing is based only on the phonological awareness scale and reading accuracy is based only on the regular word reading accuracy scale; α = Cronbach's alpha; SD = standard deviation; λ = regression coefficient; Var = variance.

Table 6.7: Single Indicator Coefficients for Children with DD (*n* = 50)

Variable	α	1-α	SD	Variance (SD^2)	λ = SD√α	Error = Var (1-α)
Phonological processing	0.92	0.08	10.67	113.85	10.23	9.11
Reading accuracy	0.85	0.15	0.92	0.85	0.85	0.12

Note. Phonological processing is based only on the phonological awareness scale and reading accuracy is based only on the regular word reading accuracy scale; α = Cronbach's alpha; SD = standard deviation; λ = regression coefficient; Var = variance.

Table 6.8: Single Indicator Coefficients for CA Matched Controls (*n* = 50)

Variable	α	1-α	SD	Variance (SD^2)	λ = SD√α	Error = Var (1-α)
Phonological processing	0.93	0.07	13.02	169.52	12.55	11.86
Reading accuracy	0.85	0.15	1.14	1.30	1.05	0.19

Note. Phonological processing is based only on the RAN scale and reading accuracy is based only on the regular word reading accuracy scale; α = Cronbach's alpha; SD = standard deviation; λ = regression coefficient; Var = variance.

RA matched controls: Measurement model (reading accuracy). The hypothesised measurement model, with the results from the single group CFA in the relationship between phonological processing and reading accuracy for RA matched controls is shown in Figure 6.1. There was a significant, positive relationship between phonological processing and reading accuracy (p = .01). The size of the coefficient relating phonological processing to reading accuracy was lower than Study 1, where reading accuracy in the larger group of early stage readers was assessed with a coefficient of .90. Nevertheless, the measurement model was identified without any errors. The correlation between the two indicators (i.e., phonological awareness and regular words) for each latent construct was .32. Figure 6.1 also provides the values for the squared multiple correlation for each indicator (in italics).

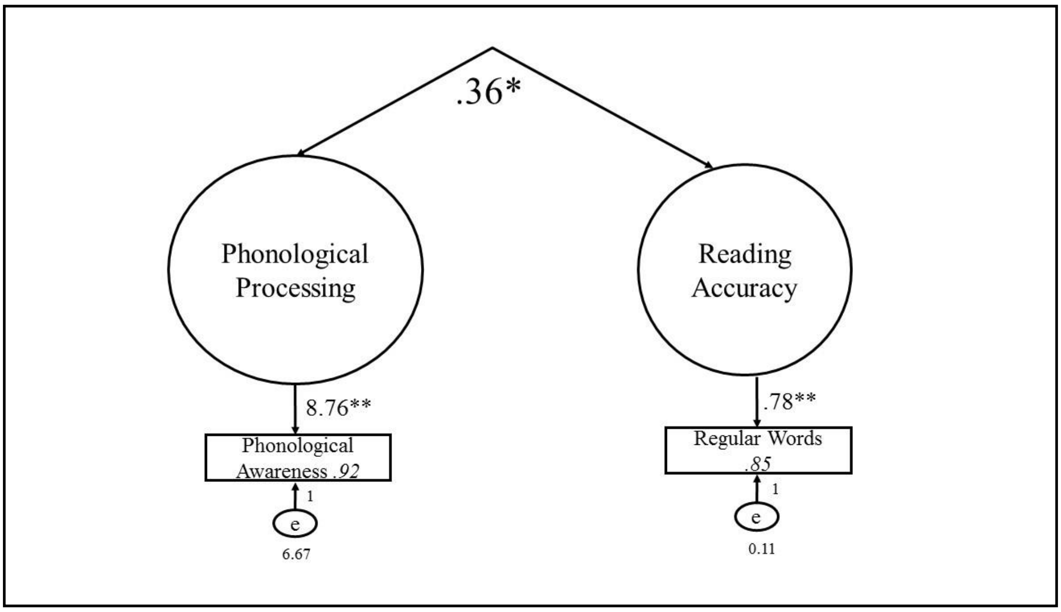


Figure 6.1. Single indicator measurement model with CFA results (standardised estimates) for the hypothesised relationship between phonological processing and reading accuracy for RA matched controls (n = 50). **Correlation was strong and significant ($p < .001$) at the .05 level (2-tailed). *Correlation was significant ($p < .05$) at the .05 level (2-tailed).

Early stage readers: Structural analysis of total, indirect, and direct effects.

*Visual attention***.** The structural model was identified without any errors. Tables 6.9 to 6.11 illustrate the total, indirect, and direct effects for the relationship between visual (alerting, orienting, and executive) attention, phonological processing, and reading accuracy. The results demonstrated that there were non-significant direct and indirect effects of visual alerting and visual executive attention. In contrast, there was a significant total effect of visual orienting upon reading through phonological processing, as Table 6.10 illustrates. The significant total effect suggests that there is an effect to be mediated between visual orienting and reading accuracy (Kenny, 2018). However, given that the estimate of the indirect effect through phonological processing is smaller (.09) than the direct effect (.23), the significant total effect suggests that there is an effect of visual orienting upon reading accuracy that may not be mediated via phonological processing.

Table 6.9: Total, Direct, and Indirect Effects between Visual Alerting, Phonological Processing, and Reading Accuracy in RA Matched Controls (*n* = 50)

Model	β		95% CI, *p* value
	Visual alerting	Phonological processing	
Direct			
Visual alerting		-0.04	[-0.09, 0.46], *p* = .20
Reading accuracy	0.18	0.36	
Indirect			
Visual alerting		-0.01	[-0.10, 0.08], *p* = .81
Reading accuracy			
Total			
Visual alerting		-0.04	[-0.12, 0.46], *p* = .24
Reading accuracy	0.17	0.36	

Note. The single pathway between visual alerting and phonological processing was not significant ($p = .80$); β = beta (standardised coefficient); CI = confidence interval.

Table 6.10: Total, Direct, and Indirect Effects between Visual Orienting, Phonological Processing, and Reading Accuracy in RA Matched Controls (*n* = 50)

Model	β		95% CI, *p* value
	Visual orienting	Phonological processing	
Direct			
Visual orienting		0.31	[-0.06, 0.51], *p* = .11
Reading accuracy	0.23	0.36	
Indirect			
Visual orienting		0.09	[-0.03, 0.22], *p* = .13
Reading accuracy			
Total			
Visual orienting		0.31	[0.06, 0.59], *p* = .02
Reading accuracy	0.33	0.36	

Note. The single pathway between visual orienting and phonological processing was significant (*p* = .02); β = beta (standardised coefficient); CI = confidence interval.

Table 6.11: Total Direct, and Indirect Effects between Visual Executive, Phonological Processing, and Reading Accuracy in RA Matched Controls (*n* = 50)

Model	β		95% CI, *p* value
	Visual executive	Phonological processing	
Direct			
Visual executive		0.04	[-0.34, 0.21], *p* = .65
Reading accuracy	-0.07	0.36	
Indirect			
Visual executive		0.01	[-0.08, 0.10], *p* = .81
Reading accuracy			
Total			
Visual executive		0.04	[-0.34, 0.23], *p* = .71
Reading accuracy	-0.06	0.36	

Note. The single pathway between visual executive attention and phonological processing was not significant (*p* = .80); β = beta (standardised coefficient); CI = confidence interval.

Auditory attention. The structural model was identified without any errors. Tables 6.12 and 6.13 illustrate the total, indirect and direct effects of the auditory alerting and auditory executive attention networks. The results demonstrate that there were non-significant total, direct, and indirect effects in the relationship between auditory (alerting and executive) attention, phonological processing, and reading accuracy for RA matched controls.

Table 6.12: Total, Direct, and Indirect Effects between Auditory Alerting, Phonological Processing, and Reading Accuracy in RA Matched Controls (*n* = 50)

Model	β		95% CI, *p* value
	Auditory alerting	Phonological processing	
Direct			
Auditory alerting		0.15	[-0.27, 0.31], *p* = .88
Reading accuracy	0.02	0.36	
Indirect			
Auditory alerting		0.07	[-0.06, 0.19], *p* = .32
Reading accuracy			
Total			
Auditory alerting		0.15	[-0.22, 0.40], *p* = .58
Reading accuracy	0.09	0.36	

Note. The single pathway between auditory alerting and phonological processing was not significant ($p = .28$); β = beta (standardised coefficient); CI = confidence interval.

Table 6.13: Total, Direct, and Indirect Effects between Auditory Executive, Phonological Processing, and Reading Accuracy in RA Matched Controls (*n* = 50)

Model	β		95% CI, *p* value
	Auditory executive	Phonological processing	
Direct			
Auditory executive		0.04	[-0.26, 0.33], *p* = .75
Reading accuracy	0.04	0.36	
Indirect			
Auditory executive		0.02	[-0.10, 0.14], *p* = .78
Reading accuracy			
Total			
Auditory executive		0.04	[-0.26, 0.36], *p* = .82
Reading accuracy	0.05	0.36	

Note. The single pathway between auditory executive attention and phonological processing was not significant ($p = .78$); β = beta (standardised coefficient); CI = confidence interval.

Figure 6.2 illustrates the relationship between auditory orienting and reading accuracy through phonological processing in RA matched controls. This indirect relationship was negative and marginally significant (95% CI [-0.31, 0.01], with a point estimate of -0.15, $p = .07$). The pattern of this result aligns with that observed in Study 1 for early stage readers. Moreover, this finding suggests that a larger auditory orienting effect is associated with poorer phonological processing, and thus lower reading accuracy in RA matched controls. The total (95% CI [-0.26, 0.38], with a point estimate of 0.06, $p = .71$) and direct (95% CI [-0.10, 0.52], with a point estimate of 0.21, $p = .19$) effects were non-significant.

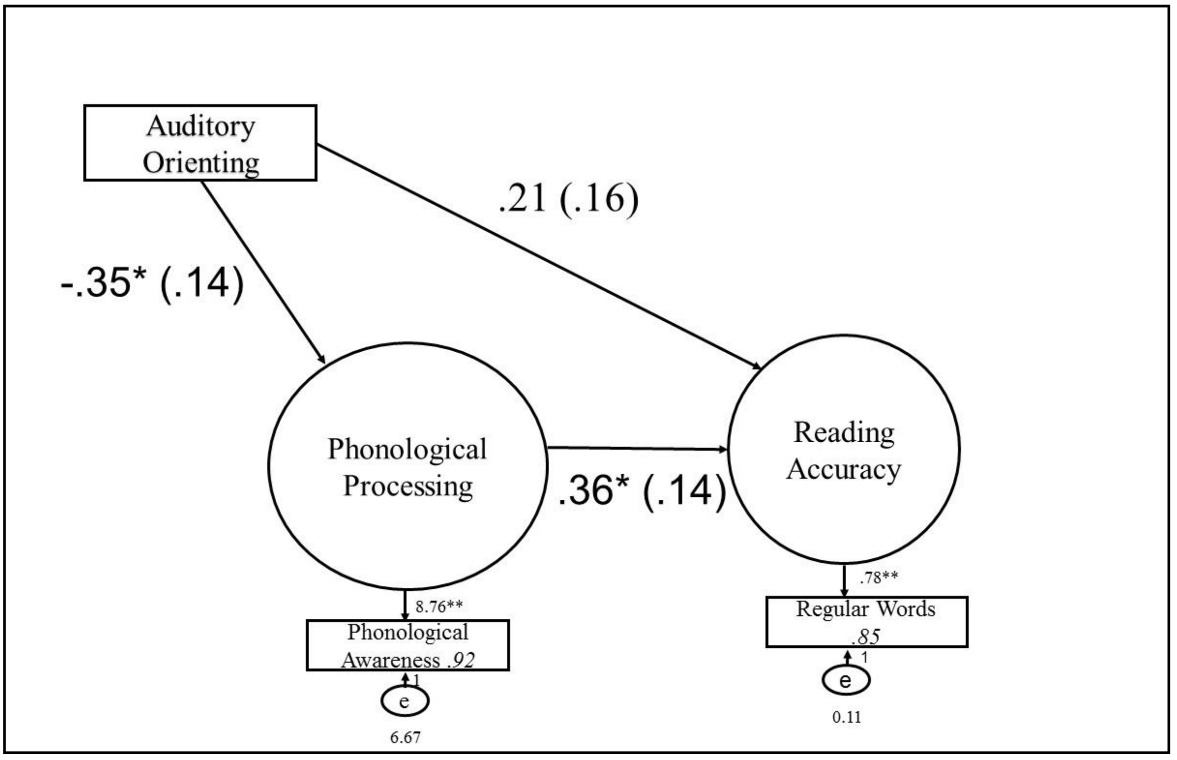


Figure 6.2. The relationship between auditory orienting and reading accuracy through phonological processing in RA matched controls ($n = 50$). Auditory alerting and auditory executive attention were also assessed in this model, but for ease of illustration, and given its marginal significance, only auditory orienting is illustrated. **Correlation was strong and significant ($p < .001$) at the .05 level (2-tailed). *Correlation was significant ($p < .05$) at the .05 level (2-tailed). The single pathway from auditory orienting to phonological processing was significant ($p = .01$). Standard errors are provided in parentheses.

Finally, to determine if there were any significant correlations between attention networks across modality, as well as with executive functioning for RA matched controls, Pearson's correlation analysis was conducted. Table 6.14 provides a correlation matrix that illustrates these results. There were no significant correlations within and across attention modality, or between visual and auditory attention and executive functioning for the RA matched control group.

Table 6.14: Pearson's Correlation Matrix between Visual and Auditory Attention Networks, and Executive Functioning for RA Matched Controls (*n* = 50)

	1	2	3	4	5	6
1. Visual alerting						
2. Visual orienting	.02					
3. Visual executive	-.21	.03				
4. Auditory alerting	-.13	.15	-.17			
5. Auditory orienting	-.02	-.10	.01	.18		
6. Auditory executive	-.09	-.12	.10	.01	-.20	
7.Executive functioning	-.15	-.16	.02	.11	-.11	.11

Children with DD: Measurement model (reading accuracy). The hypothesised measurement model, including the results from a single group CFA, for the relationship between phonological processing and reading accuracy in children with DD is shown in Figure 6.3. There was a significant, positive relationship between phonological processing and reading accuracy ($p < .001$). The measurement model was identified without any errors. The correlation between the two indicators (i.e., phonological awareness and regular words) for each latent construct was .43. Figure 6.3 also provides the values for the squared multiple correlation for each indicator (in italics).

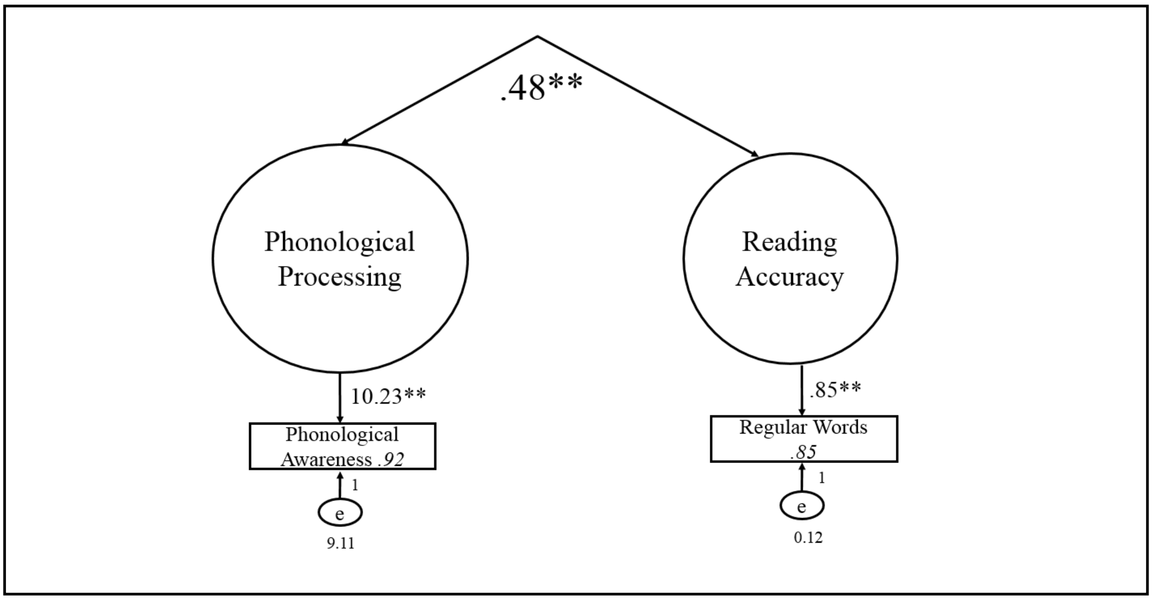


Figure 6.3. Single indicator measurement model with CFA results (standardised estimate) for the hypothesised relationship between phonological processing and reading accuracy for children with DD (n = 50). **Correlation was strong and significant (p < .001) at the .05 level (2-tailed).

Children with DD: Structural analysis of total, indirect, and direct effects.

Visual attention. The structural model was identified without any errors. Table 6.15 illustrates the total, indirect, and direct effects of visual executive attention, the only visual attention network that did not contribute significantly to the relationship between (visual) attention, phonological processing, and reading accuracy for children with DD.

Table 6.15: Total, Direct, and Indirect Effects between Visual Executive, Phonological Processing, and Reading Accuracy in Children with DD (*n* = 50)

Model	β		95% CI, *p* value
	Visual executive	Phonological processing	
Direct			
Visual executive		-0.03	[-0.37, 0.16], *p* = .44
Reading accuracy	-0.11	0.48	
Indirect			
Visual executive		-0.01	[-0.17, 0.14], *p* = .86
Reading accuracy			
Total			
Visual executive		-0.03	[-0.42, 0.18], *p* = .44

Reading accuracy	-0.12	0.48

Note. The single pathway between visual executive attention and phonological processing was not significant (p = .86); β = beta (standardised coefficient); CI = confidence interval.

In contrast to the non-significant effect of visual executive attention, Figure 6.4 illustrates the significant effect in the relationship between visual alerting and reading accuracy in children with DD. The indirect effect through phonological processing, (95% CI [-0.19, 0.12], with a point estimate of -0.04, p = .66), and the total (95% CI [-0.04, 0.55], with a point estimate of 0.25, p = .09) effects were non-significant. In contrast, the direct effect (95% CI [0.03, 0.55], with a point estimate of 0.29, p = .03) was positive and significant, suggesting that higher visual alerting scores are related to more accurate reading in children with DD.

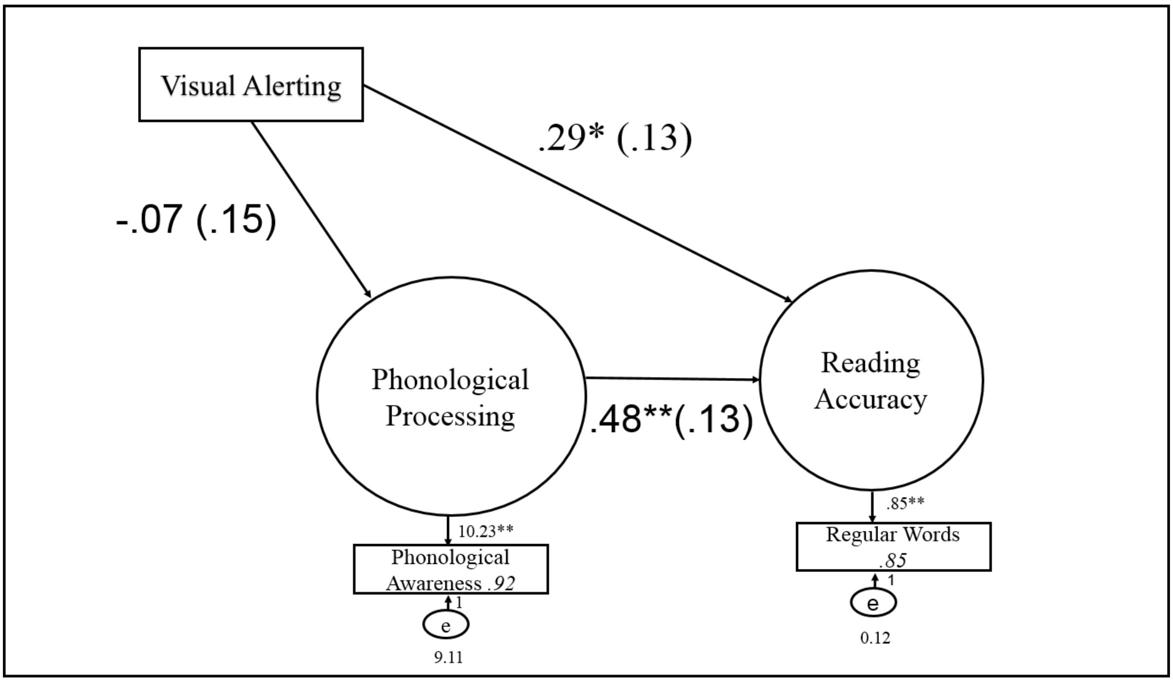


Figure 6.4. The relationship between visual alerting and reading accuracy through phonological processing in children with DD (n = 50).Visual orienting and visual executive attention were also assessed in this model, but for ease of illustration, and given its significance, only visual alerting is illustrated. **Correlation was strong and significant (p < .001) at the .05 level (2-tailed). *Correlation was significant (p < .05) at the .05 level (2-tailed). The single pathway from visual alerting to phonological processing was not significant (p = .66). Standard errors are provided in parentheses.

Similarly, Figure 6.5 illustrates the relationship between visual orienting and reading accuracy through phonological processing in children with DD. The direct relationship between visual orienting and reading accuracy was positive and marginally significant (95% CI [-0.02, 0.53], with a point estimate of 0.25, $p = .07$), suggesting that higher visual orienting scores are related to more accurate reading. The total (95% CI [-0.10, 0.52], with a point estimate of 0.21, $p = .19$) and indirect (95% CI [-0.21, 0.12], with a point estimate of -0.05, $p = .58$) effects were non-significant.

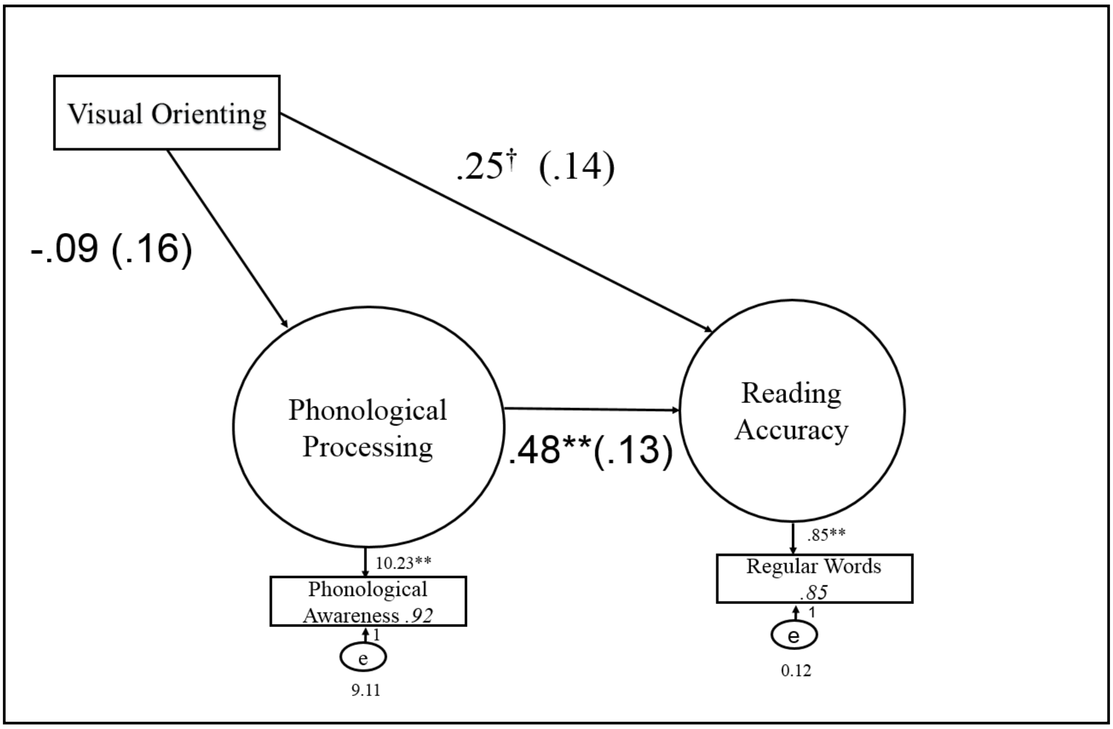


Figure 6.5. The relationship between visual orienting and reading accuracy via phonological processing in children with DD ($n = 50$).Visual alerting and visual executive attention were also assessed in this model, but for ease of illustration, and given its marginal significance, only visual orienting is illustrated. **Correlation was strong and significant ($p < .001$) at the .05 level (2-tailed). †Correlation was marginally significant at the $p < .05$ level. The single pathway from visual orienting to phonological processing was not significant ($p = .58$). Standard errors are provided in parentheses.

Auditory attention. The structural model was identified without any errors. Table 6.16 illustrates the total, indirect, and direct effects of auditory alerting, the only auditory attention network that did not contribute significantly to the relationship between (auditory) attention, phonological processing, and reading accuracy for children with DD.

Table 6.16: Total, Direct, and Indirect Effects between Auditory Alerting, Phonological Processing, and Reading Accuracy in Children with DD (*n* = 50)

Model	β		95% CI, *p* value
	Auditory alerting	Phonological processing	
Direct			
Auditory alerting		0.25	[-0.39, 0.20], *p* = .51
Reading accuracy	-0.10	0.48	
Indirect			
Auditory alerting		0.13	[-0.03, 0.28], *p* = .11
Reading accuracy			
Total			
Auditory alerting		0.25	[-0.28, 0.34], *p* = .86
Reading accuracy	0.03	0.48	

Note. The single pathway between auditory alerting and phonological processing was marginally significant (*p* = .06); β = beta (standardised coefficient); CI = confidence interval.

Figure 6.6 illustrates the relationship between auditory orienting and reading accuracy through phonological processing in children with DD. The indirect relationship between auditory orienting and reading accuracy via phonological processing was negative and significant, (95% CI [-0.37, -0.02], with a point estimate of -0.19, *p* = .03). This suggests that larger auditory orienting scores are related to lower phonological processing scores and in turn lower reading accuracy. The total (95% CI [-0.50, 0.09], with a point estimate of -0.20, *p* = .17) and direct (95% CI [-0.31, 0.29], with a point estimate of -0.01, *p* = .95), effects were non-significant.

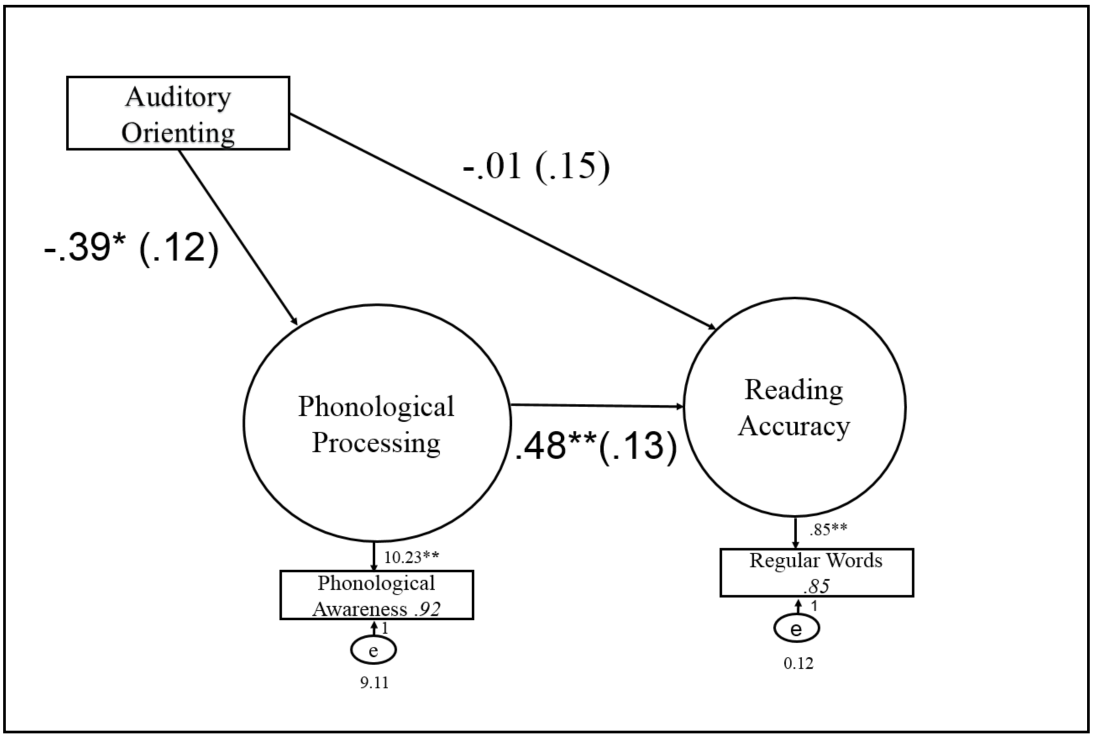


Figure 6.6. The relationship between auditory orienting and reading accuracy through phonological processing in children with DD (n = 50). Auditory alerting and auditory executive attention were also assessed in this model, but for ease of illustration, and given its significance, only auditory orienting is illustrated. **Correlation was significant ($p < .001$) at the .05 level (2-tailed). *Correlation was significant ($p < .05$) at the .05 level (2-tailed). The single pathway from auditory orienting to phonological processing was significant ($p = .002$). Standard errors are provided in parentheses.

Figure 6.7 illustrates the relationship between auditory executive attention and reading accuracy through phonological processing in children with DD. The indirect relationship between auditory executive attention and reading was significant and negative (95% CI [-0.34, -0.004], with a point estimate of -0.17, $p = .04$). This suggests that a larger auditory executive attention score is related to poorer phonological processing, and in turn lower reading accuracy. The total (95% CI [-0.48, 0.13], with a point estimate of -0.18, $p = .26$) and direct (95% CI [-0.31, 0.31], with a point estimate of -0.00, $p = .99$), effects were non-significant.

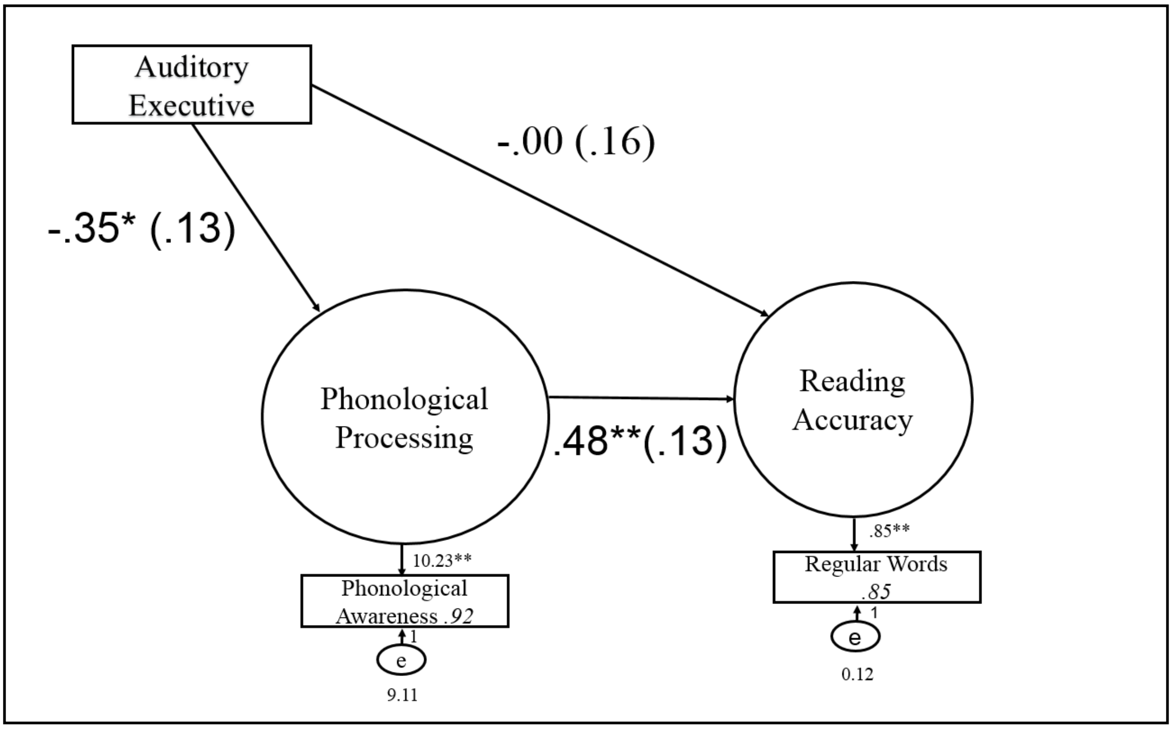


Figure 6.7. The relationship between auditory executive attention and reading accuracy through phonological processing in children with DD ($n = 50$). Auditory alerting and auditory orienting were also assessed in this model, but for ease of illustration, and given its significance, only auditory executive attention is illustrated. **Correlation was strong and significant ($p < .001$) at the .05 level (2-tailed). *Correlation was significant ($p < .05$) at the .05 level (2-tailed). The single pathway from auditory executive attention to phonological processing was significant ($p = .01$). Standard errors are provided in parentheses.

Finally, to determine if there were any significant correlations between attention networks across modality, as well as with executive functioning for children with DD, Pearson's correlation analysis was conducted. Table 6.17 provides a correlation matrix that illustrates these results. There was a significant, negative correlation between visual alerting and visual orienting (r = -.30, p = .03). There was also a significant, negative relationship between visual orienting and visual executive (r = -.30, p =.03) attention. The relationship between visual orienting and auditory executive attention was marginally significant and negative (r = -.28, p =.051). There was a significant, positive relationship between visual executive and auditory executive (r = .58, p < .001) attention, as well as a positive, significant relationship between auditory alerting and auditory executive (r = .29, p = .04) attention. The relationship between auditory orienting and executive functioning was marginally significant and positive (r = .25, p = .08). All other correlations were non-significant.

Table 6.17: Pearson's Correlation Matrix between Visual and Auditory Attention Networks in Children with DD (*n* = 50)

	1	2	3	4	5	6
1. Visual alerting						
2. Visual orienting	-.30*					
3. Visual executive	.09	-.30*				
4. Auditory alerting	.17	-.15	.22			
5. Auditory orienting	.14	.15	-.23	-.01		
6. Auditory executive	.05	- .28†	.58**	.29*	-.17	
7. Executive functioning	-.02	.22	.05	.05	.25†	-.02

Note. *Correlation was strong and significant at the p < .05 level; *Correlation was significant at the p < .05 level; †Correlation was marginally significant at the p < .05 level.

CA matched controls: **Measurement model (reading accuracy)**. The hypothesised measurement model, with the results from a single group CFA, for the relationship between phonological processing and reading accuracy in the CA matched control group is shown in Figure 6.8. There was a significant, positive relationship between phonological processing and reading accuracy (p = .004). The correlation between the two indicators (i.e., RAN and regular words) for each latent construct was .35. Figure 6.8 also provides the values for the squared multiple correlation for each indicator (in italics).

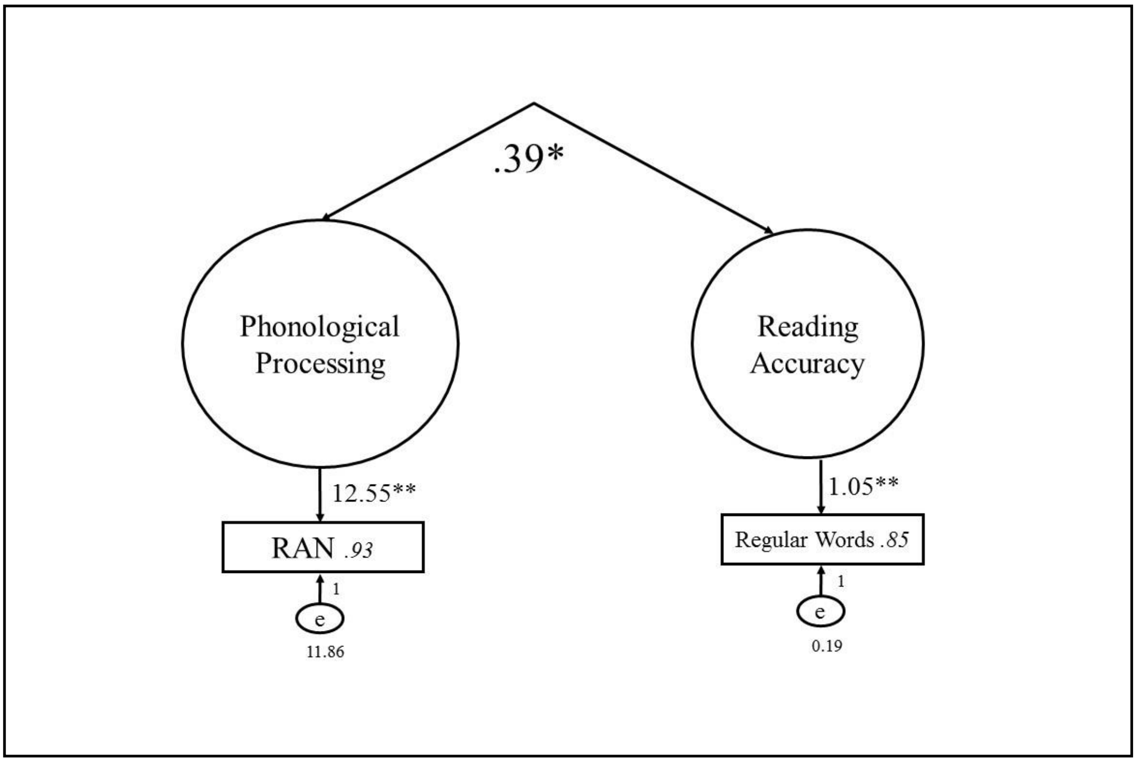


Figure 6.8. Single indicator measurement model with CFA results (standardised estimates) for the hypothesised relationship between phonological processing and reading accuracy for CA matched controls (n = 50). **Correlation was strong and significant ($p < .001$) at the .05 level (2-tailed). *Correlation was significant ($p < .05$) at the .05 level (2-tailed). RAN = rapid automatised naming.

CA matched controls: Structural analysis of total, indirect, and direct effects.

Visual attention. The structural model was identified without errors. Tables 6.18 and 6.19 illustrate the total, indirect, and direct effects of the visual alerting and visual executive attention networks. The results demonstrate non-significant total, direct, and indirect effects for these attention networks.

Table 6.18: Total, Direct, and Indirect Effects between Visual Alerting, Phonological Processing, and Reading Accuracy in CA Matched Controls (*n* = 50)

Model	β		95% CI, *p* value
	Visual alerting	Phonological processing	
Direct			
Visual alerting		-0.04	[-0.30, 0.30], *p* = .99
Reading accuracy	0.00	0.39	
Indirect			
Visual alerting		-0.02	[-0.17, 0.13], *p* = .79
Reading accuracy			
Total			
Visual alerting		-0.04	[-0.35, 0.31], *p* = .90
Reading accuracy	-0.02	0.39	

Note. The single pathway between visual alerting and phonological processing was not significant (p = .79); β = beta (standardised coefficient); CI = confidence interval.

Table 6.19: Total, Direct, and Indirect Effects between Visual Executive, Phonological Processing, and Reading Accuracy in CA Matched Controls (*n* = 50)

Model	β		95% CI, *p* value
	Visual executive	Phonological processing	
Direct			
Visual executive		-0.00	[-0.08, 0.50], *p* = .16
Reading accuracy	0.21	0.39	
Indirect			
Visual executive		-0.00	[-0.15, 0.15], *p* = .98
Reading accuracy			
Total			
Visual executive		-0.00	[-0.11, 0.53], *p* = .20
Reading accuracy	0.21	0.39	

Note. The single pathway between visual executive attention and phonological processing was not significant (p = .98); β = beta (standardised coefficient); CI = confidence interval.

Figure 6.9 illustrates the relationship between visual orienting and reading accuracy through phonological processing in CA matched controls. The indirect relationship was negative and significant, (95% CI [-0.38, -0.01], with a point estimate of -0.19, $p = .04$), suggesting that larger visual orienting scores are related to lower phonological processing (i.e., lower RAN scores indicate slower and less accurate naming) and in turn, lower reading accuracy. The total (95% CI [-0.28, 0.37], with a point estimate of 0.05, $p = .78$) and direct (95% CI [-0.07, 0.55], with a point estimate of 0.24, $p = .13$) effects were non-significant. These findings replicate the results that were observed in Study 1, in the larger group of later stage readers.

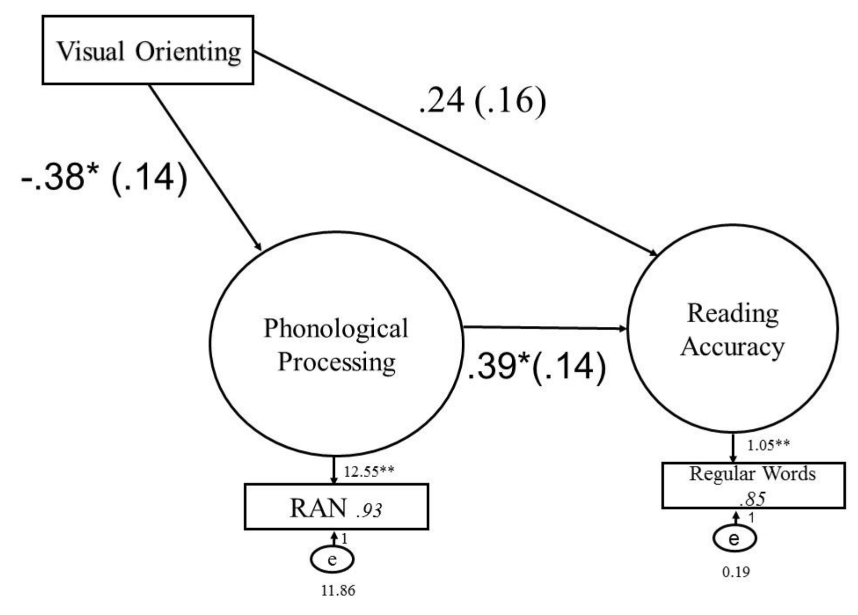


Figure 6.9. The relationship between visual orienting and reading accuracy through phonological processing in CA matched controls ($n = 50$).Visual alerting and visual executive attention were also assessed in this model, but for ease of illustration, and given its significance, only visual orienting is illustrated. **Correlation was strong and significant ($p < .001$) at the .05 level (2-tailed). *Correlation was significant ($p < .05$) at the .05 level (2-tailed). The pathway between visual orienting and phonological processing was significant ($p = .01$). Standard errors are provided in parentheses. RAN = rapid automatised naming.

Auditory attention. The structural model for auditory attention was identified without any errors. Tables 6.20 to 6.22 illustrate the total, indirect, and direct effects of the auditory alerting, orienting, and executive attention networks. The results showed non-significant total, direct, and indirect effects for these networks.

Table 6.20: Total, Direct, and Indirect Effects between Auditory Alerting, Phonological Processing, and Reading Accuracy in CA Matched Controls (*n* = 50)

Model	β		95% CI, *p* value
	Auditory alerting	Phonological processing	
Direct			
Auditory alerting		-0.04	[-0.17, 0.39], *p* = .46
Reading accuracy	0.11	0.39	
Indirect			
Auditory alerting		-0.02	[-0.13, 0.09], *p* = .78
Reading accuracy			
Total			
Auditory alerting		-0.04	[-0.21, 0.39], *p* = .55
Reading accuracy	0.09	0.39	

Note. The single pathway between auditory alerting and phonological processing was not significant (*p* = .78); β = beta (standardised coefficient); CI = confidence interval.

Table 6.21: Total, Direct, and Indirect Effects between Auditory Orienting, Phonological Processing, and Reading Accuracy in CA Matched Controls (*n* = 50)

Model	β		95% CI, *p* value
	Auditory orienting	Phonological processing	
Direct			
Auditory orienting		0.10	[-0.09, 0.48], *p* = .17
Reading accuracy	0.20	0.39	
Indirect			
Auditory orienting		0.04	[-0.08, 0.15], *p* = .53
Reading accuracy			
Total			
Auditory orienting		0.10	[-0.06, 0.53], *p* = .12
Reading accuracy	0.23	0.39	

Note. The single pathway between auditory orienting and phonological processing was not significant (*p* = .52); β = beta (standardised coefficient); CI = confidence interval.

Table 6.22: Total, Direct, and Indirect Effects between Auditory Executive, Phonological Processing, and Reading Accuracy in CA Matched Controls (*n* = 50)

Model	β		95% CI, *p* value
	Auditory executive	Phonological processing	
Direct			
Auditory executive		-0.07	[-0.30, 0.28], *p* = .96
Reading accuracy	-0.01	0.39	
Indirect			
Auditory executive		-0.03	[-0.14, 0.09], *p* = .64
Reading accuracy			
Total			
Auditory executive		-0.07	[-0.34, 0.27], *p* = .82
Reading accuracy	-0.03	0.39	

Note. The single pathway between auditory executive attention and phonological processing was not significant (*p* = .63); β = beta (standardised coefficient); CI = confidence interval.

Finally, to determine if there were any correlations between attention networks across modality, as well as with executive functioning, Pearson's correlation analysis was conducted. Table 6.23 provides a correlation matrix that illustrates these results. There was a significant, negative relationship between visual executive attention and visual alerting ($r = -.32$, $p = .02$). The relationships between and visual orienting and visual alerting (positive, $r = .27$, $p = .06$), visual alerting and auditory alerting (negative, $r = -.27$, $p = .06$), visual orienting and auditory executive (positive, $r = .26$, $p = .07$) attention, auditory orienting and auditory executive ($r = -.26$, $p = .07$) attention, were marginally significant. All other correlations were non-significant.

Table 6.23: Pearson's Correlation Matrix between Visual and Auditory Attention Networks in CA Matched Controls (*n* = 50)

	1	2	3	4	5	6
1. Visual alerting						
2. Visual orienting	.27[†]					
3. Visual executive	-.32*	.21				
4. Auditory alerting	-.27[†]	.08	.20			
5. Auditory orienting	-.23	-.01	.03	.17		
6. Auditory executive	.16	.26[†]	-.03	-.20	-.26[†]	
7. Executive functioning	.12	-.24	-.16	.03	-.01	-.16

Note. *Correlation was significant at the $p < .05$ level; [†]Correlation was marginally significant at the $p < .05$ level.

Reading speed. Figure 6.10 illustrates the hypothesised model for the relationship between phonological processing and reading speed, which was assessed for both RA matched controls and children with DD. Figure 6.11 illustrates this same relationship, but for the CA matched control group, with the phonological processing construct being represented by RAN.

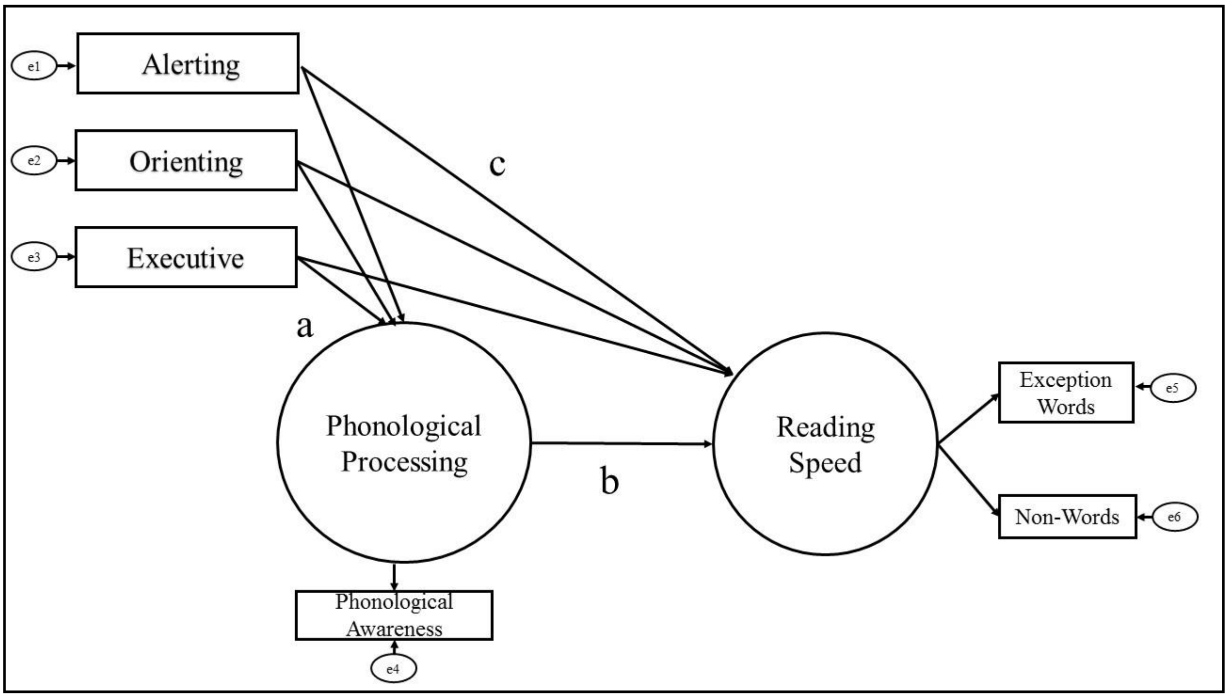


Figure 6.10. Hypothesised two factor model of the relationship between attention (visual and auditory assessed separately), phonological processing, and reading speed for both RA matched controls (n = 50) and children with DD (n = 50).

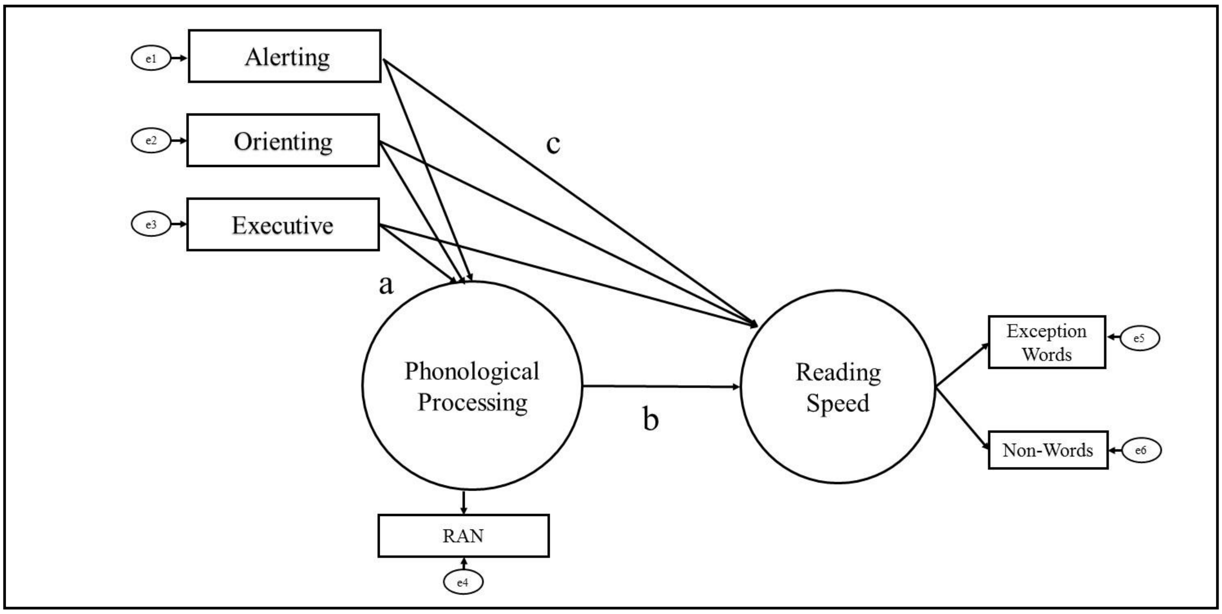


Figure 6.11. Hypothesised two factor model of the relationship between attention (visual and auditory assessed separately), phonological processing, and reading speed for CA matched controls (*n* = 50); RAN = rapid automatised naming.

Table 6.24 provides the fit indices for the measurement model comprising the relationship between phonological processing and reading speed for each reading ability group. The fit of the hypothesised models was initially tested (separately) for each of the three groups of readers─RA matched controls, children with DD, and CA matched controls─to determine the suitability of conducting invariance testing. The initial model for the RA matched control group did not converge, with the output showing a small, negative residual variance for the exception word reading speed observed variable. Given that this variance was small and non-significant, it was fixed to zero, in line with the suggestions of Muthén (2013). With this modification, the model for RA matched controls gained 1 degree of freedom, as illustrated in Table 6.24. This adjustment permitted model convergence and the fit statistics suggested a good fit to the data. Children with DD and CA matched controls had saturated measurement models (*df* = 0), with no warning errors from the M*plus* software. Given that degrees of freedom were not calculated for two of the three groups, a multiple-group approach including the assessment of invariance is currently not testable within this framework, at least when some models are saturated (Muthén, 2018a). These outcomes are not uncommon for models that include single indicator latent constructs (Kenny, 2013). Therefore, a single group SEM analysis for the relationship between attention, phonological processing, and reading speed was conducted, instead of multiple-group SEM analysis.

Table 6.24: Fit Indices for the Relationship between Phonological Processing and Reading Speed in Children with DD (*n* = 50) and their RA (*n* = 50) and CA (*n* = 50) Matched Controls in Study 3

Model	X^2	*df*	*p*	CFI	TLI	RMSEA	SRMR	Decision
RA matched	1.40	1	.24	.99	.98	.09	.03	Accept
DD	0.00	0	.00	1.00	1.00	.00	.00	Accept
CA matched	0.00	0	.00	1.00	1.00	.00	.00	Accept

Note. RA = reading age; DD = developmental dyslexia; CA = chronological age; X^2 = chi-square; *df* = degrees of freedom; CFI = comparative fit index; TFI = Tucker-Lewis index; RMSEA = root mean square error of approximation; SRMR = standardised root mean square residual.

RA matched controls: Measurement model (reading speed). The hypothesised measurement model, with the results from a single group CFA for the relationship between phonological processing (phonological awareness) and reading speed, for RA matched controls is shown in Figure 6.12. The values for the squared multiple correlation for each indicator (in italics) are also provided in 6.12. The figure illustrates that phonological processing (phonological awareness) did not significantly predict reading speed (*p* = .11).

RA matched controls: Structural analysis of total, indirect, and direct effects.

*Visual attention***.** The structural model was a good fit to the data for visual attention, X^2 (4) = 3.62, *p* = 0.46, CFI = 1.00, TLI = 1.00, RMSEA = 0.00, and SRMR = 0.02. The relationship between visual alerting and reading speed through phonological processing had non-significant total (95% CI [-0.18, 0.38], with a point estimate of 0.11, *p* = .45), indirect (95% CI [-0.03, 0.03], with a point estimate of 0.00, *p* = .82), and direct (95% CI [-0.18, 0.38], with a point estimate of 0.10, *p* = .48), effects.

The relationship between visual orienting and reading speed through phonological processing had non-significant total (95% CI [-0.30, 0.25], with a point estimate of -0.02, *p* = .86), indirect (95% CI [-0.13, 0.07], with a point estimate of -0.03, *p* = .52), and direct (95% CI [-0.28, 0.30], with a point estimate of 0.01, *p* = .96) effects.

The relationship between visual executive attention and reading speed through phonological processing had non-significant total (95% CI [-0.35, 0.21], with a point estimate of -0.07, p = .61), indirect (95% CI [-0.03, 0.03], with a point estimate of -0.00, p = .82), and direct (95% CI [-0.35, 0.21], with a point estimate of -0.07, p = .63) effects.

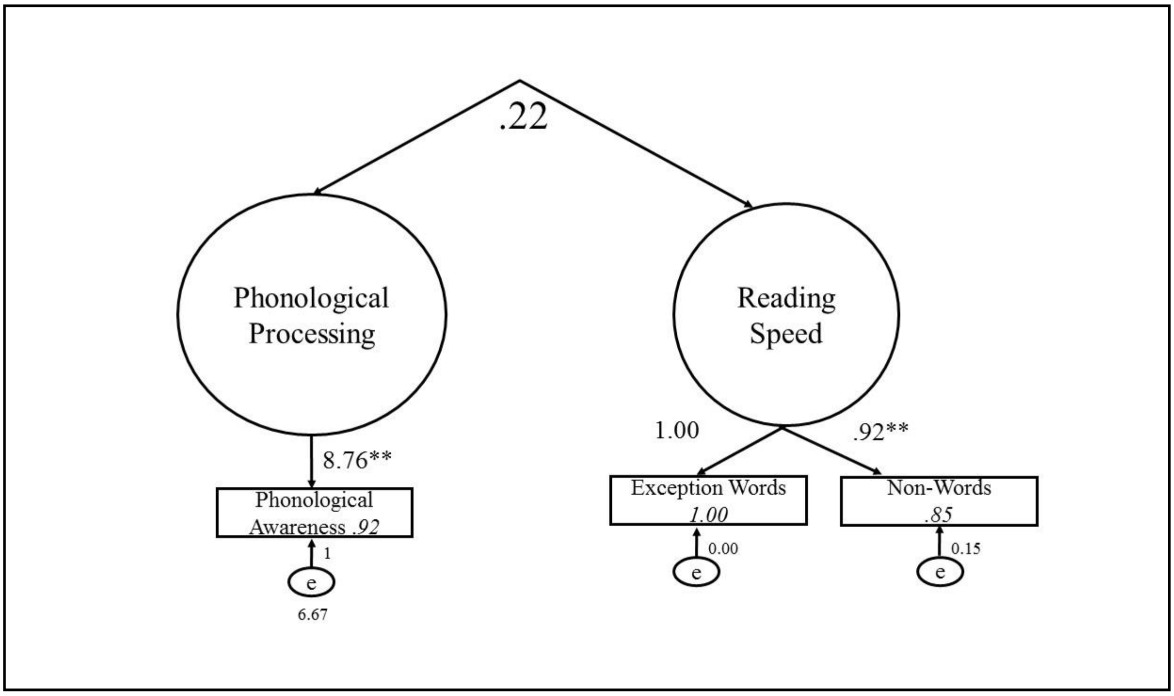


Figure 6.12. Measurement model with CFA results (standardised estimates) for the hypothesised relationship between phonological processing and reading speed for RA matched controls (n = 50). **Correlation was strong and significant (p < .001) at the .05 level (2-tailed).

Auditory attention. The structural model was a good fit to the data for auditory attention, X^2 (4) = 4.14, p = 0.39, CFI = 0.99, TLI = 0.99, RMSEA = 0.03 and, SRMR= 0.02. The relationship between auditory alerting and reading speed through phonological processing had a non-significant indirect effect (95% CI [-0.10, 0.04], with a point estimate of -0.03, p = .40). In contrast, the total (95% CI [0.12, 0.61], with a point estimate of 0.36, p = .004), and direct (95% CI [0.15, 0.64], with a point estimate of 0.39, p = .002) effects were positive and significant, suggesting that higher auditory alerting scores are related with slower reading speed in RA matched controls. However, this finding should be approached with caution, given that the ANOVA results that were reported in Stage 2 of Study 3 showed that there was no auditory alerting effect for RA matched controls.

The relationship between auditory orienting and reading speed through phonological processing had non-significant total (95% CI [-0.37, 0.17], with a point estimate of -0.10, p = .48), indirect (95% CI [-0.05, 0.18], with a point estimate of 0.07, p = .25), and direct (95% CI [-0.45, 0.12], with a point estimate of -0.17, p = .25) effects.

The relationship between auditory executive attention and reading speed through phonological processing had non-significant total (95% CI [-0.33, 0.21], with a point estimate of -0.06, p = .66), indirect (95% CI [-0.06, 0.05], with a point estimate of -0.01, p = .79), and direct (95% CI [-0.32, 0.21], with a point estimate of -0.05, p = .70) effects.

Children with DD: **Measurement model (reading speed).** The hypothesised measurement model, with the results from a single group CFA for the relationship between phonological processing (phonological awareness) and reading speed, for children with DD is shown in Figure 6.13. The values for the squared multiple correlation for each indicator (in italics) are also provided in Figure 6.13. The figure illustrates that phonological processing did not predict reading speed for children with DD (p = .64).

Children with DD: Structural analysis of total, indirect, and direct effects.

Visual attention. The structural model was a satisfactory fit to the data for visual attention, X^2 (4) = 5.80, p = 0.21, CFI = 0.92, TLI = 0.75, RMSEA = 0.10, and SRMR = 0.04, but, note that the TLI value was very poor. The relationship between visual alerting and reading speed through phonological processing had non-significant total (95% CI [-0.13, 0.43], with a point estimate of 0.15, p = .30), indirect (95% CI [-0.02, 0.03], with a point estimate of 0.00, p = .77) and direct (95% CI [-0.14, 0.43], with a point estimate of 0.15, p = .31) effects.

The relationship between visual orienting and reading speed through phonological processing had non-significant total (95% CI [-0.09, 0.49], with a point estimate of 0.20, p = .18), indirect (95% CI [-0.03, 0.04], with a point estimate of 0.01, p = .75), and direct (95% CI [-0.10, 0.49], with a point estimate of 0.19, p = .20) effects.

The relationship between visual executive attention and reading speed through phonological processing had non-significant total (95% CI [-0.28, 0.29], with a point estimate of 0.01, p = .95), indirect (95% CI [-0.02, 0.02], with a point estimate of 0.00, p = .87), and direct (95% CI [-0.28, 0.29], with a point estimate of 0.01, p = .96) effects.

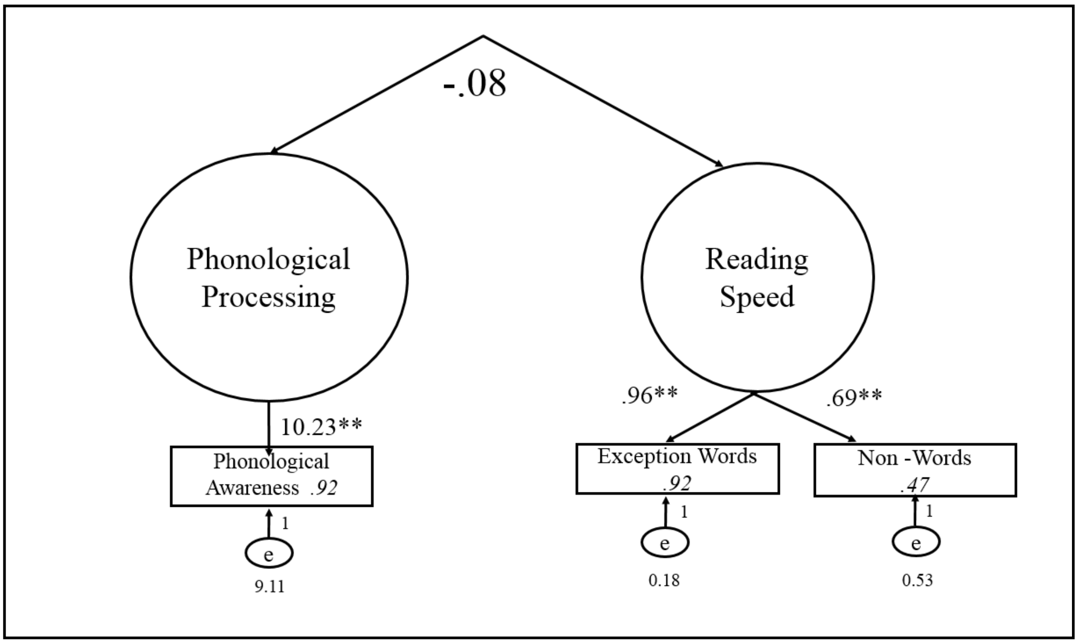


Figure 6.13. Measurement model with CFA results (standardised estimates) for the hypothesised relationship between phonological processing and reading speed for children with DD (n = 50). **Correlation was strong and significant (p < .001) at the .05 level (2-tailed).

Auditory attention. The structural model was a good fit to the data for auditory attention, X^2 (3) = 3.36, p = 0.34, CFI = 0.99, TLI = 0.96, RMSEA = 0.05 and SRMR = 0.03. The relationship between auditory alerting and reading speed through phonological processing had a non-significant indirect effect (95% CI [-0.08, 0.10], with a point estimate of 0.01, p = .83). In contrast, the total (95% CI [-0.72, -0.10], with a point estimate of -0.41, p = .01), and direct (95% CI [-0.75, -0.09], with a point estimate of -0.42, p = .01) effects were negative and significant, suggesting that higher auditory alerting scores are related with faster reading speed for children with DD. However, this finding should be approached with caution, given that the

ANOVA results that were reported in Stage 2 of Study 3 showed that there was no auditory alerting effect for children with DD.

The relationship between auditory orienting and reading speed through phonological processing had non-significant total (95% CI [-0.15, 0.43], with a point estimate of 0.14, p = .35), indirect (95% CI [-0.15, 0.12], with a point estimate of -0.02, p = .83), and direct (95% CI [-0.18, 0.49], with a point estimate of 0.16, p = .36) effects.

The relationship between auditory executive attention and reading speed through phonological processing had non-significant total (95% CI [-0.42, 0.30], with a point estimate of -0.06, p = .76), indirect (95% CI [-0.14, 0.11], with a point estimate of -0.01, p = .83), and direct (95% CI [-0.44, 0.35], with a point estimate of -0.04, p = .83) effects.

CA matched controls: **Measurement model (reading speed).** The hypothesised measurement model, with the results from a single group CFA for the relationship between phonological processing (RAN) and reading speed, for CA matched controls is shown in Figure 6.14. The values for the squared multiple correlation for each indicator (in italics) are also provided in Figure 6.14. The figure illustrates that higher phonological processing is related to faster reading speed (p < .001).

CA matched controls: Structural analysis of total, indirect, and direct effects.

Visual attention. The structural model was a good fit to the data for visual attention, X^2 (4) = 1.76, p = 0.78, CFI = 1.00, TLI = 1.00, RMSEA = 0.00, and SRMR = 0.01. The relationship between visual alerting and reading speed through phonological processing had non-significant total (95% CI [-0.40, 0.22], with a point estimate of -0.09, p = .55), indirect (95% CI [-0.03, 0.03], with a point estimate of -0.00, p = .81), and direct (95% CI [-0.40, 0.22], with a point estimate of -0.09, p = .57) effects.

The relationship between visual orienting and reading speed through phonological processing had non-significant total (95% CI [-0.33, 0.27], with a point estimate of -0.03, p = .83), indirect (95% CI [-0.15, 0.09], with a point estimate of -0.03, p = .61), and direct (95% CI [-0.33 to 0.32], with a point estimate of -0.00, p = .99) effects.

The relationship between visual executive attention and reading speed through phonological processing had non-significant total (95% CI [-0.30, 0.31], with a point estimate of 0.01, p = .97), indirect (95% CI [-0.03, 0.02], with a point estimate of 0.00, p = .98), and direct (95% CI [-0.30, 0.31], with a point estimate of 0.01, p = .96) effects.

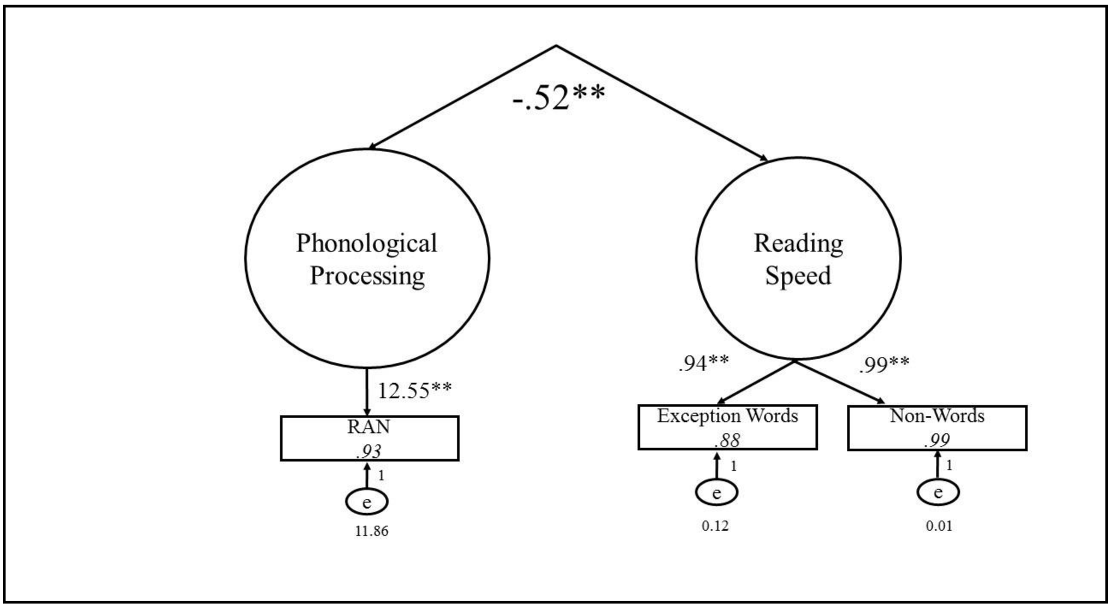


Figure 6.14. Measurement model with CFA results (standardised estimates) for the relationship between phonological processing and reading speed for CA matched controls (n = 50). **Correlation was strong and significant (p < .001) at the .05 level (2-tailed); RAN = rapid automatised naming.

Auditory attention. The structural model was a good fit to the data for auditory attention, X^2 (4) = 3.83, p = 0.43, CFI = 1.00, TLI = 1.00, RMSEA = 0.00, and SRMR = 0.02.The relationship between auditory alerting and reading speed through phonological processing had non-significant total (95% CI [-0.25, 0.31], with a point estimate of 0.03, p = .85), indirect (95% CI [-0.03, 0.02], with a point estimate of -0.00, p = .81), and direct (95% CI [-0.25, 0.31], with a point estimate of 0.03, p = .83) effects.

The relationship between auditory orienting and reading speed through phonological processing had non-significant total (95% CI [-0.08, 0.47], with a point estimate of 0.20, p = .17), indirect (95% CI [-0.03, 0.04], with a point estimate of 0.01, p = .68), and direct (95% CI [-0.09, 0.47], with a point estimate of 0.19, p = .19) effects.

The relationship between auditory executive attention and reading speed through phonological processing had non-significant total (95% CI [-0.29, 0.28], with a point estimate of -0.01, p = .98), indirect (95% CI [-0.04, 0.03], with a point estimate of -0.01, p = .73), and direct (95% [CI -0.28, 0.29], with a point estimate of 0.00, p = .99) effects.

Stage 4. Scatterplots and Bi-directionality of Significant SEM Relationships

Correlational analysis with scatterplots. Pearson's correlation analysis accompanied the primary SEM results reported in Stage 3 of Study 3. As a reminder, the primary SEM results, involving the relationship between attention and phonological processing, found significant or meaningful influences for visual orienting (CA matched controls), auditory orienting (RA matched controls and children with DD), and auditory executive (children with DD) attention, upon phonological processing skills. Moreover, given that single-indicators for phonological processing were used in the primary SEM analysis, the scatterplots in Figures 6.15 to 6.17 include only the specific indicator assessed for each reading ability group. That is, phonological awareness for RA matched controls and children with DD and RAN for CA matched controls.

RA matched controls. The scatterplot in Figure 6.15 illustrates the relationship between auditory orienting and phonological awareness for the RA matched controls. There was a significant, negative relationship between auditory orienting and phonological awareness (r = -.32, p = .03), demonstrating that higher auditory orienting difference scores are associated with lower phonological awareness scores. The pattern of this relationship was also identified in the larger sample of early stage readers in Study 1.

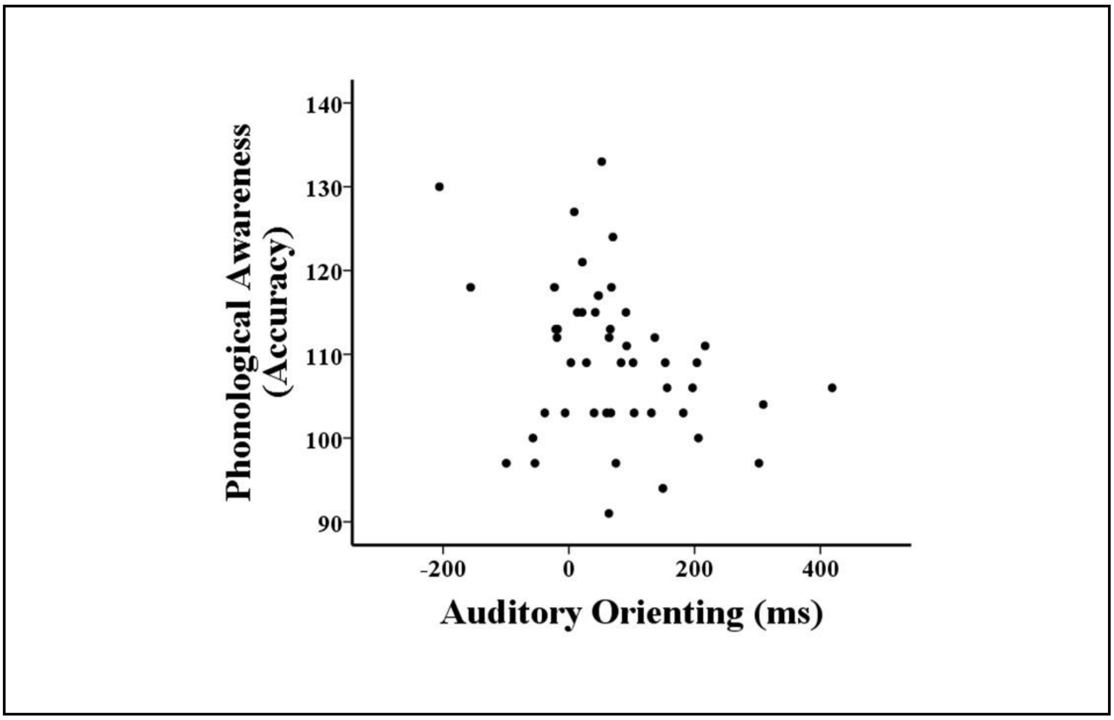


Figure 6.15. Scatterplot of the correlation between auditory orienting (ms) and phonological awareness (accuracy) in RA matched controls (n = 50); ms = milliseconds.

Children with DD. The scatterplot in Figure 6.16 illustrates the relationship between auditory orienting attention and phonological awareness for children with DD. There was a significant, negative relationship between auditory orienting and phonological awareness (r = -.32, p = .03), demonstrating that higher auditory orienting difference scores are associated with lower phonological awareness scores. In the primary SEM analysis, auditory executive attention had a significant, negative indirect effect upon reading accuracy through phonological processing for children with DD. In the correlational analysis, while the relationship between auditory executive attention and phonological processing (phonological awareness) did not reach significance (r = -.20, p = .16), it was negative, demonstrating that higher auditory executive attention difference scores are associated with lower phonological awareness scores.

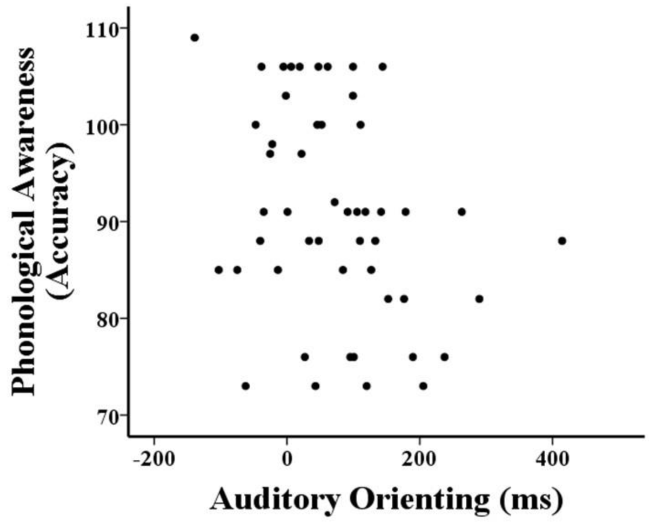


Figure 6.16. Scatterplot of the correlation between auditory orienting (ms) and phonological awareness (accuracy) in children with DD (n = 50); ms = milliseconds.

CA matched controls. The scatterplot in Figure 6.17 illustrates the relationship between visual orienting and RAN for the CA matched controls. There was a significant, negative relationship between visual orienting and RAN (r = -.38, p = .01), demonstrating that higher visual orienting difference scores are associated with lower RAN scores. The pattern of this relationship was also identified in the larger sample of later stage readers in Study 1, although in Study 1, the negative relationship was identified between visual orienting and phonological memory.

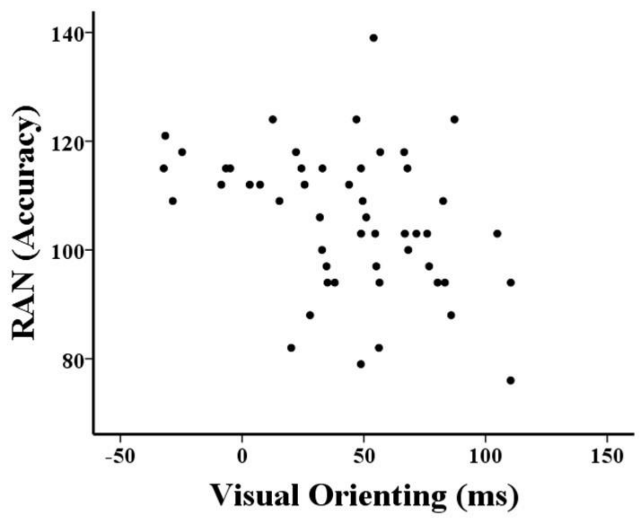


Figure 6.17. Scatterplot of the correlation between visual orienting (ms) and RAN (accuracy) in CA matched controls (n = 50); ms = milliseconds.

Testing the bi-directionality of significant SEM relationships. Given the significant (and meaningful) relationship between attention networks, phonological processing, and reading accuracy for both RA and CA matched controls, and children with DD, additional SEM analysis was conducted to clarify this relationship for each reading ability group. This was aimed at assessing if phonological processing influenced attention. Therefore, in this additional SEM analysis, phonological processing was defined as the predictor, and attention was defined as the mediator. Single group SEM analysis was conducted (instead of multiple-group analysis) to match the analysis of the primary SEM analysis reported in Stage 3 of the current study.

RA matched controls

*Visual attention***.** The structural model was a good fit to the data, X^2 (3) = 2.20, p = .53, CFI = 1.00, TLI = 1.00, RMSEA = 0.00, and SRMR = 0.05. The relationship between phonological processing, and reading accuracy through visual attention had non-significant indirect effects for alerting (95% CI [-0.06, 0.05], with a point estimate of -0.01, p = .80), orienting (95% CI [-0.03, 0.18], with a point estimate of 0.07, p = .18), and executive (95% CI [-0.03, 0.02], with a point estimate of -0.00, p = .78) attention. The total (95% CI [0.09, 0.64], with a point estimate of 0.30, p = .04) and direct (95% CI [0.01, 0.59], with a point estimate of 0.36, p = .01) effects were significant.

Auditory attention. The structural model was a poor fit to the data, X^2 (3) = 4.08, p = .25, CFI = 0.85, TLI = 0.50, RMSEA = 0.09, and SRMR = 0.06. Therefore, no further analysis was warranted. While the bi-directional nature of this relationship could not be assessed, the poor fit of this model indicates that the theoretical configuration of this model was not robust, suggesting that phonological processing is unlikely to predict auditory attention.

Summary of bi-directionality analysis for RA matched controls. Together, for visual and auditory attention, these findings suggest that the significant relationship between phonological processing and reading accuracy was not mediated through visual or auditory alerting, orienting, and executive attention. As such, there was no evidence of a bi-directional relationship, for the observed significant relationship between auditory orienting, phonological processing, and reading accuracy, in RA matched controls. That is, auditory orienting significantly influenced phonological processing (as shown in the main SEM analysis in which auditory orienting was the predictor, and phonological processing was the mediator), but phonological processing does not influence auditory orienting.

Children with DD.

Visual attention. The structural model was a poor fit to the data, even with correlating error variances, as suggested by M*plus'* MIs, X^2 (3) = 9.65, p = .02, CFI = 0.61, TLI = 0.31, RMSEA = 0.21, and SRMR = 0.10.

Auditory attention. The structural model was a poor fit to the data, even with correlating error variances, as suggested by M*plus'* MIs, X^2 (3) = 10.36, p = 0.02, CFI = 0.62, TLI = 0.28, RMSEA = 0.22 and, SRMR = 0.09. Therefore, no further analysis was warranted.

Summary of bi-directionality analysis for children with DD. While the bi-directional nature of these relationships could not be assessed, the poor fit of these models indicates that their theoretical configurations were not robust, and that phonological processing is unlikely to significantly predict visual or auditory attention. Furthermore, given that the models in primary SEM analysis (i.e., attention was the predictor, and phonological processing was the mediator) had a good fit to the data, these models are likely to be more theoretically sound compared with a model in which phonological processing is hypothesised to predict reading accuracy through visual or auditory attention in children with DD.

CA matched controls.

*Visual attention***.** The structural model was a poor fit to the data, even with correlating error variances, as suggested by M*plus'* MIs, X^2 (3) = 13.23, *p* = .00, CFI = 0.58, TLI = 0.41, RMSEA = 0.26, and SRMR = 0.10. Therefore, no further analysis was warranted.

Auditory attention. The structural model was a poor fit to the data, even with correlating error variances, as suggested by M*plus'* MIs, X^2 (3) = 6.09, *p* = 0.11, CFI = 0.52, TLI = 0.60, RMSEA = 0.14 and SRMR, = 0.08. Therefore, no further analysis was warranted.

Summary of bi-directionality analysis for CA matched controls. While the bi-directional nature of these relationships could not be assessed, the poor fit of these models indicates that their theoretical configurations were not robust, and that phonological processing is unlikely to significantly predict visual or auditory attention. Furthermore, given that the models in primary SEM analysis (i.e., attention was the predictor, and phonological processing was the mediator) had a good fit to the data, these models are likely to be more theoretically sound compared with a model in which phonological processing is hypothesised to predict reading accuracy through visual or auditory attention in CA matched controls.

Summary and Discussion of Study 3

Study 3 aimed to determine group differences in the relationship between visual and auditory attention networks, phonological processing, and reading in children with DD (aged 9 to 10 years) compared with their RA (aged 6 to 7 years) and CA (aged 9 to 10 years) matched controls. Study 3 also aimed to determine if there was a group difference in the modality of attention that influences reading (via phonological processing or directly) among the three reading ability groups. In interpreting the results of Study 3, consideration must be given to the fact that a multiple-group SEM, which confirms invariance and genuine group differences, could not be implemented because of the just-identified nature of the models for each reading ability group (Muthén, 2018b). Nevertheless, the results from the single group SEM are valuable in providing an understanding of potential differences that are likely to exist among the three reading ability groups.

Aim 1: Determining group differences in the relationship between attention, phonological processing, and reading.

Reading accuracy. The findings showed significant relationships between attention, phonological processing, and reading accuracy for all three groups of readers. In the RA matched controls, there was a marginally significant, negative, indirect effect of auditory orienting upon reading accuracy through phonological processing. This suggests that larger auditory orienting scores are related to poorer phonological processing and in turn, lower reading accuracy. Another finding in RA matched controls was the significant total effect in the relationship between visual orienting, phonological processing, and reading accuracy, suggesting that there is a potential effect of visual orienting upon reading accuracy that could be mediated through phonological processing. The nature of the total effect could not be determined from the results, as both the direct and indirect effects were non-significant with small effect sizes. However, based on the pattern of results from Studies 1 and 2, it is likely that if there is any effect of visual orienting, it would be mediated via phonological processing. For CA matched controls, the findings showed that there was a significant, negative, indirect effect of visual orienting upon reading accuracy through phonological processing, suggesting that larger visual orienting scores are related to poorer phonological processing and less accurate reading. Together, the findings for the RA and CA matched controls support the hypothesis of Study 3 and replicate the pattern of results identified in the multiple-group SEM analysis of Study 1 for the early and later stage reading groups, respectively. In the General Discussion, the implications of these consistent results across each study are presented in the context of a proposal for an attention network model of reading.

In contrast with their matched controls, the SEM analysis for children with DD showed significant relationships between multiple attention networks and reading accuracy, which were either unmediated or mediated via phonological processing. Firstly, there was a significant, negative, indirect effect between auditory orienting and reading accuracy through phonological processing, suggesting that larger auditory orienting scores are related to lower phonological processing scores, and less accurate reading. There was also a significant, negative, indirect relationship between auditory executive attention, phonological processing, and reading accuracy, suggesting that weaker auditory executive attentional control, is related to poorer phonological and in turn poorer reading accuracy. In addition to this, there were significant and marginally significant positive direct relationships between visual attention (visual alerting and visual orienting) and reading accuracy, indicating that larger visual alerting and visual orienting scores are related to more accurate reading. These findings align with the idea that there is an overactive attention network in children with DD, which may reflect a need to compensate for their phonological deficits (Boada & Pennington, 2006). Such a proposition is a likely since there are direct routes between visual attention and reading accuracy in children with DD; such routes are otherwise mediated via phonological processing for typically developing CA matched controls in the present study, as well as Studies 1 and 2 later stage readers.

In addition, the number of attention network interactions within each reading ability group differed. For RA matched controls, there were no significant relationships between auditory or visual orienting with other attention networks and executive functioning. This suggests that any effects of orienting upon reading accuracy, through phonological processing, was not significantly influenced by other attention networks or executive functioning (Duncan et al., 2007). For CA matched controls, there was a marginally significant, positive relationship between visual alerting and visual orienting (visual orienting was found to be significant in the SEM analysis for reading accuracy in CA matched controls), which suggests that higher levels of alertness are related to higher levels of orienting. There was also a marginally significant relationship between visual orienting and auditory executive attention in CA matched controls, suggesting that higher levels of alertness to visual stimuli relates to a reduce ability to inhibit auditory information.

However, children with DD showed a larger number of within and across modality interactions for the attention networks that were identified as being important to reading accuracy. Firstly, the relationship between visual alerting and visual orienting was negative, suggesting that higher alerting relates to less orienting. Secondly, there was a significant, negative relationship between visual orienting and visual executive attention, suggesting that higher orienting or use of visual spatial cues is related to a greater ability to inhibit irrelevant visual stimuli. Thirdly, there was a marginally significant, negative relationship between visual orienting and auditory executive attention, again suggesting that higher orienting or use of visual orienting spatial cues is related to a greater ability to inhibit irrelevant auditory stimuli. In addition, there was a significant positive relationship between visual and auditory executive attention, suggesting a supramodal executive attention network. There was also a significant, positive relationship between auditory alerting and auditory executive attention indicating that higher alerting is related to a reduced ability to inhibit irrelevant auditory information. Finally, the relationship between executive functioning and auditory orienting was marginally significant and positive, suggesting that elevated executive functioning is related to an increase in auditory orienting. While some of these interactions are not uncommon in previous research on attention networks in typically developing children (e.g., Pozuelos et al., 2014), it is likely that more activation within the attention network (perhaps indexed by higher numbers of within and across modality interactions) is detrimental to phonological processing and reading accuracy. Further details regarding the nature of these interactions and their implications for reading are discussed in the General Discussion. In addition to this, there was no evidence of a bi-directional relationship between attention and phonological processing, a finding which applies to all three reading ability groups. This provides more robust support for the finding that attention impacts upon phonological processing, rather than the converse.

Reading speed. The primary SEM analysis showed significant relationships between attention (auditory alerting), phonological processing, and reading speed, only for RA matched controls and children with DD. Specifically, in the RA matched control group, there was a significant, positive, direct relationship between auditory alerting and reading speed, suggesting that higher alerting scores are related with slower reading speed. In contrast, for children with DD, there was a significant, negative, direct relationship between auditory alerting and reading speed, suggesting that higher alerting scores are related with faster reading speed. However, these findings should be approached with caution, given that the calculation of the auditory attention network effects showed that there was no auditory alerting effect for both the RA matched controls and children with DD. In contrast to RA matched controls and children with DD, there were no significant relationships between attention, phonological processing, and reading speed in CA matched controls (and CA matched controls exhibited an auditory alerting effect). The finding of no auditory alerting effect for RA matched controls aligns with previous literature showing that younger children are generally poorer at using warning cues to benefit RT processing (Rueda et al., 2004). However, that children with DD also exhibited a failure to use auditory warning cues suggests a developmental effect (delay) in the ability to take advantage of cues, in line with the views of previous research (e.g., Jennings et al., 2007).The proposition of a developmental delay is further qualified by the finding in Study 3 that there were no significant differences in the auditory alerting effect between the RA matched controls and children with DD.

Aim 2: Determining group differences in the modality of attention that influences reading (via phonological processing or directly) between reading ability groups. For auditory attention, the primary SEM analysis showed that auditory orienting significantly influenced reading accuracy through phonological processing in RA matched controls and children with DD. In addition, there was a role for auditory executive attention in reading accuracy for children with DD, and a role for auditory alerting in reading speed for both RA matched controls and children with DD. In contrast, for CA matched controls, there were no significant indirect and direct effects of any auditory attention network upon reading accuracy. For visual attention, the analysis showed that visual orienting significantly influenced reading accuracy through phonological processing in CA matched controls. In contrast, for RA matched controls, there were no significant indirect and direct effects of any visual attention network upon reading accuracy. But, for children with DD, there was a role for visual alerting and visual orienting in reading accuracy. Together, these results support the hypothesis of Study 3, which predicted that for the RA controls, auditory attention would be significant for reading compared with visual attention, and that for CA matched controls, visual attention would be more significant for reading compared with auditory attention. These findings replicate the results of Study 1 with the larger group of early and later stage readers. In contrast, the finding that both visual and auditory attention were important in reading for children with DD does not support the hypothesis that auditory attention would be more significant than visual attention. This outcome suggests that the role of the attention system in reading for children with DD is modality independent, whereas in typically developing reading, it is likely to be primarily modality specific, at least for the age ranges in Study 3 (Gomes, Wolfson, et al., 2007; Ward, 1994).

Chapter 7 : General Discussion

Chapter Overview

This final chapter will discuss the overall findings of the three studies presented in this thesis and consider their overall theoretical and practical implications. Then, both the limitations of this programme of research, and related future research will be discussed, followed by an overall conclusion.

The goal of the current series of studies was three-fold. In Study 1, there was a cross-sectional examination to determine if there existed group differences in the relationship between the visual and auditory attention networks, phonological processing, and reading between typically developing early and later stage readers. In Study 2, there was a longitudinal examination to assess the stability in the pattern of group differences for the mediation between visual and auditory attention networks and phonological processing as predictors of subsequent reading in typically developing early and later stage readers. In this longitudinal study, there was a one year gap between the first and second round of testing. Finally, in Study 3, a quasi-experimental study determined whether group differences existed in the relationship between visual and auditory attention networks, phonological processing, and reading accuracy between children with DD and their typically developing (RA and CA) matched controls.

Group Differences in the Relationship between Visual and Auditory Attention Networks, Phonological Processing, and Reading in Early and Later Stage Readers: A Cross Sectional View

Study 1 proposed two hypotheses. Firstly, it was predicted that for early stage readers, phonological processing would mediate the relationship between attention and reading, but for later stage readers, the mediated pathway would diminish and the direct pathway from attention to reading would be strengthened. Secondly, it was predicted that for early stage readers, auditory attention would be more predictive of reading accuracy, compared with visual attention. In contrast, for later stage readers, visual attention would be more predictive of reading accuracy, compared with auditory attention. It should be noted that there were no significant relationships between attention, phonological processing, and reading speed for the cross-sectional study. Therefore, the discussion of reading in the context of the cross-sectional results refers only to reading accuracy, unless otherwise specified.

Early and later stage readers adopt a mediated pathway to reading. The cross-sectional results were consistent with the hypothesis that the relationship between attention and reading operates through phonological processing for early stage readers. In contrast, the cross-sectional results did not support the hypothesis that the pathway between attention and phonological processing would be reduced, in favour of a more direct relationship between attention and reading for later stage readers. These findings suggest that the mediated pathway through phonological processing is central to reading across both early (aged 6 to 7 years) and later (aged 9 to 10 years), more fluent, stages of reading. Although the present findings for early stage readers are generally consistent with previous research (e.g., Dally, 2006; Dice & Schwanenflugel, 2012), the continued importance of phonological processing for reading in later stage readers is unexpected.

Previous work identifies at least two roles for phonological processing in reading: one is fundamental, the other is optional (Ashby, 2010; Coltheart et al., 2001; Leinenger, 2014).The fundamental role has been associated more strongly with beginning readers, who rely predominantly on the sub-lexical pathway to word recognition (Castles et al., 2009; Ehri, 2013; Jackson & Coltheart, 2001). In contrast, the role of phonological processing during later reading stages have been mixed (Baron, 1973; Goswami et al., 2001; Rayner et al., 2012), and there is extensive debate regarding the use of this recoding mechanism among more fluent readers (see Leinenger, 2014 for review). This mechanism facilitates the conversion of written words to their stored lexical referent by firstly recoding the visual symbols into a phonological (sound) code. Subsequently, there is an extensive search to match sound based information to details in the reader's mental lexicon (Taft, 2013). Although it has been proposed that phonological recoding occurs early in processing and is therefore fundamental for lexical access (Lukatela & Turvey, 1994; Van Orden, 1987), other researchers have explained that sound codes are used optionally by more fluent readers (Dehaene & Cohen, 2011; LaBerge & Samuels, 1974; Seidenberg, 2005). In line with this latter view, the dual-route model of reading suggests that more skilled reading predominantly uses the lexical route, involving a visually-mediated, direct pathway from print to meaning (Coltheart et al., 2001). The use of the lexical route is thought to increase reading accuracy and efficiency. However, the findings of the present cross-sectional study for later stage readers fit more closely with the activation-verification model of reading, which emphasises that the phonology of words is the primary code used to locate and activate pre-lexical information from an internal lexicon (Ashby, 2010; Jared & O'Donnell, 2017; Lukatela & Turvey, 1991; Van Orden, 1987).

One account for observing a phonologically-mediated (indirect) rather than a more direct reading route in later stage readers might reflect a conservation of limited resources to maintain accurate reading patterns. For example, the constant use of a visually mediated access requires the memorisation of multiple letter shapes and word units, which places a high demand on cognitive resources (Fowler, 1978). This is likely to deplete attentional resources, thus increase errors during reading. In view of this, phonological processing skills are likely to enable the brain to compensate for the unnatural processing of reading, since the orthographic lexicon relies heavily upon the speech processing system (i.e., spoken language is a natural part of evolution) (Posner & Rothbart, 2007). Evidence for this is shown by the activation of the visual word form area, an area of the visual cortex that stores connections between the orthographic and phonological dimensions of words (Dehaene & Cohen, 2011).

Furthermore, previous studies identifying a reduced activation of phonological processing come from samples comprising predominantly adult skilled readers (Rayner et al., 2012). Although later stage readers in the present study read significantly faster than early stage readers, suggesting more skilled word reading, significant reading speed differences have been shown between skilled adult readers and fluent primary-aged readers (Speelman & Kirsner, 2005). Moreover, adult readers make significantly fewer mistakes in reading than children (Bruck, 1992). These differences, in addition to the need to conserve cognitive resources, are likely to influence the reliance upon phonological processing for lexical access for the later stage readers in the sample in the current cross-sectional study. Thus, while a more direct route to reading might exist for more advanced readers (as later argued in the longitudinal results of Study 2), phonological processing is still fundamental to attaining reading accuracy at the two reading stages in the present cross-sectional study (Coltheart et al., 2001; Posner & Rothbart, 2007). Altogether, the cross-sectional results have shown that both early (aged 6 to 7 years) and later (aged 9 to

10 years) stage readers share a similar attention network pathway that involves the use of phonological processing for reading. However, this conclusion should be considered in tandem with the shift from auditory to visual orienting attention in older readers, reflecting the possibility of a qualitative shift in how phonological processing interacts with reading pathways.

The mediated pathway to reading for early and later stage readers differs based on attention modality. Despite the similarity in the strength of the mediated pathway across early and later stage readers, there were differences in attention modality. For example, the negative, indirect effect for the relationship between auditory orienting and reading accuracy through phonological processing was large (-.39) and significant (p = .03) among early stage readers; although the positive, mediating effect of visual orienting was large (.31), it was only marginally significant (p = .07). Moreover, the confidence interval surrounding the indirect effect for visual orienting included zero and did not significantly overlap with that of auditory orienting. In contrast, for later stage readers, the negative, indirect effect for the relationship between visual orienting and reading accuracy through phonological processing was large (-.39) and significant (p = .03); but, neither the direct nor indirect effects for auditory attention were large nor significant. It should be further noted that the total effect of auditory orienting was large (.27) and significant (p = .04) for later stage readers, suggesting some combined influence of auditory orienting and phonological processing to reading accuracy during the later stages of reading. However, that this relationship was close to being marginally significant and comprised medium sized effects for the direct (.15) and indirect effects (.12) implies that the role for auditory orienting at this specific stage of later years reading is not qualitatively meaningful. Together, these findings support the second hypothesis of the cross-sectional study that during the early stages of reading, auditory attention is more significant for reading compared with visual attention. However, during the later stages of reading, visual attention is likely be more significant for reading compared with auditory attention.

These modality differences imply that although early and later stage readers use phonological information prior to lexical access at the level of linguistic (phonological) processing, as evidenced by the mediation through phonological processing, there are group differences in the type of access at the level of cognitive (attentional) processing. For example, given the significant relationship between auditory orienting and reading accuracy through phonological processing, early stage readers may rely more heavily upon an auditory driven cognitive route to word reading. This cognitive route might involve processes that prioritise a word's auditory characteristics (e.g., phonemes), during early levels of information processing. Of note, however, is that despite the absence of statistical significance, the large effect size in the relationship between visual orienting and reading accuracy through phonological processing for early stage readers suggests that visual orienting could also be important for reading at this early stage. In fact, fMRI data show that the ventral (visual) stream is not merely added to the reading network at more advanced stages, but it is an important part of the network across reading development (Wise Younger et al., 2017). In view of this, and given the absence of a statistically significant influence of visual orienting upon reading accuracy for early stage readers, it could be that relying more heavily on visual attention for lexical access is dependent upon a more advanced reading stage that is not yet completely attained by the early stage readers in the present study (Brunswick et al., 2012).

Consistent with this view, the current findings showed a significant relationship between visual (orienting) attention and reading accuracy through phonological processing in later stage readers, implying that more advanced stages of reading adopt a visually driven cognitive route to reading. Such a route might involve processes that prioritise a word's visual characteristics during early levels of information processing. The current results further suggest that the efficiency to control the spatial orientation of the eyes and inhibit irrelevant information for visual stimulus discrimination predicts phonological knowledge level in a way that is relevant to achievement in reading at later stages of reading. Thus, there might be a qualitative shift in orthographic processing, including processing more complex orthographic units of written words in a more sophisticated way than letter to sound correspondences. More precise control over eye movements that is required to identify orthographic units may therefore be a hallmark of better reading. It might also be that this shift in orthographic knowledge, which involves the last stage of reading development in Frith's (1985) model, involves or even necessitates a tight orthographic-to-phonological unit binding or unitisation. Hence, the involvement of stronger phonological skills is also linked to this developmental shift, thereby explaining the mediated relationship between visual orienting and reading through phonological processing for later stage readers (Van Orden, 1987).

So far, the relationship between attention, phonological processing, and reading in early and later stage readers have been discussed. The cross-sectional findings have shown that the processing of phonological information largely plays a fundamental role in reading, irrespective of whether children are beginning or more fluent readers, at least for primary aged children up to the age of 10. However, although phonological processing was central for both early and later stages readers, the differences in the pattern of mediation indicate that such processing should be considered in relation to attention modality. Moreover, at both stages of reading, orienting attention, involving the localisation of information (rather than alerting or executive attention), was indirectly related to reading accuracy through phonological processing. Thus, an efficient orienting attention system is likely to augment reading accuracy (Adams, 1990; Dally, 2006; Dice & Schwanenflugel, 2012; Dittman, 2013). This proposition makes sense because word recognition largely involves the identification of words that are characterised by conjunctions (i.e., different features such as the spectral and visual characteristics of words) that need to be bound together. This binding process is heavily reliant upon spatial localisation, and reflects a preliminary step before information is identified (Treisman & Gelade, 1980). Given the importance of orienting attention across both early and later stages of reading, a closer look at its interaction with phonological processing and reading is warranted to gather a more detailed understanding of the nature of the interaction.

The nature of the relationship between orienting attention, phonological processing, and reading in typically developing early and later stage readers. The orienting of attention facilitates the efficiency of information processing at cued locations; this has been previously called the orienting effect (Macleod et al., 2010; Mezzacappa, 2004; Pozuelos et al., 2014; Rueda et al., 2004). While reading, the orienting of attention is directed to the internal or external representations, or both, of letters, sounds, and words. Efficiency in orienting to these representations involves the ability to accurately and rapidly manipulate auditory and visual information, as well as the ability to readily adjust to varying task demands (e.g., reading of new words) (Reynolds & Besner, 2006). Therefore, a higher orienting effect has been previously interpreted as reflecting more efficient performance within the orienting attention network (Posner, personal communication, May 2017). However, the results of Study 1 are not entirely consistent with this interpretation. For example, in line with the common expectation, there was a positive relationship between visual orienting and phonological processing for early stage readers (i.e., facilitatory effect of a larger orienting score), suggesting that a higher orienting effect relates to more efficient processing of phonological information. In contrast, there was a negative relationship between orienting and phonological processing for audition in early stage readers, and for both vision and audition in later stage readers (i.e., inhibitory effect of a larger orienting score). It is this unexpected, negative (inhibitory) relationship that requires an explanation. One account could be that some inhibitory effects of higher orienting are only evident during more advanced stages of information processing, such as during the processing of linguistic or phonological information (Deutsch & Deutsch, 1963). Therefore, although at the level of cognitive (attentional) processing, higher orienting scores may reflect greater levels of efficiency, the opposite effect might be observed when orienting attention engages with linguistic processing. Given the unexpected finding of a negative relationship between orienting and phonological processing for both reading stages, the remainder of the discussion of the cross-sectional results will be devoted to advancing a potential explanation of this inhibitory relationship between orienting and phonological, and in turn, what the nature of this relationship suggests about the process of achieving reading accuracy.

To understand the inhibitory effect of orienting attention upon reading through phonological processing, it is important to firstly highlight specific reading processes that rely upon an efficient mapping between attention and phonology. These processes include (a) regulating the direction of attention across the text, (b) monitoring saccades to ensure that attention is focused upon a particular grapheme (i.e., letters), (c) preventing the processing of other irrelevant graphemes, (d) ensuring that adequate time is spent focusing on a particular grapheme to ensure its proper processing, and (e) shifting attention from a specific point in the text to another point to engage in the processing of new information (Cain & Parrila, 2014; Facoetti, 2001; Kamza, 2017; Wagner & Torgesen, 1987). Against this background (and based on the scatterplots presented in the results section of Chapter 4 in Figures 4.11, and 4.12, also in Chapter 6, Figures 6.15, 6.16, and 6.17), three different levels of the relationship between orienting attention and phonological processing are proposed: (a) a *maximum level of orienting attention,* which is associated with below average to average phonological processing accuracy scores; (b) a *sufficient/minimal level of orienting attention*, which is associated with average to above average phonological processing accuracy scores and; (c) an *absent level of orienting attention*, which is associated with above average to superior phonological processing accuracy scores. The first two levels on the continuum comprise participants who exhibited an orienting effect (i.e., faster RT scores on spatial cue conditions), and the third level comprises participants with no orienting effect.

***Maximum levels of orienting attention*.** The first level of significant orienting effects (i.e., spatial cue benefits) involve participants who engaged in *maximum* levels of orienting. Given that larger orienting effect scores were related to lower (generally within an average range) phonological processing scores, it might be that higher levels of orienting attention are not necessarily a prerequisite for better phonological processing. Central to this proposition, and confirmed by early theories of attention, is the idea that the attention system is limited in the amount of information that it can process, or the number of tasks in which it can engage simultaneously (Kahneman, 1973). Engaging in phonological processing is a cognitive demanding task; it involves detection, retention, shifting, and alignment (Melby-Lervåg et al., 2012). Viewed from this perspective, the results suggest that better phonological processing relies upon the extent to which adequate resources are available for efficient orienting to occur among these tasks. This further echoes early attention theories which explained that efficient information processing (in this case phonological processing) is heavily influenced by the capacity limits of the attention system (Kahneman, 1973; Moray, 1967). Access to adequate resources further rely on the ability to appropriately engage and disengage with information. That means there is an upper limit concerning the amount of attention that can be allocated for efficient task completion, a central idea in Kahneman's (1973) capacity model. From the data in the current study, it is not possible to specify the upper limit concerning the interaction between orienting and phonological processing. However, the data suggest that, if the upper capacity limit for the orienting attention network is exceeded, this results in less accurate phonological processing, and in turn, lower reading accuracy.

Further to this, it is possible that some of the children in the current study who produced larger orienting difference scores have less mature or poorly developed phonological representations. This was evidenced by their below average or poor scores on either the phonological awareness, phonological memory, or RAN task (Bird & Bishop, 1992; Boada & Pennington, 2006). Interestingly, Sokolov

(1963) who first detected the orienting effect (which he called the orienting response), along with other researchers (e.g., Hakerem & Sutton, 1966; Kahneman et al., 1967), observed that larger orienting effects usually followed stimuli that were either weak or ambiguous, reflecting more effort to process such stimuli. Kahneman (1973) later found that higher orienting responses depreciated the amount of resources available for the attention system to efficiently coordinate other relevant processes. It is possible that inefficiency in the orienting attention system create degraded phonological units, thus demanding a higher mental workload when children attempt to access them. This is likely to reduce the amount of resources available to the orienting network to efficiently and accurately process other phonological units, which may or may not be well-developed. Then, as confirmed by the findings of the present study, as well as previous work, poor phonological processing adversely impacts upon word reading accuracy (Castles & Coltheart, 2004; Castles et al., 2018; Melby-Lervåg et al., 2012).

***Minimal levels of orienting attention*.** The second group of children attaining spatial cue benefits were those who engaged in what might be referred to as *minimal* levels of orienting. Like maximum levels of orienting, as described in the previous paragraphs, it is not entirely clear where this minimal orienting region lies. However, the present evidence suggest that, in comparison with maximum level orienting, smaller auditory (early stage readers) and visual (later stage readers) spatial cue benefits are related to better (generally within the average range) phonological processing. According to the Load Theory of Attention, efficient task completion hinges upon adequate access to attentional resources (Lavie et al., 2014; Lavie et al., 2004). As a reminder, spatial cues facilitate focusing on a specific location. However, if fixation time is not regulated, then valuable information for task completion will be missed. Furthermore, the more fixation time spent on specific phonological units, the more resources are being utilised to process those units. In view of this, the current results suggest that if attention is overworked, its capacity may be reduced. In reading, the overworking of attention may be a consequence of a constant fixation on a specific phoneme (i.e., letter sound), thus leading to insufficient resources to efficiently orient to and access additional phonological information for other task relevant processes and comprehension (Broadbent, 1958; Kahneman, 1973; Moray, 1967).

An absent level of the orienting effect. Finally, the third group of children comprise participants who showed no significant orienting effect. That is, they responded faster to central cue (central attention) compared with spatial cue (spatial attention) conditions. Note however, that, if the orienting effect is weak, then chance factors (e.g., noise) may determine whether spatial cues are faster than central cues or vice versa. So, it is not clear that a faster RT for central cues is a meaningful result. Nevertheless, the interesting finding for participants at this level of the continuum is, that, generally, they tended to attain phonological processing accuracy scores that fell within the above average to very superior range. This finding fits well with the early attention literature examining the conditions under which the orienting response is present or absent. For example, the orienting response is generated when novel stimuli are presented; the response is reduced or even disappears when one becomes habituated to stimuli or expects the stimuli (Maltzman & Raskin, 1965; Unger, 1964; Zimny et al., 1969). As Sokolov (1963) previously showed, this expectation effect is indexed by a reduction in the orienting response. The concepts from these early works offer a lens to explain the current finding of why children who do not show an orienting effect are those who tend to obtain higher phonological processing scores and, in turn, higher reading accuracy scores (Ashby, 2010; Brady & Shankweiler, 2013; Gillon, 2018). That is, these *non-orienters* seemingly spend less time orienting to specific phonological units, perhaps because these units have become so familiar. Such familiarity or habituation, as Sokolov previously argued, serve an optimal function, such that attention resources are freed to be directed to more important tasks.

A preliminary hypothesis of the reading process when the orienting effect is absent is that incoming sensory information (e.g., phonological information) arrives at a mental lexicon, at which point it is matched to previously stored information (Aitchison, 2012; Taft, 2013). Preliminary analysis of this information either (a) enables the allocation of resources for further analysis, in the case of unfamiliar phonological information, thereby eliciting an orienting effect; or (b) bypasses a detailed analysis for habituated phonological information, which is characterised by a reduction or absence of an orienting effect. If pathway *a* is adopted by the reader, more attention is required to determine these stimuli, thus reducing the amount of available resources, resulting in lower phonological processing and reduced quality of reading responses. Concurrently, there is also a pause in the ongoing activity of word recognition to deal with the analysis of unfamiliar stimuli. The opposite however, is speculated if pathway *b* is adopted, with faster selection of responses and higher reading accuracy. Note, however, that this hypothesis does not imply that a period of orienting is not necessary for accurate phonological processing. In fact, it is likely that the first stage of becoming habituated to a stimulus, and in this case, phonological information, occurs through an active orienting mechanism. This view is supported by the concept of obligatory looking (Posner & Rothbart, 2007), which explains that a period of necessary fixation is required to accurately discriminate among relevant information. In the case of reading and reading acquisition, this relevant information refers to letter forms (obligatory looking) and letter sounds (*obligatory hearing*). It is therefore predicted that this obligatory period occurs during minimal levels of orienting, since there are significant spatial cue benefits at this level, but not to a marked detriment upon phonological processing and reading, as in the maximum orienting condition.

Overall, the cross-sectional findings indicate that, at both early and later stages of reading, an efficient orienting attention network provides an optimal environment for more accurate phonological processing. There was, however, a distinction between groups in orienting attention modality, with auditory orienting being more significant for early stage readers, whereas visual orienting was more significant for later stage readers. Finally, and more critically, was the finding that less orienting of attention was related to more accurate phonological processing and more accurate reading. Together, the findings of Study 1 suggest that during the process of reading, an efficient orienting attention system is likely to provide sufficient resources for the reader to consistently refresh phonemes and graphemes during the reading task, which in turn strengthens the representation of phonological and lexical information (Facoetti, Trussardi, et al., 2010; Fukuda et al., 2015; Matsukura & Vecera, 2015; Raye et al., 2007). These findings, though valuable, are limited. That is, cross-sectional approaches do not confirm if orienting attention precedes reading in time, and if this relationship is still mediated through phonological processing. Although cross-sectional designs, as used in Study 1, are useful for identifying relationships between different variables at a specific point in time, longitudinal studies are more valuable for confirming the interaction between variables across time (Cole & Maxwell, 2003; Kenny, 1979). Consequently, the findings of Study 2, which are reported in the next section, provide a more detailed understanding of the stability of the relationship between visual and auditory attention networks, phonological processing, and reading in early versus later stage readers.

The Stability in the Relationship between Visual and Auditory Attention Networks, Phonological Processing, and Reading in Early and Later Stage Typically Developing Readers: A Longitudinal View

In Study 2, it was hypothesised that, for early stage readers, phonological processing at Time 1 (T1) would mediate the relationship between attention at T1 and reading at Time 2 (T2). However, for later stage readers, the direct influence of attention at T1 would be a stronger predictor of reading at T2, in comparison with the indirect path through T1 phonological processing. Unlike the cross-sectional results, Study 2 found a significant impact of attention and phonological processing upon both reading accuracy and reading speed. Thus, this section will present the findings firstly for reading accuracy followed by reading speed.

Early stage readers adopt a mediated pathway to subsequent reading accuracy. The longitudinal data supported the hypothesis that in the early stages of reading, attention is related to subsequent reading accuracy through its impact upon phonological processing. The nature and pattern of this relationship (i.e., T1 auditory orienting → T1 phonological processing → T2 reading accuracy) replicated the cross-sectional results of Study 1 for early stage readers. As well, the pattern of this relationship, involving a mediated effect of phonological processing, supports previous longitudinal research using subjective measures of attention. For example, teacher reports of inattention and phonological processing skills in kindergarten have been found to predict subsequent reading in Grade 2 above and beyond maternal education (Dally, 2006; Dice & Schwanenflugel, 2012; Walcott et al., 2010). Moreover, like the cross-sectional results in Study 1, the longitudinal study replicated the finding that while visual (orienting) attention did not significantly predict subsequent reading accuracy through phonological processing (p = .11), the size of the indirect effect was large (.28), suggesting that it may be meaningful. This finding further implies that a visually driven cognitive route to lexical access through phonological processing may be associated with a reading stage that was still not entirely attained by early stage readers at T2.

Later stage readers adopt both a mediated and unmediated pathway to subsequent reading accuracy, based on attention modality. Most strikingly, there were two important differences between the present cross sectional and longitudinal findings for later stage readers. Firstly, in contrast with the cross-sectional findings of Study 1, the longitudinal data of Study 2 supported the hypothesis that the indirect pathway between attention and phonological processing would be reduced, in favour of a more direct pathway between attention and reading. However, this direct pathway was observed for auditory (orienting) but not visual attention.[19] Secondly, in addition to visual orienting, as observed in Study 1, visual executive attention was also found to be meaningful for subsequent reading accuracy through phonological processing. Given that these findings extend the results of Study 1 for later stage readers, the remainder of this section will firstly advance a potential explanation of how auditory orienting, visual orienting, and visual executive attention might work in tandem to achieve subsequent reading accuracy in later stage reading. Then, possible reasons for the observed pathway differences between visual and auditory attention for later stage readers will be examined.

Visual and auditory orienting attention locate information, while visual executive attention filters information to achieve reading accuracy. During reading, auditory orienting might be used to directly access the spatial location of lexical information, while visual orienting is also likely to be recruited to access the same information but through phonological processing. Then, consistent with early filter theories of attention, visual executive attention serves as a bottleneck to ensure that only the most important information is semantically processed (Broadbent, 1958). Moreover, in line with later filter attention theories, since multiple representations (i.e., phonological and lexical) are processed during reading, attention is required for focus (Deutsch & Deutsch, 1963; Prinz, 2012; Wu, 2011). For example, in the current study, a mixed list of different word types was presented in the reading accuracy task. Therefore, the finding that visual executive attention is related to

[19] Although the mediated and direct pathways were not significant for visual orienting, the total effect (i.e., sum of indirect and direct pathways) was significant (-0.27, p = .03). The estimate for the indirect pathway (-0.29, p = .30) between visual orienting and reading accuracy via phonological processing was larger, compared with the estimate of the direct pathway (0.02, p = .95). There was a similar finding for visual executive attention, with a significant total effect (0.34, p = .01), but insignificant indirect (0.46, p = .21) and direct (-0.12, p = .75) effects. The non-significance of the indirect and direct effect suggests that the data were unable to provide a precise estimate that was distinguishable from zero. However, this does not imply that there are zero effects. In such cases, it is advised to first examine the parameter estimates and determine the precision of these estimates based on the standard errors or the 95% confidence intervals. Then, the focus should be on what can be deduced about the estimate, considering the value of the parameter estimations (Schechter, 2017).

reading accuracy suggests that at T2, reading was heavily guided by an internal task switching parameter that regulates word recognition. This task switching ability is a feature of executive control (Besner et al., 2016).

Additionally, the roles of orienting and executive attention networks can be considered from the lens of the feature integration theory (Treisman, 2006; Treisman & Gelade, 1980). According to this theory, during reading, different features of letters are activated. To ensure that these features are correctly bound, they are relocated to a specific window that functions as a spotlight of attention. The task of the reader is to accurately bind these features together, which is achieved by an efficient orienting attention system. As information is being bound, the executive attention network ensures that any unselected information is excluded from processing. Finally, orienting attention then serially processes the information, which is then localised and identified. However, the ordering of these processes, as explained here, is purely theoretical and will need further research to confirm this possibility.

Attention modality clarifies the debate on how reading pathways are adopted by later stage readers. As a reminder, the longitudinal findings of Study 2 showed that while the indirect effects of visual orienting (negative) and visual executive (positive) upon reading accuracy through phonological processing were not statistically significant, their effect sizes were large. More critically, the importance of the indirect pathway in the relationship between visual orienting attention and reading accuracy replicates the finding of the cross-sectional data in Study 1. This implies that the visual attention network relies upon phonological processing to accomplish reading accuracy for later stage readers. In contrast, there was a direct, positive relationship between auditory orienting and reading accuracy, suggesting that greater levels of auditory orienting are subsequently related to more accurate reading. But, why does the auditory orienting network for later stage readers use a direct route to reading accuracy, yet their visual (orienting and executive) attention networks continue to adopt an indirect route?

It might be that adopting an indirect route involving two auditory based systems (i.e., auditory orienting and phonological) could be inhibitory for reading accuracy, since the scanning processes for auditory orienting attention might have become more advanced for the later stage readers in Study 2. This maturity permits a more direct recognition of words (LaBerge & Samuels, 1974; Posner & Rothbart, 2007). Moreover, that reading among later stage readers requires lexical restructuring, the development of orthographic coding skills at this stage of reading will perhaps depend more upon efficient auditory, rather than visual, attention mechanisms. Recent fMRI longitudinal data supports this interpretation showing a developmental change in the importance of the dorsal (decoding pathway) and ventral connectivity over time (Wise Younger et al., 2017). Similarly, previous behavioural data suggest that more fluent readers rely on a lexical (unmediated) rather than a sub-lexical (mediated) route to reading (Henderson, 2018). However, conclusions about which route is adopted by later stage readers is still largely debated and have remained equivocal, thus leading researchers to favour the view that the selection of which pathway is used depends on different factors such as word type or reading ability (Castles et al., 2018; Leinenger, 2014).

The longitudinal findings of Study 2 have provided some reconciliation for this debate. That is, given the distinction in reading pathways based on visual (i.e., indirect) and auditory (i.e., direct) attention, the present findings suggest that attention modality could distinguish how reading pathways are used by later stage readers. Moreover, this modality distinction further implies that reading accuracy at more fluent stages is likely to continue to be dependent on individual differences in phonological processing for visual, but not auditory attention. Support for this interpretation comes from EMG data demonstrating that later stage readers continue to sub-vocalise during reading (Sokolov, 1963). Similarly, brain activity data also show that although decoding is important during early reading, it remains important throughout adulthood (Church et al., 2008; Rayner et al., 2012; Turkeltaub et al., 2003). Thus, while more advanced readers rely less on phonological processing (for auditory attention), the transformation of visual to auditory information does not entirely disappear and sub-vocalisation may depend on attention modality, with a continued mediated access to word recognition through phonological information for the visual (orienting and executive) attention networks (Perfetti, 2013).

The view that pathway differences are based on attention modality is also consistent with specific elements of LaBerge and Samuel's (1974) model of information processing. This model proposed that the association between (visual) attention and the phonological system functions in two distinct ways. The first is that the relationship between the two systems is based on automatised visual units (unmediated access); the second is based on two systems that are not yet well learnt, and therefore require additional activations (mediated access). The findings of the current longitudinal study support this proposition, but also extend this model by including the auditory modality as well as showing that reading is not as automatic as previously proposed (Augustinova & Ferrand, 2014; LaBerge & Samuels, 1974). At T2 data collection (longitudinal study), perhaps the relationship between the visual attention and phonological system was not yet well learnt, hence the finding of a relationship between visual (orienting and executive) attention and reading accuracy through phonological processing. In contrast, that auditory attention was directly related to reading is likely to reflect a relationship that have become more efficient. That is, an efficient attention system is likely to detect words more easily, demands less analysis upon encountering words, and demands less cognitive resources. Therefore, a direct route taken by later stage readers reflects the view that the auditory orienting attention system has become more efficient in the scanning and selection of information (Posner & Rothbart, 2007; Treisman, 1969). This strategy is likely to conserve attentional resources to facilitate more efficient and, therefore, more accurate reading performance. Alternatively, the continued importance of phonological processing for the visual orienting and executive networks reflects a dual mechanism that clarifies responses that have been selected by the direct route of auditory attention. Thus, as previously explained for the cross-sectional results, the mediated access by visual attention might reflect greater control over eye movements, leading to a shift in orthographic knowledge, involving a tight orthographic-to-phonological unitisation (Frith, 1985; Van Orden, 1987). Together, a dual activation of both reading pathways based on attention modality might therefore be a hallmark of more advanced reading. More research is however needed to distinguish between these possibilities.

Finally, the pathway difference based on attention modality for later stage readers was clearly articulated by the longitudinal, but not in the cross-sectional data. It should however be noted that, in the cross-sectional data, there was a significant total effect of auditory orienting on reading accuracy in later stage readers, suggesting a relationship between these variables. However, the nature of this effect could not be confirmed from the cross-sectional data, given the small effects sizes of the effects that comprise the total effect. Furthermore, the cross-sectional data for later stage readers were recorded while they were in Years 4 and 5, whereas the longitudinal data were recorded while participants graduated to Years 5 and 6, respectively, indicating a sequential shift in any reliance that auditory orienting has on phonological processing (Wise Younger et al., 2017). Therefore, the longitudinal findings suggest a developmental progression, such that, the unmediated pathway between auditory orienting and reading accuracy (while controlling for phonological processing) may only be observed at more advanced stages of reading, as captured by the longitudinal data of Study 2.

***A strategic interaction between alerting and executive attention for later stage readers*.** In the longitudinal results**,** there was a positive interaction between (visual and auditory) alerting and visual executive (higher executive scores represent less efficiency), suggesting that higher levels of alertness is related to a reduced ability to inhibit irrelevant visual information (Callejas et al., 2004; Pozuelos et al., 2014; Weinbach & Henik, 2011, 2012, 2013). This interaction is important given the present finding in later stage readers that the association between visual executive and subsequent reading accuracy through phonological processing was positive and qualitatively meaningful. Therefore, higher visual executive scores are likely to be related to better phonological processing, and in turn more accurate reading. Intuitively, this seems unusual, as higher visual executive scores represent a reduced ability to inhibit distracting information. But, previous studies have argued that alerting cues (which interacted significantly with visual executive attention in the current study) oftentimes activate two simultaneous processes – one is inhibitory and the other, strategic (Coull & Nobre, 1998; Weinbach & Henik, 2013). Regarding the inhibitory effect of alerting cues, previous studies examining the relationship between (visual and auditory) alerting and visual executive attention have generally found that the presentation of an alerting cue produces a global processing bias for visual stimuli (Callejas et al., 2004; Macleod et al., 2010; Pozuelos et al., 2014). A global bias increases the congruency effect, which is associated with a reduced capacity of the executive attention network to efficiently process relevant information.

In contrast, the strategic use of alerting cues, generally resulting from temporal expectancy of a stimulus (associated with a fixed ISIs or fore period), has been found to reduce this congruency effect. Temporal expectancy is associated with the ability to focus attention upon precise moments in time following the presentation of alerting cues (Coull & Nobre, 1998). In a very important study, Weinbach and Henik (2013) showed that at a longer fore period, there was a reduction in RT following an auditory alerting cue, and the usual inhibitory effect on congruency was absent. In view of this, the positive relationship between visual executive and phonological processing in the current study suggests that alerting cues might have had a beneficial, rather than an inhibitory, impact upon executive network efficiency. This is even more likely since the ANTs in the current study facilitated temporary expectancy of the alerting cues (i.e., both the conditions for measuring the visual and auditory alerting effect had fixed ISIs and the auditory alerting effect was measured using a long ISI of 750 ms), which is associated with a more strategic usage of alerting cues (Coull & Nobre, 1998). Altogether, these findings suggest a strategic role for alerting cues in influencing executive attention. In turn, the executive attention network helps later stage readers to better distinguish and process phonological information more accurately, which in turn increases reading accuracy.

Early and later stage readers adopt a mediated pathway via phonological processing to reading speed, but this pathway differs based on attention modality. As a reminder, the longitudinal, but not the cross-sectional data, showed that during the early stages of reading, phonological processing mediated the relationship between auditory orienting and reading speed. In contrast, during the later stages of reading, visual orienting was related to reading speed through phonological processing. In both cases, larger orienting scores were related to lower phonological processing scores and in turn, slower reading speed. Consistent with previous research, RAN skills explained the majority of the variance in the relationship between phonological processing and reading speed for both reading stages (Cardoso-Martins & Pennington, 2004; Katzir et al., 2008). However, most reading fluency studies using a developmental approach explain that the phonological processes required for fluency differ based on reading stage. For example, it has been shown that phonological awareness is a unique predictor of early reading, even after controlling for phonological memory and RAN (Brady & Shankweiler, 2013; Melby-Lervåg et al., 2012). But, there is a developmentally changing role of phonological processing with reading proficiency, such that RAN begins to predict reading fluency at more fluent stages of reading (Kirby et al., 2003; Wolf & Bowers, 1999). Yet, other researchers have found that as reading becomes more proficient, the RAN-word reading relationship decreases (Protopapas et al., 2013; Rodríguez et al., 2015).

The results of the present longitudinal study offer a different perspective. That is, in addition to confirming the important role of phonological processing, especially RAN, to subsequent reading speed at both early and later stages of reading, attention modality was found to differ based on reading stage. It is this difference, in the interaction primarily with RAN, which might distinguish between less and more advanced patterns of reading fluency. Moreover, the findings of the present study suggest that the relationship between phonological processing and reading fluency is present because both are tapped by a global construct (Kirby et al., 2003; Landerl & Wimmer, 2008; Norton & Wolf, 2012). This global construct, according to the results, is the orienting of attention, which determines the efficiency of accessing phonological information. Together, the modality differences suggest that early stage readers may rely more upon an *auditory driven* (auditory attention*)* cognitive route to word reading speed through phonological processing, whereas, later stage readers may adopt a *visually driven* (visual attention) cognitive route. However, more research is needed to validate the presence of and distinction between these two cognitive routes.

Summary of the Cross-Sectional and Longitudinal Findings

Altogether, the cross-sectional and longitudinal findings of Studies 1 and 2, respectively, suggest that both auditory and visual orienting attention networks play an important role for reading accuracy and reading speed in typically developing readers (Facoetti, Trussardi, et al., 2010). In addition, visual executive attention eventually becomes significant for reading accuracy at more advanced stages of reading (Besner et al., 2016; Reynolds & Besner, 2006). The findings also provide behavioural evidence of how the relationship between attention, phonological processing, and reading accuracy changes with reading stage, with later stage readers eventually adopting an unmediated route to reading (accuracy). However, the route that is used by later stage readers differs based on attention modality. That is, auditory orienting adopts an unmediated, direct route to reading accuracy, while visual orienting and visual executive attention adopt a mediated, indirect route through phonological processing. These findings are therefore not compatible with a strict dorsal-to-ventral shift view, which explains that as reading stage matures, there is an overall increase in the occipital-temporal connections, with less reliance on phonological information (Sandak et al., 2004; Wise Younger et al., 2017).

Altogether, the hypothesis that in early stage readers, phonological processing would mediate the relationship between (auditory) attention and reading was supported. In contrast, the hypothesis that in later stage readers, the mediated pathway would diminish and the direct pathway from (visual) attention to reading would be strengthened was partially supported. That is, the results showed that there is likely to be an activation of both indirect and direct routes as reading becomes more advanced. Despite the value of these findings to understanding the attentional processes involved in typically developing reading, it is still unknown precisely how the interaction between attention, phonological processing, and reading operates in children with DD. Therefore, the final study of the current research aimed to clarify this relationship through a quasi-experimental approach.

Examining the Relationship between Visual and Auditory Attention Networks, Phonological Processing, and Reading in Children with DD: A Quasi-Experimental View

In quasi-experimental studies, it is often concluded that any difference between the control and experimental group demonstrates that the skill being measured by the experimental task potentially causes the reading difficulty (Eden et al., 2015; Goswami, 2015; Goswami & Bryant, 1989; Jackson & Butterfield, 1989). Therefore, there are two likely outcomes from the current quasi-experimental design: (a) either children with DD (aged 9 to 10 years) perform significantly different to either RA (aged 6 to 7 years, similar to the early stage readers in Study 1) or CA (aged 9 to 10 years, similar to the later stage readers in Study 1) matched controls on measures that are hypothesised as being related to reading; or (b) no significant group differences exist (Eden et al., 2015). In view of this, Study 3 had two aims. The first aim was to examine group differences in the relationship between attention networks, phonological processing, and reading in children with DD compared with their RA and CA matched controls. The second aim was to determine if there was a group difference in the modality of attention that influences reading (via phonological processing or directly) between children with DD and their (RA and CA) matched controls.

It was predicted that the strength and modality of the hypothesised mediation pathway would vary as a function of group. For RA matched controls, a mediated relationship between auditory attention and reading via phonological processing was expected. However, for CA matched controls, an unmediated relationship between visual attention and reading was expected. It was further predicted that children with DD would present with a similar pattern of mediation as their RA matched controls, although, it was expected that they would perform less efficiently on measures of attention, and more poorly on measures of phonological processing and reading. As well, it was hypothesised that for children with DD, auditory attention would be more significant for reading compared with visual attention. In the subsequent sections, findings that partially support these predictions will be presented, firstly by comparing children with DD with their RA matched controls, and then with their CA matched controls. Then, a final section will present evidence of potential differences between children with DD and their matched controls in the number of attention network interactions and the number of routes to reading accuracy. It should be noted that there were no significant or meaningful relationships between attention, phonological processing, and reading speed in the quasi-experimental study.[20] Therefore, the discussion of reading in the context of the quasi-experimental results refers only to reading accuracy, unless otherwise specified.

RA matched controls and children with DD. Like the pattern of mediation for RA matched controls, a significant, negative, indirect relationship was identified between auditory orienting and reading accuracy through phonological processing for children with DD. This suggest that, in children with DD, as auditory orienting increases, phonological processing decreases, and in turn, there is lower reading accuracy. The nature of this relationship (i.e., an inhibitory effect of larger orienting upon phonological processing) replicates the findings observed in Studies 1 and 2 in typically developing early stage readers. Furthermore, although there were significant group differences in phonological processing scores, the efficiency of auditory orienting attention processes did not significantly differ between the RA matched controls and children with DD. Therefore, the hypotheses of Study 3 were partially supported.

Phonological processing differences imply a developmental deficit rather than a developmental lag for children with DD. Consistent with previous research, significant group differences in the phonological processing (phonological

[20] There was a significant direct effect of auditory alerting upon reading speed for RA matched controls and children with DD. Note, however, that ascribing significance to this relationship is approached with caution given that the ANOVA results of Study 3 showed no auditory alerting effect for both groups.

awareness) task were identified, in which children with DD performed significantly poorer than their RA matched controls, thus leading to significantly poorer reading accuracy (Eden et al., 2015; Gillon, 2018). This finding is consistent with the well-documented literature that phonological skills are poorer in children with DD and less skilled readers (Castles & Friedmann, 2014; Caylak, 2010; Szenkovits & Ramus, 2005). For example, it has been found that readers with difficulty were worse at recognising phonological oddities compared with their RA matched controls (Bowey et al., 1992). Furthermore, readers with DD have previously shown difficulty in the matching of printed nonsense words to the spoken word or in the reading of nonsense words, compared to their RA matched controls (Brady & Shankweiler, 2013; Vellutino & Scanlon, 1989). These findings align with the broad idea that phonological skills play a key role in reading accuracy (see Castles et al., 2018 for extensive review).

Moreover, given the significant differences in phonological awareness, the present findings do not align with the developmental lag hypothesis that children with DD are progressing through the same developmental stages as their typically developing RA peers, but at a slower rate (Kuppen & Goswami, 2016; Stanovich et al., 1988). Instead, the significantly lower phonological awareness skills for children with DD align with the developmental deficit hypothesis, that there is a qualitative difference in the phonological processes that are related to reading (Francis et al., 1996; Ramus, 2014; Valdois et al., 2004).

An absence of auditory orienting differences does not imply efficient auditory orienting processes in children with DD. In contrast to significant group differences for phonological awareness, no significant group differences between children with DD and their RA matched controls were identified for auditory orienting network efficiency. This is inconsistent with previous work showing that, compared to their matched controls, children with DD are deficit in their ability to accurately and efficiently use auditory spatial cues to improve performance (Asbjørnsen & Bryden, 1998; Facoetti et al., 2003; Facoetti, Trussardi, et al., 2010). Instead, the present findings align with White et al. (2006), who failed to identify any auditory deficits among children between the ages of 8 and 12 years with dyslexia. Together, these findings would suggest that an inefficient auditory attention system is not likely a potential explanation of reading difficulties. However, caution should be taken in the interpretation of the results from the study by White and colleagues, because participants described as having dyslexia scored within a normal range on phonological and reading tests, whereas the control group scored above average. In addition to this, the auditory tasks that they used were initially designed to be administered to adults. These tasks were not modified for use among children, and were therefore quite difficult, even for the control group (Menghini et al., 2010; Tallal, 2006). Nevertheless, several other studies using a representative sample of people with DD, as well as reliable auditory attention tests, have confirmed the absence of deficits in auditory processes among children with DD (Ramus et al., 2003; Rosen, 2003; Wright et al., 1997), although there is still no consensus regarding the nature of the auditory processing deficits (Witton & Talcott, 2018).

Despite the finding in the current study that auditory orienting attention efficiency was not significantly different across the RA matched controls and children with DD, it has been argued that tasks which do not produce group differences cannot be unequivocally discarded as a potential source of the reading failure (Goswami & Bryant, 1989). For example, although both groups have similar reading ages, children with DD might have better metacognitive skills and executive functioning (Jackson & Butterfield, 1989). Moreover, being older, their perceptual-motor responses may not be matched which could affect RT. Better regulation of these skills enable readers to have more efficient metacognitive strategies, which helps with self-monitoring (Alvarez & Emory, 2006; Bryce et al., 2015; Carver & Scheier, 2012). These skills might therefore mask any genuine group differences in auditory orienting efficiency. But, this is unlikely, since the RA matched controls in the current study had significantly better executive functioning compared to children with DD. However a key argument for not discounting poorer auditory orienting efficiency as a potential cause of reading failure emerges from a comparison of auditory orienting patterns between children with DD and their CA matched controls in the current study (Goswami & Bryant, 1989; Jackson & Butterfield, 1989).

CA matched controls and children with DD. Interestingly, the findings of Study 3 showed significant differences in auditory orienting efficiency between CA matched controls and children with DD, with the latter group performing significantly poorer. But, it has also been advised that the presence of group differences in CA matched designs should be cautiously interpreted, because differences in other processes (e.g., metacognitive skills) contribute to differences in cognitive skills (Jackson & Butterfield, 1989). Thus, the failure to completely control for metacognition across groups might have accounted for the observed differences, rather than a genuine group difference in auditory orienting efficiency (Goswami & Bryant, 1989; Jackson & Butterfield, 1989). Evidence for this possibility in a previous study was identified when children with DD and their CA matched controls were matched on memory skills and then administered a phonological confusability task (Johnston et al., 1987). The authors found that both groups demonstrated similar facilitation effects for remembering phonological dissimilar items, a finding that contrasts with the previously found reduced facilitation effects in children with DD (Liberman et al., 1977). Similarly, in the current study, it is possible that the significantly poorer executive functioning of children with DD compared with their CA matched controls is responsible for the observed group differences in auditory orienting, as well as, in phonological processing and reading accuracy. The influence of executive functioning is even more likely, since there was also a marginally significant, positive relationship between auditory orienting and executive functioning for children with DD. That is, higher auditory orienting was related to increased executive functioning scores (higher executive functioning scores indicate poorer executive functioning). However, given that this effect was small (r = .25), and that executive functioning was not significantly related to phonological processing or reading accuracy for children with DD, the impact of executive functioning is likely to be negligible. Furthermore, children with DD and CA matched controls in the present study were matched on IQ, thus controlling for any further potential differences in metacognitive skills (Campbell & Stanley, 2015).

Against this background, and given the consistent relationship between the auditory orienting network and reading accuracy (across all studies in the current thesis), the efficiency of this network is likely to be an important component of reading, and more broadly, a potential cause of reading failure (Facoetti et al., 2003; Facoetti, Trussardi, et al., 2010). Therefore, the significant group difference between CA matched controls and children with DD in auditory orienting efficiency suggests that older, CA matched controls are more efficient at deploying their cognitive resources when using auditory spatial cues during reading. This does not imply that children with DD are unable to use auditory spatial cues to benefit information processing. In fact, the results of the current study argue otherwise (c.f. Asbjørnsen & Bryden, 1998; Facoetti et al., 2003). However, the significant cue by congruency interaction in the auditory attention task for children with DD (not observed in either

RA or CA matched controls), suggests an over-reliance on these auditory spatial cues. This possibility is addressed later in greater detail in the section examining attention network interactions in children with DD. But, for now, it is sufficient to propose that an over-reliance upon spatial cues might contribute to poorer auditory orienting network efficiency for children with DD, because it has adverse effects upon the rapid shifting of attention between different sounds for accurate discrimination. A rapid shifting of attention, as well as an accurate discrimination of information, is needed for more accurate reading (Tallal, 1980).

The pathway between visual orienting and reading accuracy is unmediated for children with DD, but mediated for CA matched controls. Study 3 results further showed that for CA matched controls, the relationship between visual orienting and reading accuracy was mediated by phonological processing. This replicated the findings of Study 1, as well as the pattern of results from Study 2 for later stage readers, indicating that when visual orienting attention is involved, there is a fundamental role of phonological processing to reading accuracy (Grainger et al., 2012; Melby-Lervåg et al., 2012).

In contrast, for children with DD, there was a marginally significant, direct, positive relationship between visual orienting and reading accuracy (p = .07). This direct route is likely to reflect a method of compensating for poor or degraded phonological representations in children with DD (Boada & Pennington, 2006). That is, stronger visual perception skills, including mechanisms of visual attention, might compensate to some extent for difficulties in learning letter to sound rules arising from a phonological deficit (Rayner et al., 2012). These perceptual skills appear to be related to reading independently of level of phonological processing skill in children with DD, in line with the findings of previous researchers (Bosse et al., 2007; Facoetti et al., 2000; Vidyasagar & Pammer, 2010).[21]

However, Fowler (1978) explained that while a direct route to reading is primarily efficient, it can be cognitively demanding because of the need to remember a large database of information. The attention demanding nature of continuously using the direct route to reading is thus likely to deplete attention resources, which

[21] The difference in mediation patterns between children with DD and CA matched controls is not the result of the difference in phonological skills used for each group. That is, when RAN was used to represent the phonological processing construct for children with DD, the indirect (0.05, p = .52), direct (0.16, p = .27) and total (0.21, p =.19) effects for the relationship between visual orienting, phonological processing, and reading was still not significant, with a small effect size for the indirect effect.

then, requires children with DD to recruit additional resources from elsewhere. But, when the information processing system is divided across multiple functions (e.g., in the process of recruiting additional resources), attention resources are likely to be further exhausted, and phonological or orthographic representations, or both, are identified, but integrated inaccurately, therefore lowering reading accuracy (Fallon et al., 2018; Mitko et al., 2015; Treisman & Schmidt, 1982). Thus, although visual orienting efficiency in children with DD was not atypical to controls in the present study, whether the direct pathway between visual orienting and reading accuracy represents a compensatory route for a resource deprived system or whether it in fact continues to deplete attention resources in children with DD, will need to be further examined.

Differences in attention network interactions and attention network routes distinguish between typically developing and disordered readers. In contrast with their RA and CA matched controls, children with DD relied on multiple routes to accomplish reading accuracy. That is, in addition to using auditory orienting (like their RA matched controls) and visual orienting (similar to their CA matched controls, although the pattern of mediation was different), children with DD also relied on the visual alerting (direct route to reading) and auditory executive (indirect route through phonological processing) attention networks for reading accuracy. In addition, there were significant attention network interactions involving these multiple routes for children with DD, a finding that was also not observed in the matched control groups. Therefore, in this final section, these different attention network interactions, which are likely to influence the observed multiple routes to reading for children with DD, will be examined, in relation to their reading difficulties.

An antagonistic interaction between visual alerting and visual orienting attention in children with DD. There was a significant, negative relationship between visual alerting and visual orienting, suggesting that a higher level of alertness is related to a reduced capacity to use visual spatial cues. This correlation is important given the finding in the present study that, in children with DD, there was a marginally significant direct, positive relationship between visual orienting and reading accuracy, as well as significant relationship between visual alerting and reading accuracy. The direct benefits of visual orienting and visual alerting upon strengths in reading accuracy in children with DD (but absent in controls), reflect the view that reading is constrained by deficits in phonological processing in children with DD (Castles & Friedmann, 2014). Moreover, this correlation between visual alerting and visual orienting for children with DD further informs us about why the reading route involving visual attention potentially differs from typically developing (CA) matched controls who adopt an indirect route to reading via phonological processing.

Previous work on the interaction between alerting and orienting in adults with dyslexia have described this association as antagonistic (Goldfarb & Shaul, 2013). Whereas the alerting network is responsible for processing global information, the orienting network is responsible for processing local information (Flevaris et al., 2010; Goldfarb & Shaul, 2013; Lamb et al., 1989). Consequently, an increase in visual alertness (global processing) decreases the ability of the visual orienting network to access local information (e.g., phonological information), since both networks cannot be activated simultaneously. Hence, in the current study, although the visual alerting and visual orienting effects of children with DD were not atypical relative to controls, their interaction might be antagonistic thus giving rise to an atypical pattern in the relationship between visual orienting, phonological processing, and reading accuracy for children with DD (i.e., a direct route between visual orienting and reading accuracy instead of a mediated route as observed in typically developing readers). Then, because an over-reliance on this direct route to reading is likely to reduce attention resources (Fowler, 1978), the route between visual alerting and reading accuracy also observed in children with DD (but not observed in RA or CA matched controls) might be recruited to compensate for resource exhaustion.

An antagonistic interaction between auditory alerting and auditory executive attention networks in children with DD. There was also a significant, positive relationship between auditory alerting and auditory executive attention in children with DD, suggesting that a higher level of alertness is related to a reduced capacity to inhibit irrelevant auditory information (higher executive attention scores denote poorer efficiency). This correlation is important given the finding in the present study that for children with DD, there was a negative, indirect effect of auditory executive attention upon reading accuracy through phonological processing (phonological awareness). Although auditory alerting has been previously found to increase speed in attentional shifts, which enhances focusing of attention (e.g., Callejas et al., 2004; Fuentes & Campoy, 2008; Pozuelos et al., 2014), high alertness levels could be detrimental when it influences the relationship between auditory executive attention and phonological processing. Consequently, less efficient auditory executive attention does not provide adequate opportunity for relevant phonological information to be processed with high levels of precision which in turn results in lower reading accuracy. Moreover, given that higher alerting attention is associated with a bias for processing global information (e.g., Weinbach & Henik, 2011; Weinbach & Henik, 2012, 2013), the relationship between auditory alerting and auditory executive attention could further indicate that an inefficiency in the auditory alerting system in children with DD limits their ability to engage with local, relevant information (e.g., phonological cues provided by words) that would normally facilitate higher reading accuracy (Melby-Lervåg et al., 2012). However, it is important to note that there was not a genuine auditory alerting effect (i.e., no significant RT benefit to processing when provided with an auditory warning cue) for children with DD, therefore, any effect of auditory alerting should be interpreted with caution.

Nevertheless, it is important to note that the finding of a detrimental impact of higher auditory executive attention scores upon phonological processing and reading in the present study for children with DD is consistent with previous research. That is, children with DD who show a larger impact of conflict when listening to sounds have weaker phonological processing (phonological awareness) and this leads to poorer reading (Cao et al., 2006). Moreover, in the current study, that the auditory executive effect of children with DD was not atypical relative to their matched controls, indicates that strengths in the auditory executive network (a reduced effect of conflict) serves as a protective factor in children who are otherwise at risk of phonological processing deficits. But, this protective factor does not directly benefit reading accuracy, given its interaction with phonological processing. Moreover, that the pattern for a similar relationship for the visual executive attention effect was absent suggests that the influence of the auditory executive attention effect upon phonological processing in DD is not shared with the visual executive attention effect. Therefore, auditory executive attention may be a modality specific factor, in spite of the auditory and visual executive attention effects being correlated in DD (Gomes, Wolfson, et al., 2007).

Visual orienting cues provide facilitatory effects for the auditory executive attention network. There was a marginally significant, negative relationship between visual orienting and auditory executive attention in children with DD, suggesting that a higher usage of visual orienting cues helped rather than hindered the inhibition of irrelevant auditory information. This correlation is important given the finding in the present study that, in children with DD, there was a significant, indirect, negative relationship between auditory executive attention and reading accuracy. Previous research on the interaction between orienting and executive attention have consistently observed a facilitatory effect of visual spatial cues on conflict processing (see review by Macleod et al., 2010). The findings of the present study align with this view, suggesting that higher attentional focus in advance does seem to confer an advantage upon filtering irrelevant auditory information during word recognition. It could be that greater usage of or reliance upon visual orienting cues improves focusing of attention, leading to improvements in perceptual discrimination by the auditory executive attention network, and in turn, increases word recognition accuracy (MacLean et al., 2010).

Cue by congruency interaction in auditory attention. Finally, the cue by congruency interaction observed for children with DD in the auditory ANT should be acknowledged because it relates to the relationship between auditory orienting (cue) and auditory executive (congruency) attention. This interaction is important given the finding that both auditory orienting and auditory executive attention were indirectly related to reading accuracy through phonological processing. But, how does this cue by congruency interaction in auditory attention relate to reading accuracy for children with DD?

Auditory spatial cues help to resolve auditory conflict, but may reduce cognitive resources. In the current study, the task that was used to assess reading accuracy asked students to read aloud regular words of varying frequencies.[22] Some examples of high frequency words were long (755), life (715), and hand (431). In contrast, low frequency words included crux (2), magnate (1), and creole (1) (Castles et al., 2009; Coltheart, 1981). It is possible that during the process of word recognition, low frequency words create conflict for the reader, since it would be unusual to see such words in everyday reading (Meschyan & Hernandez, 2002; Rastle, 2015). Thus, resolving this conflict is likely to be heavily dependent upon an efficient auditory executive attention network. This network would help the reader to

[22] Frequency ratings for each word are in parentheses. Higher numbers represent higher frequency (Coltheart, 1981).

quickly decipher the novelty of low frequency words, then efficiently help to locate relevant, correct pronunciations. However, given that a spatial cue was also found to reduce conflict for children with DD, the findings further suggest that when presented with low frequency words, children with DD might rely heavily on the use of auditory cues within these words (e.g., letter sounds) when accessing the mental lexicon (Aitchison, 2012; Taft, 2013). Subsequently, these cues might then be matched with previously stored pronunciations to facilitate an accurate reading of words (cf. McCann et al., 1992 showed that spatial attention may influence processes that occur before word frequency effects). Together, this suggests that spatial cues are likely to protect the children with DD from the inhibitory or distracting effect of a conflicting stimulus.

However, as explained elsewhere in this thesis, higher (or perhaps prolonged) usage of auditory spatial cues is likely to be costly, since this exhausts cognitive resources which are needed for other important reading processes. This view is further supported by the negative relationship between auditory orienting and phonological processing in children with DD, suggesting that a larger orienting effect is associated with poorer phonological awareness (a similar finding of this relationship was observed in RA matched controls). Phonological awareness helps readers to accurately map graphemes to phonemes (Brady & Shankweiler, 2013; Castles et al., 2009; Castles & Friedmann, 2014; Rayner et al., 2012). According to the dual-route model of reading, readers who have good phonological representations and good grapheme to phoneme skills are easily able make use of the sub-lexical route for more accurate word recognition (Castles et al., 2009; Coltheart et al., 2001). Similar arguments are advanced within the connectionist framework, such that well developed phonological representations heighten accurate connections between grapheme and phonemes. These connections are strengthened as the reader engages in different reading contexts (Harm & Seidenberg, 1999). Lower phonological processing scores are therefore associated with lower reading accuracy. Thus, the possible adverse effects of higher reliance on spatial cues upon the development of phonological processing and reading accuracy cannot be ignored. For children with DD, these adverse effects are likely to involve an increase in the attention dwell time upon phonological representations, contribute to difficulties relating to engagement and disengagement with such representations, and perhaps reduce the available resources of auditory executive attention to ignore irrelevant information (Amitay et al., 2002; Hari & Renvall, 2001). Together, these lower the accuracy of word recognition.

Summary of the Quasi-Experimental Findings

Study 3 was designed to examine the relationship between visual and auditory attention networks, phonological processing, and reading in children with DD, and compare the pattern of this relationship with that of their RA and CA matched controls. For all groups, there was a compulsory role for phonological processing, in which reading accuracy requires an accurate mapping to phonology. This efficiency depends on auditory orienting attention for RA matched controls and visual orienting for CA matched controls. The hypothesis that children with DD would exhibit a similar pattern of mediated access as RA matched controls was partially supported. That is, in addition to auditory orienting, children with DD also relied upon visual orienting (direct route), visual alerting (direct route), and auditory executive attention (indirect route) to accomplish reading accuracy. Moreover, the findings support the second hypothesis that the attention modality of the reading pathways varies across reading ability group.

Another striking finding was the significant attention network interactions in children with DD, which was not observed for the matched control groups. These interactions involved all of the key attention networks that were found to predict reading accuracy in children with DD. Finally, the significant auditory cue by congruency interaction which showed a heavy reliance upon auditory spatial cues to resolve auditory conflict in children with DD was not observed in the matched control groups. Previous studies that have directly examined a relationship between visual and auditory attention networks, phonological processing, and reading in children with DD is sparse. To current knowledge, the only study that has examined this relationship is Marzocchi et al. (2009), and this was conducted with Italian readers. However, although their measures assessed auditory and visual sustained (tonic alerting) attention, their orienting and executive measures were focused only on the visual modality. Therefore, the results of Study 3 provide novel, more specific information about the cognitive routes to reading (accuracy) in English children with DD. Together, the findings of Study 3 lend support to a modality-independent attentional model that guides reading accuracy for children with DD, in contrast to modality-specific attention networks (Facoetti, Trussardi, et al., 2010; Gomes, Wolfson, et al., 2007).

Research Implications

Theoretical implications: Summary proposal for an attention network model of reading. Previous studies examining the relationship between attention and reading were limited in that they (a) focused exclusively on typically developing early stage or beginning readers (e.g., Dice & Schwanenflugel, 2012; Dittman, 2013; van de Sande et al., 2013), (b) assessed attention only from a visual perspective (van de Sande et al., 2013), and (c) assessed only one type of attention. Consequently, it could not be determined whether the previously observed relationship between attention and reading through phonological processing existed for typically developing fluent or later stage readers and for children with DD. Moreover, the findings from these previous studies were unable to determine if there existed any attention modality differences based on stage of reading, or whether there were contributions of specific types of attention while controlling for the effects of other attention types. In the present cross-sectional (Study 1) and longitudinal (Study 2) studies, early stage readers accomplish reading accuracy through an interaction between auditory orienting and phonological processing. In contrast, later stage readers, rely on an interaction between visual orienting and reading accuracy through phonological processing. But, at more advanced, stages of reading (Study 2), there is also (a) an indirect relationship between visual executive and reading accuracy via phonological processing, and (b) a direct relationship between auditory orienting and reading accuracy. Finally, children with DD rely upon multiple routes and attention network interactions to accomplish reading accuracy (Study 3). Together, these findings support three working principles that likely govern the processes involved in an attention network model of reading, which in turn serve as a potential basis to explain disordered reading patterns.

Principle 1. Reading stage and attention modality determine the configuration of the mediation between visual and auditory attention networks, phonological processing, and reading. There is an extensive debate regarding the mechanisms involved in how children read (Coltheart et al., 2001; Hulme et al., 2005; Leinenger, 2014). There has been much consensus that a phonologically mediated route is fundamental for early stage reading, a view supported by the findings of the current thesis. Consequently, much of the debate is heavily focused upon the processes involved in more fluent, or later stage reading. Some theories advocate an indirect, phonologically mediated route (Rayner et al., 2012; Van Orden, 1987), others a direct, unmediated route (LaBerge & Samuels, 1974; Perfetti, 2013), and others advocate that route selection depends on different factors including word type, reading level or writing system (Castles et al., 2018). The attention network model of reading, as proposed by the current research, suggests that later stage reading differs from these three views in a fundamental way: accuracy in word recognition is accomplished by a simultaneous activation of the indirect and direct routes. This simultaneous activation is consistent with previous computational simulations of word meaning (e.g., Harm & Seidenberg, 2004).

Moreover, for later stage reading accuracy, pathway selection is likely to depend upon attention modality; a mediated pathway is preferred for visual attention, but a direct pathway is preferred for auditory attention. One possibility for this difference could reflect the distinct nature of vision and audition. For example, the visual attention system is limited in its intake of spatial information at any one time. This means that the eyes must be visually oriented, as a first step, to decide what information will be given attention. In contrast, all auditory information is imposed upon the ears, even if disproportionately, thus implying a more effortful process to classify, evaluate, and select relevant auditory information for additional processing (Baldwin, 2012; Gomes et al., 2000; Julesz & Hirsh, 1972). Therefore, the direct relationship between auditory (orienting) attention and reading accuracy could reflect a strategy for conserving attention resources. But, the visual orienting and visual executive attention networks engage the phonological processing system because of less constraints on these systems. This suggests that in even more proficient readers (later stage readers), at least some aspects of attention networks are still mediated by phonological processing. This is inconsistent with the view that developing visual orthographic knowledge (after the phonological recoding stage) is purely visual-orthographic and therefore independent of phonological skills (Ehri, 2014; Henderson, 2018). Rather, phonological skill continues to play a role in the challenges of learning the complexities of an orthographic script faced by children who are at a more advanced or later stage of reading acquisition. This argument is consistent with theories favouring the view that phonological codes play an intrinsic role in the decoding of printed words in advanced readers (Van Orden, 1987).

Together, the attention network model of reading provides a reconciliation to the longstanding debate of whether older, typically developing children use phonological processing for word recognition. That is, when taking attention modality into account, previous results are no longer contradictory but indicate a distinction between the functions of auditory and visual attention networks in their activation of phonological processing. As well, the findings further support the view that attention is not a stable system (Posner et al., 2016); it is likely to develop with age and to impact differently across modality.

Principle 2. Less is more for reading in the relationship between orienting attention and phonological processing. The initially proposed idea within the attention network theory was that higher orienting attention scores reflect higher levels of efficiency (Macleod et al., 2010; Posner, personal communication, May 2017). In contrast, the proposed attention network model of reading is different from this previous suggestion, particularly in the context of how the orienting mechanism influences reading related processes. For example, in the current series of studies, there was a consistent finding of an important role of orienting attention for reading accuracy. However, the findings generally suggested that higher orienting scores are related with poorer phonological processing accuracy and in turn less accurate reading. This implies that less orienting is related with more accurate processing of phonological information and more accurate reading.

However, one exception to this *less is more* principle was the finding of a positive relationship between visual orienting and phonological processing for early stage readers (Studies 1 and 2). Although early stage readers seem to rely primarily on auditory orienting for reading, the findings suggested a meaningful role for visual orienting attention. This exception therefore implies that the influence of visual orienting upon phonological processing at early and later stages of reading depend on the same underlying neural circuit but have a different engagement with this circuit according to reading stage. The findings further indicate that, as visual orienting becomes more significantly predictive of reading accuracy at later stages of reading, larger orienting difference scores associate with lower phonological processing and lower reading accuracy. Therefore, greater eye control precision, evidenced by smaller visual orienting difference scores, might be one hallmark of better reading in typically developing children (Chace, Rayner, & Well, 2005; Rayner, 2009; Rayner et al., 2012).

Principle 3. Fewer activation of attention network routes and fewer attention network interactions are necessary for higher reading accuracy. The ANT used in the current research permitted an assessment of within and across modality attention network interactions. The findings consistently showed no significant interactions between networks that were identified to play a significant or meaningful role in early stage readers. However, the longitudinal results suggested a strategic relationship between alerting and executive control for later stage readers at more advanced stages of reading. In addition, the attention tasks further facilitated an assessment of the specific attention networks that were involved in the routes to reading. As noted before, typically developing reading was characterized primarily by orienting attention and, eventually, at more advanced stages, executive attention became significant.

In contrast, multiple interactions and reading routes involving the alerting (visual), orienting (visual and auditory), and executive (auditory) functions of attention were observed for children with DD. Note, however, that the presence of these interactions and additional routes are not, by themselves, the cause of lower reading accuracy for children with DD. Instead, it is the higher number of these interactions and route usage (compared to typically developing readers) that are likely to play a fundamental role in reducing cognitive resources, thus lower attention network efficiency. This view is further qualified by the finding of less efficient attention network scores in children with DD compared with their CA matched controls. Poorer attention efficiency is likely to impede the development of well-specified processing capabilities (Facoetti, Trussardi, et al., 2010; Franceschini et al., 2012). Reading then becomes more demanding, as attention resources are depleted. Depletion of resources continues to motivate the recruitment of additional networks and reading routes to accomplish reading accuracy, as Study 3 suggested for children with DD. This additional recruitment is further likely to increase fatigue and increase errors in word recognition. Thus, typically developing reading patterns are underpinned by the adoption of fewer attention network routes to reading, echoing *Principle 2* of the proposed attention network model of reading that less is more.

Practical implications. It has been well established that children with DD are impaired in their phonological processing skills (Castles & Friedmann, 2014). However, the phonological processing deficit hypothesis does not address the attention deficits observed in children with DD. Furthermore, while other theories of

DD (e.g., double-deficit, sensorimotor, and magnocellular hypotheses) have subsequently aimed to explain the phonological deficit, they too have failed to account for the attention deficits (Bellebaum & Daum, 2007; Nicolson & Fawcett, 2006; Wolf & Bowers, 1999). Indeed, the findings of the present research clearly show that children with DD were impaired in both their word reading ability and phonological processing skills. But, the present study also showed a relationship between different attention networks and phonological processing in impacting reading among children with DD. Moreover, no evidence in the current research suggested that phonological processing impacted upon attention during word reading. Therefore, although clinicians usually identify an individual with DD using their phonological processing and reading profiles (which is in fact necessary to monitor their progress), the findings from this research suggest that using language measures alone may not provide a reliable representation of the deficits that underlie reading difficulties associated with DD.

Instead, the findings suggest that clinicians, as well as teachers, should eventually consider implementing supplementary assessments of visual and auditory attention network efficiency, at least among children with DD, aged 9 to 10 years old. More importantly, the pattern of these results does not undermine the phonological deficit hypothesis. Instead, the influence of attention upon phonological processing may be meaningful not only for identifying specific attentional deficits of children with DD, but it is likely to provide more individualised remediation programs to augment reading success (Tang & Posner, 2009). Moreover, this research offers an auditory ANT that can be used as a complement to the previously developed vANT, to provide a more specific assessment of the deficits in attention networks among children with DD. Note, however, that given that the research on how attention relates to phonological processing and reading is still in a formative stage, more research is needed on how to measure attention, before making any meaningful changes to assessment practices. Altogether, these findings are likely to advance diagnostic methods, as well as intervention and policy planning which may include strategies for training attention skills, thus enhancing mental capital (Beddington et al., 2008; Tang & Posner, 2009).

Limitations of the Current Research and Recommendations for Future Research

Although the findings from this programme of research uniquely contribute to reading research, there are a few limitations. First, consistent with similar studies using RA and CA matched control designs (e.g., see Jackson & Butterfield, 1989), multiple-group analysis could not be conducted in Study 3. While single-indicator models offer an opportunity to advance more precise theories, such models are oftentimes just-identified or saturated, thus fit the data perfectly. In such instances, fit indices are not generated (Bengt Muthén, personal communication, 2018), which is a common feature of single-indicator SEM approaches (Levente Littvay, personal communication, 2018). Although the data (and parameter estimates) from just-identified models (as produced in Study 3) can be analysed, measurement and structural invariance cannot be assessed because of the zero values for chi-square and degrees of freedom (Muthén, 2016, 2018a, 2018b). This means that although children with DD were carefully matched with their controls on reading and chronological age and IQ, inferences regarding measurement and structural invariance and genuine group differences in the tested model cannot be advanced. For example, it is possible that these matched groups are not equivalent samples, since they are from different populations ─ that is, the results might be biased by the nature of the ability within each group (Jackson & Butterfield, 1989).

It might, however, be claimed that it is in fact these varying abilities or processes that are the motivation of control matched designs, and group differences in, for example, attention pathways, will be evident by differences in how attention affects reading through phonological processing (Stanovich et al., 1988). Although there is evidence of invariance from the results of Study 1 and Study 2 (in typically developing children), the influence of variance from innate characteristics of children with DD cannot be entirely ruled out. Without testing for group invariance, it is difficult to determine if there existed any genuine group difference in task effects (through SEM) for the attention, phonological processing, and reading tasks used in Study 3. Thus, the findings of Study 3 are most valuable for advancing hypotheses regarding *likely* group differences in the attention routes to reading accuracy between children with DD and their RA and CA matched controls. Clearly, future research using the design of Study 3 in this research should aim to develop a model with additional inputs, which includes multiple measures of phonological awareness (for RA matched controls and children with DD), and RAN (for CA matched controls) and regular word reading accuracy, as well as including more participants. This will be aimed at ensuring that the model is over-identified to establish comparability of the measures across reading ability groups, thus advancing genuine group differences (Leslie Hayduk, personal communication, 2018).

The pathways that link attention and phonological processing are perhaps more intricate than what the present research has described. Indeed, future studies might have a different approach to measuring the phonological processing latent variable (phonological awareness, phonological memory, and RAN) in Studies 1 and 2. One might view these measures as tapping distinct skills that may have a different impact upon reading accuracy and speed. Given that the present study has shown weak associations between RAN and phonological awareness and phonological memory, it would be interesting for future studies to examine the pattern of relationship between attention and reading (accuracy and speed) for a latent variable that includes only RAN, and for a latent variable that includes only phonological awareness and phonological memory. Moreover, it would be interesting for future studies to examine if attention network efficiency impacts reading not only at T2, but how this efficiency might influence the development of reading across a student's current grade level.

In addition to this, some scholars (e.g., Macleod et al., 2010; Michael Posner, personal communication, 2017, Posner, 2008) have previously suggested that higher orienting attention difference scores suggest more efficient attention networks. In contrast, for later stage readers in the present study, a higher visual orienting score was related to lower phonological processing scores. Similarly, for early stage readers, higher auditory orienting scores relate to lower phonological processing scores. This negative relationship between orienting and phonological processing is therefore counterintuitive to previous explanations. Although a potential explanation of this unexpected correlation has been advanced, at length, in the General Discussion, this paradox requires further empirical support and clarification.

Furthermore, in later stage readers (Study 2), while there was a direct relationship between auditory (orienting) attention and reading accuracy, visual (orienting and executive) attention continued to associate with reading accuracy through phonological processing. First, it would be of interest to know whether this pattern is maintained for even more advanced readers (e.g., high school children and adults). Although phonological processing is important for reading, more skilled readers regularly bypass the phonologically mediated route (LaBerge & Samuels, 1974; Perfetti, 2013). It was proposed in the General Discussion that the phonologically mediated route for visual attention might reflect a qualitative shift in orthographic processing for later stage readers, which may imply greater control over eye movements. Therefore, future research in this area would benefit from exploring developmental changes in eye movement during reading, and how this relates to the interaction between visual attention and phonological processing. In fact, previous eye tracking evidence in skilled readers have shown that the phonological characteristics of words are accessed prior to lexical access, and that word identification is mediated by this information. Further, phonological processing of forthcoming words in sentences prior to direct fixation has been observed (Chace et al., 2005; Miellet & Sparrow, 2004; Sereno & Rayner, 2000). This finding implies a pre-lexical role for phonology and suggests an important role for phonological recoding in the activation of lexical entries during reading. Therefore, examining markers of eye movement during word reading and better targeted measures of orthographic knowledge could test the hypothesis of a qualitative shift in orthographic processing across development (Andrews, 1997; Andrews & Lo, 2012; Andrews, Miller, & Rayner, 2004). This can be further operationalised by comparing more advanced readers who differ in visual orienting attention efficiency (a high efficiency and low efficiency group), as well as, in their level of phonological processing and reading accuracy, eye movements and orthographic knowledge. Based on the argument for a qualitative shift in orthographic processing, it would be expected that the high efficiency visual orienting attention group would show better control over eye movements and better orthographic knowledge than the low efficiency visual orienting attention group.

Previous scholars have also proposed a number of other ways by which attention affects phonological processing and reading. For example, previous studies have examined the role of executive functioning, including behavioural regulation and metacognitive skills, which may influence the development of attention and phonological processing skills (Duncan et al., 2007; Liew, 2012; Miyake et al., 2000; Posner & Rothbart, 2007; Wiebe & McFall, 2014). In fact, in the current study, there was evidence of a correlation between executive functioning and exception word reading accuracy and speed among early stage readers. Similarly, there was a marginally significant correlation between auditory orienting and executive functioning in children with DD. Executive functions have been broadly understood as those cognitive abilities that play a supervisory role in directing and controlling other cognitive processes. These functions (which also require attention resources) are inclusive of, but not limited to, inhibition, task switching, planning, and sequencing (Baddeley, 2007; Miyake et al., 2000). Acknowledging the role of executive functions in reading is important because they serve as a potential supervisory system for underlying processes of phonology, memory, attention, and cross modal binding, which are key cognitive processes underpinning reading (Baddeley, 2012; Carver & Scheier, 2012). Moreover, these underlying processes have been proposed as contributing factors in disordered reading (Facoetti et al., 2003; Jones, Branigan, Parra, & Logie, 2013; Stoodley & Stein, 2013). However, in the current study, by including other variables that are considered as potentially moderating or mediating, or both, the relationship between attention and reading, this increases the possibility of measurement or structural model under-identification (Bollen, 1989a). This occurs if there are more proposed parameters than the number of available data points. Furthermore, if the model is identified, having more parameters than data points decreases predictive power (Byrne, 2012). Therefore, a primary limitation is being unable to include all variables believed to be important, given the data unavailability. Nevertheless, the variables included in the tested models were guided by previous theoretical and empirical evidence indicating that the ordering of this set of variables was sensible (Dally, 2006; Dice & Schwanenflugel, 2012; Dittman, 2013; van de Sande et al., 2013). However, to develop more specific theories of reading, it would be useful for studies assessing attention and reading to also account for the role of executive functioning.

The measures aimed at representing alerting, orienting, and executive attention in this programme of research have been constructed to target the functioning of specific functions of attention. Moreover, while the cAANT-SL in the current study elicited an orienting effect, the cue that preceded target presentation cues the responses as well as cues the orientation of attention to the ear of target presentation. Therefore, it is possible that responses were primed, even though this effect was controlled for by using a 150 ms ISI. These restrictions may underestimate the contributions of other types of attention to reading, since the cVANT and cAANT-SL do not capture the range of attention network functioning in its entirety (Dosenbach et al., 2008). Although the findings from this research were novel in its focus on the three attention networks in different modalities, other aspects of attention have not yet been linked to reading. Therefore, it remains uncertain which specific aspects of attention, in which modality, predict reading acquisition. Using behavioral experiments, novel, objective measurements of attention networks in different contexts should be developed. For example, RT and accuracy measurements could be collected in contexts where primary school-aged children remain vigilant for long periods (tonic alerting), locate information without shifting focus (covert orienting), and inhibit distractions for long periods (maintaining executive control). This could be complemented by another dataset using the same children where they remain vigilant for short periods (phasic alerting), locate information by shifting focus (overt orienting) and inhibit distractions for short periods (initiating executive control). A comparison of these datasets with younger (aged 6 to 7) and older (aged 9 to 10) children's reading accuracy, as well as with children with DD, would provide a more comprehensive investigation of the specific risk factors that predict reading at different developmental stages, and reading difficulties, than has been currently achieved. Furthermore, future research using the auditory ANT, as described in the current thesis, would benefit from distinguishing between the effects of early orienting attention versus response priming (Wühr & Heuer, 2017).

Conclusion

This research has examined the roles of visual and auditory attention networks and phonological processing in reading for both typically developing and disordered reading. There is ample evidence that reading is not only affected by phonological processing, a linguistic skill, but is also significantly influenced by attention, a non-linguistic skill. Surprisingly, there has been little research into how attention network efficiency interacts with phonological processing skills to influence reading accuracy and reading speed, particularly for later stage readers and children with DD, and how this differs across visual and auditory attention. The distinction between how attention network efficiency affects reading differently, based on reading stage, reading abilities, and attention modality is important, as this reflects differences in the representation, acquisition, and use of knowledge. This information guides how we view the representation of information in the brain, and ultimately, influences the approach to reading instruction and the assessment of reading difficulties.

The series of studies presented in this thesis were designed to fill these research gaps by providing an auditory ANT for children and using this task to evaluate the interaction between visual and auditory attention networks, phonological processing, and reading, to better understand how reading pathways differ based on reading stage and reading ability. The findings of this research highlight the reading pathways that are important for 6 to 8 year-old, early stage, and 9 to 11 year-old, later stage typically developing readers, as well as 9 to 10 year-old children with DD. The findings suggest that, for all participants, there is a compulsory role for phonological processing, and reading requires an efficient mapping to phonology. This efficiency depends on auditory orienting attention for early stage readers and visual orienting for later stage readers. However, as later stage readers gain more reading proficiency, there is a direct route between auditory orienting and reading accuracy. Children with DD rely upon both visual and auditory orienting attention and recruit additional networks (visual alerting and auditory executive attention) to accomplish reading accuracy.

Altogether, these findings support the proposition of an attention network model of reading, which seeks to provide a more detailed understanding of the differences in reading pathways based on reading ability. This is a working model that will require further research and replication. Nevertheless, the three key principles that are proposed by this model involves (a) a distinction between reading pathway based on reading ability and attention modality, (b) the finding that less orienting of attention increases phonological processing and in turn, more accurate and efficient reading, and (c) the finding that more accurate reading is characterised by fewer pathways to word recognition as well as fewer interactions between the visual and auditory attention networks that are important for reading accuracy. It is hoped that the findings and propositions from this research will serve as a framework to provide further evidence for the role of attention networks in reading. Moreover, it is also hoped that the proposed attention network model of reading will stimulate the identification and testing of other relevant principles that might be added to this model. Overall, it is expected that the body of work and the future research that this study will inspire will ultimately improve the methods adopted in teaching children how to read, as well as the methods used to assess reading difficulties in children with DD.

References

Adams, M. J. (1990). *Beginning to Read: Thinking and Learning about Print*. Cambridge, MA: Bolt, Beranek, and Newman.

Aiken, L. S., West, S. G., & Reno, R. R. (1991). *Multiple regression: Testing and interpreting interactions.* California, USA: Sage.

Aitchison, J. (2012). *Words in the mind: An introduction to the mental lexicon.* Oxford, UK: John Wiley & Sons.

Alain, C., Arnott, S. R., Hevenor, S., Graham, S., & Grady, C. L. (2001). "What" and "where" in the human auditory system. *Proceedings of the National Academy of Sciences, 98*(21), 12301─12306.

Alegria, J., Pignot, E., & Morais, J. (1982). Phonetic analysis of speech and memory codes in beginning readers. *Memory & Cognition, 10*(5), 451─456.

Alvarez, J. A., & Emory, E. (2006). Executive function and the frontal lobes: A meta-analytic review. *Neuropsychology Review, 16*(1), 17─42.

Amitay, S., Ben-Yehudah, G., Banai, K., & Ahissar, M. (2002). Disabled readers suffer from visual and auditory impairments but not from a specific magnocellular deficit. *Brain, 125*(10), 2272─2285.

Anderson, J. R. (1992). Automaticity and the ACT theory. *The American Journal of Psychology, 105*(2), 165─180.

Andrews, S. (1997). The effect of orthographic similarity on lexical retrieval: Resolving neighborhood conflicts. *Psychonomic Bulletin & Review, 4*(4), 439─461.

Andrews, S., & Lo, S. (2012). Not all skilled readers have cracked the code: Individual differences in masked form priming. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 38*(1), 152─163.

Andrews, S., Miller, B., & Rayner, K. (2004). Eye movements and morphological segmentation of compound words: There is a mouse in mousetrap. *European Journal of Cognitive Psychology, 16*(1─2), 285─311.

Anthony, J. L., & Francis, D. J. (2005). Development of phonological awareness. *Current Directions in Psychological Science, 14*(5), 255─259.

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.). Washington, DC: Author.

Araújo, S., Reis, A., Petersson, K. M., & Faísca, L. (2015). Rapid automatized naming and reading performance: A meta-analysis. *Journal of Educational Psychology, 107*(3), 868─883.

Arnott, S. R., & Alain, C. (2011). The auditory dorsal pathway: Orienting vision. *Neuroscience & Biobehavioral Reviews, 35*(10), 2162─2173.

Arrington, C. N., Kulesz, P. A., Francis, D. J., Fletcher, J. M., & Barnes, M. A. (2014). The contribution of attentional control and working memory to reading comprehension and decoding. *Scientific Studies of Reading, 18*(5), 325─346.

Asbjørnsen, A. E., & Bryden, M. (1998). Auditory attentional shifts in reading-disabled students: quantification of attentional effectiveness by the Attentional Shift Index. *Neuropsychologia, 36*(2), 143─148.

Ashby, J. (2010). Phonology is fundamental in skilled reading: Evidence from ERPs. *Psychonomic Bulletin & Review, 17*(1), 95─100.

Astle, D. E., & Scerif, G. (2011). Interactions between attention and visual short-term memory (VSTM): What can be learnt from individual and developmental differences? *Neuropsychologia, 49*(6), 1435─1445.

Augustinova, M., & Ferrand, L. (2014). Automaticity of word reading: Evidence from the semantic Stroop paradigm. *Current Directions in Psychological Science*, *23*(5), 343─348.

Baddeley, A. (2007). *Oxford psychology series: Vol. 45. Working memory, thought, and action.* New York, NY, US: Oxford University Press.

Baddeley, A. (2012). Working memory: Theories, models, and controversies. *Annual Review of Psychology, 63*, 1─29.

Baldwin, C. L. (2012). *Auditory cognition and human performance: Research and applications*. Boca Raton: CRC Press.

Baron, J. (1973). Phonemic stage not necessary for reading. *The Quarterly Journal of Experimental Psychology, 25*(2), 241─246.

Baron, J. (2014). The word-superiority effect: Perceptual learning from reading. In W.K. Estes (Ed.), *Handbook of learning and cognitive processes (Vol. 6)* (pp. 131─166). Hove, United Kingdom: Taylor & Francis.

Baron, R. M., & Kenny, D. A. (1986). The moderator–mediator variable distinction in social psychological research: Conceptual, strategic, and statistical considerations. *Journal of Personality and Social Psychology, 51*(6), 1173─1182.

Barron, R. W., & Baron, J. (1977). How children get meaning from printed words. *Child Development, 48*(2), 587─594.

Barrouillet, P., Bernardin, S., & Camos, V. (2004). Time constraints and resource sharing in adults' working memory spans. *Journal of Experimental Psychology: General, 133*(1), 83─100.

Barrouillet, P., Gavens, N., Vergauwe, E., Gaillard, V., & Camos, V. (2009). Working memory span development: A time-based resource-sharing model account. *Developmental Psychology, 45*(2), 477─490.

Beddington, J., Cooper, C. L., Field, J., Goswami, U., Huppert, F. A., Jenkins, R., . . . Thomas, S. M. (2008). The mental wealth of nations. *Nature, 455*(7216), 1057─1060.

Bellebaum, C., & Daum, I. (2007). Cerebellar involvement in executive control. *The Cerebellum, 6*(3), 184─192.

Bentler, P. M. (1990). Comparative fit indexes in structural models. *Psychological Bulletin, 107*(2), 238─246.

Bentler, P. M., & Hu, L. (1995). Evaluating model fit. In R. H. Hoyle (Ed.), *Structural equation modeling: Concepts, issues and application* (pp. 77-99). Thousand Oaks, CA: Sage.

Bentler, P. M., & Kano, Y. (1990). On the equivalence of factors and components. *Multivariate Behavioral Research, 25*(1), 67─74.

Besner, D., Risko, E. F., Stolz, J. A., White, D., Reynolds, M., O'Malley, S., & Robidoux, S. (2016). Varieties of attention. *Current Directions in Psychological Science, 25*(3), 162─168.

Bexkens, A., Wildenberg, W. P. M., & Tijms, J. (2015). Rapid automatized naming in children with dyslexia: Is inhibitory control involved? *Dyslexia, 21*(3), 212─234.

Biemiller, A. (2006). Vocabulary development and instruction: A prerequisite for school learning. In S. Neuman & D. Dickinson (Eds.), *The handbook of early literacy research (Vol 2)* (pp. 41─51). New York, NY: Guilford Press.

Bird, J., & Bishop, D. (1992). Perception and awareness of phonemes in phonologically impaired children. *International Journal of Language & Communication Disorders, 27*(4), 289─311.

Blauert, J., & Lindemann, W. (1986). Spatial mapping of intracranial auditory events for various degrees of interaural coherence. *The Journal of the Acoustical Society of America, 79*(3), 806─813.

Boada, R., & Pennington, B. F. (2006). Deficient implicit phonological representations in children with dyslexia. *Journal of Experimental Child Psychology, 95*(3), 153─193.

Boersma, P., & Weenink, D. (2016). Praat software. University of Amsterdam. *Im Internet: http://www.fon.hum.uva nl/praat*.

Bollen, K. (1989a). *Structural equations with latent variables*. New York: John Wiley & Sons.

Bollen, K. A. (1989b). A new incremental fit index for general structural equation models. *Sociological Methods & Research, 17*(3), 303─316.

Booth, J. R., Perfetti, C. A., & MacWhinney, B. (1999). Quick, automatic, and general activation of orthographic and phonological representations in young readers. *Developmental Psychology, 35*(1), 3─19.

Borchert, K. (2015). Inquisit [computer software]. Seattle, WA: Millisecond Software. Available from http://www.millisecond.com/download/library/ant/

Bosse, M.-L., Tainturier, M. J., & Valdois, S. (2007). Developmental dyslexia: The visual attention span deficit hypothesis. *Cognition, 104*(2), 198─230.

Bowey, J. A., Cain, M. T., & Ryan, S. M. (1992). Reading-level design study of phonological skills underlying fourth-grade children's word reading difficulties. *Child Development, 63*(4), 999─1011.

Brady, S. A., & Shankweiler, D. P. (2013). *Phonological processes in literacy: A tribute to Isabelle Y. Liberman*. New York: Routledge.

Broadbent, D. (1958). *Perception and Communication*. New York: Pergamon Press.

Brown, L., Sherbenou, R. J., & Johnsen, S. K. (2010). *Test of Nonverbal Intelligence (TONI-4)*. Austin, Texas: Pro-ed.

Browne, M. W., & Cudeck, R. (1993). Alternative ways of assessing model fit. *Sage Focus Editions, 154*, 136─136.

Bruck, M. (1992). Persistence of dyslexics' phonological awareness deficits. *Developmental Psychology, 28*(5), 874─886.

Brunswick, N., Martin, G. N., & Rippon, G. (2012). Early cognitive profiles of emergent readers: A longitudinal study. *Journal of Experimental Child Psychology, 111*(2), 268─285.

Bryce, D., Whitebread, D., & Szűcs, D. (2015). The relationships among executive functions, metacognitive skills and educational achievement in 5 and 7 year-old children. *Metacognition and Learning, 10*(2), 181─198.

Bundesen, C. (1987). Visual attention: Race models for selection from multielement displays. *Psychological Research, 49*(2-3), 113─121.

Bundesen, C., & Habekost, T. (2008). *Principles of visual attention: Linking mind and brain*. Oxford: Oxford University Press.

Byrne, B. M. (2012). *Structural equation modeling with Mplus: Basic concepts, applications, and programming*. New York: Routledge.

Cain, K., & Parrila, R. (2014). Introduction to the special issue.Theories of reading: What we have learned from two decades of scientific research. *Scientific Studies of Reading, 18*(1), 1─4.

Callejas, A., Lupiánez, J., & Tudela, P. (2004). The three attentional networks: On their independence and interactions. *Brain and Cognition, 54*(3), 225─227.

Campbell, D. T., & Stanley, J. C. (2015). *Experimental and quasi-experimental designs for research*. NJ, USA: Ravenio Books.

Cao, F., Bitan, T., Chou, T.-L., Burman, D. D., & Booth, J. R. (2006). Deficient orthographic and phonological representations in children with dyslexia revealed by brain activation patterns. *Journal of Child Psychology and Psychiatry, and Allied Disciplines, 47*(10), 1041─1050.

Caravolas, M., Hulme, C., & Snowling, M. J. (2001). The foundations of spelling ability: Evidence from a 3-year longitudinal study. *Journal of Memory and Language, 45*(4), 751─774.

Caravolas, M., Lervåg, A., Mousikou, P., Efrim, C., Litavský, M., Onochie-Quintanilla, E., . . . Mikulajová, M. (2012). Common patterns of prediction of literacy development in different alphabetic orthographies. *Psychological Science, 23*(6), 678─686.

Cardoso-Martins, C., & Pennington, B. F. (2004). The relationship between phoneme awareness and rapid serial naming skills and literacy acquisition: The role of developmental period and reading ability. *Scientific Studies of Reading, 8*(1), 27─52.

Cartwright, K. B. (2012). Insights from cognitive neuroscience: The importance of executive function for early reading development and education. *Early Education & Development, 23*(1), 24─36.

Carver, C. S., & Scheier, M. F. (2012). *Attention and self-regulation: A control-theory approach to human behavior*. New York: Springer Science & Business Media.

Castles, A., & Coltheart, M. (1993). Varieties of developmental dyslexia. *Cognition, 47*(2), 149─180.

Castles, A., & Coltheart, M. (2004). Is there a causal link from phonological awareness to success in learning to read? *Cognition, 91*(1), 77─111.

Castles, A., Coltheart, M., Larsen, L., Jones, P., Saunders, S., & McArthur, G. (2009). Assessing the basic components of reading: A revision of the Castles and Coltheart test with new norms. *Australian Journal of Learning Difficulties, 14*(1), 67─88.

Castles, A., & Friedmann, N. (2014). Developmental dyslexia and the phonological deficit hypothesis. *Mind & Language*, *29*(3), 270─285.

Castles, A., Rastle, K., & Nation, K. (2018). Ending the reading wars: Reading acquisition from novice to expert. *Psychological Science in the Public Interest*, *19*(1), 5─51.

Caylak, E. (2010). The studies about phonological deficit theory in children with developmental dyslexia. *American Journal of Neuroscience, 1*(1), 1─12.

Chace, K. H., Rayner, K., & Well, A. D. (2005). Eye movements and phonological parafoveal preview: Effects of reading skill. *Canadian Journal of Experimental Psychology/Revue canadienne de psychologie expérimentale, 59*(3), 209─217.

Cheung, G. W., & Rensvold, R. B. (2002). Evaluating goodness-of-fit indexes for testing measurement invariance. *Structural Equation Modeling, 9*(2), 233─255.

Christopher, M. E., Miyake, A., Keenan, J. M., Pennington, B., DeFries, J. C., Wadsworth, S. J., . . . Olson, R. K. (2012). Predicting word reading and comprehension with executive function and speed measures across development: A latent variable analysis. *Journal of Experimental Psychology: General, 141*(3), 470─488.

Chua, A. C. K. (2013). Establishing a psycho-educational profile and assessment of a boy suspected with hyperlexia: A single-subject case study. *Journal of Reading & Literacy, 19*(7), 63─72.

Church, J. A., Coalson, R. S., Lugar, H. M., Petersen, S. E., & Schlaggar, B. L. (2008). A developmental fMRI study of reading and repetition reveals changes in phonological and visual mechanisms over age. *Cerebral Cortex, 18*(9), 2054─2065.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences (2nd ed.)* Hilsdale, NJ: Lawrence Earlbaum Associates.

Cole, D. A., & Maxwell, S. E. (2003). Testing mediational models with longitudinal data: Questions and tips in the use of structural equation modeling. *Journal of Abnormal Psychology, 112*(4), 558─577.

Coltheart, M. (1981). The MRC psycholinguistic database. *The Quarterly Journal of Experimental Psychology, 33*(4), 497─505.

Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Ziegler, J. (2001). DRC: A dual route cascaded model of visual word recognition and reading aloud. *Psychological Review, 108*(1), 204─256.

Conway, A. R., Kane, M. J., & Engle, R. W. (2003). Working memory capacity and its relation to general intelligence. *Trends in Cognitive Sciences, 7*(12), 547─552.

Corbetta, M., Kincade, J. M., Ollinger, J. M., McAvoy, M. P., & Shulman, G. L. (2000). Voluntary orienting is dissociated from target detection in human posterior parietal cortex. *Nature Neuroscience, 3*(3), 292─297.

Corp, I. (2016). *IBM SPSS Statistics for Windows, Version 24.0*. Armonk, NY: IBM Corp.

Coull, J. T., & Nobre, A. C. (1998). Where and when to pay attention: The neural systems for directing attention to spatial locations and to time intervals as revealed by both PET and fMRI. *Journal of Neuroscience, 18*(18), 7426─7435.

Craft, J. L., & Simon, J. R. (1970). Processing symbolic information from a visual display: Interference from an irrelevant directional cue. *Journal of Experimental Psychology, 83*(3), 415─420.

Dagenbach, D., & Carr, T. H. (1994). Inhibitory processes in perceptual recognition: Evidence for a center-surround attentional mechanism. In D. Dagenbach & T. H. Carr (Eds.), *Inhibitory processes in attention, memory, and language* (pp. 327-357). San Diego, CA, US: Academic Press.

Dally, K. (2006). The influence of phonological processing and inattentive behavior on reading acquisition. *Journal of Educational Psychology, 98*(2), 420–437.

Davis, C. (1998). Masked homophone and pseudohomophone priming in children and adults. *Language and Cognitive Processes, 13*(6), 625–651.

de Groot, B. J. A., van den Bos, K. P., Minnaert, A. E. M. G., & van der Meulen, B. F. (2014). Phonological processing and word reading in typically developing and reading disabled children: Severity matters. *Scientific Studies of Reading, 19*(2), 166–181.

Dehaene, S., & Cohen, L. (2011). The unique role of the visual word form area in reading. *Trends in Cognitive Sciences, 15*(6), 254–262.

Denckla, M. B., & Rudel, R. (1974). Rapid "automatized" naming of pictured objects, colors, letters and numbers by normal children. *Cortex, 10*(2), 186–202.

Deutsch, J. A., & Deutsch, D. (1963). Attention: Some theoretical considerations. *Psychological Review, 70*(1), 80–90.

Dice, J. L., & Schwanenflugel, P. (2012). A structural model of the effects of preschool attention on kindergarten literacy. *Reading and Writing, 25*(9), 2205–2222.

Dimitrov, D. M. (2006). Comparing groups on latent variables: A structural equation modeling approach. *Work, 26*(4), 429–436.

Dittman, C. K. (2013). The impact of early classroom inattention on phonological processing and word-reading development. *Journal of Attention Disorders, 20*(8), 653–664.

Dittman, C. K. (2016). Associations between inattention, hyperactivity and pre-reading skills before and after formal reading instruction begins. *Reading and Writing, 29*(9), 1771–1791.

Dosenbach, N. U., Fair, D. A., Cohen, A. L., Schlaggar, B. L., & Petersen, S. E. (2008). A dual-networks architecture of top-down control. *Trends in Cognitive Sciences, 12*(3), 99–105.

du Prel, J.-B., Hommel, G., Röhrig, B., & Blettner, M. (2009). Confidence interval or p-value?: Part 4 of a series on evaluation of scientific publications. *Deutsches Ärzteblatt International, 106*(19), 335–339.

Duncan, G. J., Dowsett, C. J., Claessens, A., Magnuson, K., Huston, A. C., Klebanov, P., . . . Brooks-Gunn, J. (2007). School readiness and later achievement. *Developmental Psychology, 43*(6), 1428─1446.

Duncan, J. (1996). Cooperating brain systems in selective perception and action. In T. Inui & J. L. McClelland (Eds.), *Attention and performance. Attention and performance 16: Information integration in perception and communication* (pp. 549-578). Cambridge, MA, US: The MIT Press.

Eden, G. F., Olulade, O. A., Evans, T. M., Krafnick, A. J., & Alkire, D. R. (2015). Developmental dyslexia. In G. Hickok & S. Small (Eds.), *Neurobiology of language* (pp. 815-826). Elsevier.

Edfeldt, A. W. (1960). *Silent speech and silent reading*. Chicago: University of Chicago Press.

Ehri, L. C. (2013). Grapheme-phoneme knowledge is essential for learning to read words in English. In J. Metsala & L. Ehri (Eds.), *Word recognition in beginning literacy* (pp. 3-40). New York: Routledge.

Ehri, L. C. (2014). Orthographic mapping in the acquisition of sight word reading, spelling memory, and vocabulary learning. *Scientific Studies of Reading, 18*(1), 5─21.

Ehri, L. C. (2017). Reconceptualizing the development of sight word reading and its relationship to recoding. In P.B. Gough, L.C. Ehri & R Treiman (Eds.), *Reading acquistion* (pp. 107─143). New York: Routledge.

Elbro, C., & Jensen, M. N. (2005). Quality of phonological representations, verbal learning, and phoneme awareness in dyslexic and normal readers. *Scandinavian Journal of Psychology, 46*(4), 375─384.

Elliott, J. G., & Grigorenko, E. L. (2014). *Cambridge studies in cognitive and perceptual development. The dyslexia debate*. New York, NY, US: Cambridge University Press.

Enns, J. T., & Di Lollo, V. (2000). What's new in visual masking? *Trends in Cognitive Sciences, 4*(9), 345─352.

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & Psychophysics, 16*(1), 143─149.

Facoetti, A. (2001). Facilitation and inhibition mechanisms of human visuospatial attention in a non-search task. *Neuroscience Letters, 298*(1), 45─48.

Facoetti, A., Corradi, N., Ruffino, M., Gori, S., & Zorzi, M. (2010). Visual spatial attention and speech segmentation are both impaired in preschoolers at familial risk for developmental dyslexia. *Dyslexia, 16*(3), 226―239.

Facoetti, A., Lorusso, M. L., Paganoni, P., Cattaneo, C., Galli, R., Umilta, C., & Mascetti, G. G. (2003). Auditory and visual automatic attention deficits in developmental dyslexia. *Cognitive Brain Research, 16*(2), 185―191.

Facoetti, A., & Molteni, M. (2001). The gradient of visual attention in developmental dyslexia. *Neuropsychologia, 39*(4), 352―357.

Facoetti, A., Paganoni, P., Turatto, M., Marzola, V., & Mascetti, G. G. (2000). Visual-spatial attention in developmental dyslexia. *Cortex, 36*(1), 109―123.

Facoetti, A., Ruffino, M., Peru, A., Paganoni, P., & Chelazzi, L. (2008). Sluggish engagement and disengagement of non-spatial attention in dyslexic children. *Cortex, 44*(9), 1221―1233.

Facoetti, A., Trussardi, A. N., Ruffino, M., Lorusso, M. L., Cattaneo, C., Galli, R., . . . Zorzi, M. (2010). Multisensory spatial attention deficits are predictive of phonological decoding skills in developmental dyslexia. *Journal of Cognitive Neuroscience, 22*(5), 1011―1025.

Facoetti, A., Turatto, M., Lorusso, M. L., & Mascetti, G. G. (2001). Orienting of visual attention in dyslexia: Evidence for asymmetric hemispheric control of attention. *Experimental Brain Research, 138*(1), 46―53.

Facoetti, A., Zorzi, M., Cestnick, L., Lorusso, M. L., Molteni, M., Paganoni, P., . . . Mascetti, G. G. (2006). The relationship between visuo-spatial attention and nonword reading in developmental dyslexia. *Cognitive Neuropsychology, 23*(6), 841―855.

Fallon, S. J., Mattiesing, R. M., Dolfen, N., Manohar, S., & Husain, M. (2018). Ignoring versus updating in working memory reveal differential roles of attention and feature binding. *Cortex*, 1―14.

Fan, J., Gu, X., Guise, K. G., Liu, X., Fossella, J., Wang, H., & Posner, M. I. (2009). Testing the behavioral interaction and integration of attentional networks. *Brain and Cognition, 70*(2), 209―220.

Fan, J., McCandliss, B. D., Sommer, T., Raz, A., & Posner, M. I. (2002). Testing the efficiency and independence of attentional networks. *Journal of Cognitive Neuroscience, 14*(3), 340―347.

Farrington-Flint, L., Coyne, E., Stiller, J., & Heath, E. (2008). Variability in children's early reading strategies. *Educational Psychology, 28*(6), 643─661.

Fernandez-Duque, D., Baird, J. A., & Posner, M. I. (2000). Executive attention and metacognitive regulation. *Consciousness and Cognition, 9*(2), 288─307.

Festa-Martino, E., Ott, B. R., & Heindel, W. C. (2004). Interactions between phasic alerting and spatial orienting: Effects of normal aging and Alzheimer's disease. *Neuropsychology, 18*(2), 258─268.

Field, A. (2013). *Discovering statistics using SPSS (4th ed.)*. London: Sage.

Finn, E. S., Shen, X., Holahan, J. M., Scheinost, D., Lacadie, C., Papademetris, X., . . . Constable, R. T. (2014). Disruption of functional networks in dyslexia: A whole-brain, data-driven analysis of connectivity. *Biological Psychiatry, 76*(5), 397─404.

Finoia, P., Mitchell, D. J., Hauk, O., Beste, C., Pizzella, V., & Duncan, J. (2015). Concurrent brain responses to separate auditory and visual targets. *Journal of Neurophysiology, 114*(2), 1239─1247.

Flevaris, A. V., Bentin, S., & Robertson, L. C. (2010). Local or global? Attentional selection of spatial frequencies binds shapes to hierarchical levels. *Psychological Science, 21*(3), 424─431.

Forster, K. I., & Forster, J. C. (2003). DMDX: A Windows display program with millisecond accuracy. *Behavior Research Methods, 35*(1), 116─124.

Fowler, C. A. (1978). Phonological coding in beginning reading, *28th Annual Meeting of the National Reading Conference*, St. Petersburg Beach, Florida, November 30-December 2, 1978 (pp. 139─145). USA: Haskins Laboratories.

Franceschini, S., Gori, S., Ruffino, M., Pedrolli, K., & Facoetti, A. (2012). A causal link between visual spatial attention and reading acquisition. *Current Biology, 22*(9), 814─819.

Francis, D. J., Shaywitz, S. E., Stuebing, K. K., Shaywitz, B. A., & Fletcher, J. M. (1996). Developmental lag versus deficit models of reading disability: A longitudinal, individual growth curves analysis. *Journal of Educational Psychology, 88*(1), 3─17.

French, B. F., & Finch, W. H. (2008). Multigroup confirmatory factor analysis: Locating the invariant referent sets. *Structural Equation Modeling, 15*(1), 96─113.

Fries, C. C. (1963). *Linguistics and Reading*. New York: Holt, Rinehart and Winston.

Frith, U. (1985). Beneath the surface of developmental dyslexia. In K. Patterson, J. C. Marshall, & M. Coltheart (Eds.), *Surface dyslexia: Neuropsychological and cognitive studies of phonological reading* (pp.32- 62). London: Lawrence Erlbaum.

Fuentes, L. J., & Campoy, G. (2008). The time course of alerting effect over orienting in the attention network test. *Experimental Brain Research, 185*(4), 667─672.

Fukuda, K., Woodman, G. F., & Vogel, E. K. (2015). Fukuda, K., Woodman, G.F. & Vogel, E.K. (2015). Individual differences in visual working memory capacity: Contributions of attentional control to storage. In Jolicoeur P., Lefebvre C., & Martinez-Trujillo J. (Eds.), *Mechanisms of Sensory Working Memory: Attention and Performance XXV* (pp. 105-120). New York: Academic Press.

Furnes, B., & Samuelsson, S. (2011). Phonological awareness and rapid automatized naming predicting early development in reading and spelling: Results from a cross-linguistic longitudinal study. *Learning and Individual Differences, 21*(1), 85─95.

Galaburda, A. M., Menard, M. T., & Rosen, G. D. (1994). Evidence for aberrant auditory anatomy in developmental dyslexia. *Proceedings of the National Academy of Sciences of the United States of America, 91*(17), 8010─8013.

Garlock, V. M., Walley, A. C., & Metsala, J. L. (2001). Age-of-acquisition, word frequency, and neighborhood density effects on spoken word recognition by children and adults. *Journal of Memory and Language, 45*(3), 468─492.

Gillon, G. T. (2018). *Phonological awareness: From research to practice*. New York, NY: Guilford Publications.

Gioia, G. A., Isquith, P. K., Guy, S. C., & Kenworthy, L. (2000). *Behavior Rating Inventory of Executive Function: BRIEF*. Odessa, Florida: Psychological Assessment Resources.

Goldfarb, L., & Shaul, S. (2013). Abnormal attentional internetwork link in dyslexic readers. *Neuropsychology, 27*(6), 725─729.

Gomes, H., Duff, M., Barnhardt, J., Barrett, S., & Ritter, W. (2007). Development of auditory selective attention: Event-related potential measures of channel selection and target detection. *Psychophysiology, 44*(5), 711─727.

Gomes, H., Molholm, S., Christodoulou, C., Ritter, W., & Cowan, N. (2000). The development of auditory attention in children. *Frontiers in Bioscience, 5,* 108─120.

Gomes, H., Wolfson, V., & Halperin, J. M. (2007). Is there a selective relationship between language functioning and auditory attention in children? *Journal of Clinical and Experimental Neuropsychology, 29*(6), 660─668.

Goolkasian, P. (2012). Research in visual pattern recognition: The enduring legacy of studies from the 1960s. *The American Journal of Psychology, 125*(2), 155─163.

Goswami, U. (2011). A temporal sampling framework for developmental dyslexia. *Trends in Cognitive Sciences, 15*(1), 3─10.

Goswami, U. (2015). Sensory theories of developmental dyslexia: Three challenges for research. *Nature Reviews Neuroscience, 16*(1), 43─54.

Goswami, U., & Bryant, P. (1989). The interpretation of studies using the reading level design. *Journal of Reading Behavior, 21*(4), 413─424.

Goswami, U., Ziegler, J. C., Dalton, L., & Schneider, W. (2001). Pseudohomophone effects and phonological recoding procedures in reading development in English and German. *Journal of Memory and Language, 45*(4), 648─664.

Grainger, J., Lété, B., Bertand, D., Dufau, S., & Ziegler, J. C. (2012). Evidence for multiple routes in learning to read. *Cognition, 123*(2), 280─292.

Gravetter, F. J. (2014). *Essentials of statistics for the behavioral sciences (8th ed.)*. Belmont, CA: Wadsworth Cengage Learning.

Gray, S. A., Rogers, M., Martinussen, R., & Tannock, R. (2015). Longitudinal relations among inattention, working memory, and academic achievement: Testing mediation and the moderating role of gender. *PeerJ, 3,* e939.

Griffiths, Y. M., & Snowling, M. J. (2002). Predictors of exception word and nonword reading in dyslexic children: The severity hypothesis. *Journal of Educational Psychology, 94*(1), 34─43.

Hakerem, G., & Sutton, S. (1966). Pupillary response at visual threshold. *Nature, 212*(5061), 485─486.

Hari, R., & Renvall, H. (2001). Impaired processing of rapid stimulus sequences in dyslexia. *Trends in Cognitive Sciences, 5*(12), 525─532.

Hari, R., Sääskilahti, A., Helenius, P., & Uutela, K. (1999). Non-impaired auditory phase locking in dyslexic adults. *Neuroreport, 10*(11), 2347─2348.

Harm, M. W., & Seidenberg, M. S. (1999). Phonology, reading acquisition, and dyslexia: Insights from connectionist models. *Psychological Review, 106*(3), 491─528.

Harm, M. W., & Seidenberg, M. S. (2004). Computing the meanings of words in reading: Cooperative division of labor between visual and phonological processes. *Psychological Review, 111*(3), 662─720.

Haroush, K., Deouell, L. Y., & Hochstein, S. (2011). Hearing while blinking: Multisensory attentional blink revisited. *Journal of Neuroscience, 31*(3), 922─927.

Hayduk, L. A., & Littvay, L. (2012). Should researchers use single indicators, best indicators, or multiple indicators in structural equation models? *BMC Medical Research Methodology, 12*(1), 1─17.

Hayes, A. F. (2009). Beyond Baron and Kenny: Statistical mediation analysis in the new millennium. *Communication Monographs, 76*(4), 408─420.

Hayes, A. F. (2013). *Introduction to mediation, moderation, and conditional process analysis: A regression-based approach*. New York, NY: Guilford Press.

Henderson, L. (2018). *Orthographies and reading: Perspectives from cognitive psychology, neuropsychology, and linguistics (3rd ed.).* London & New York: Routledge.

Hoogland, J. J., & Boomsma, A. (1998). Robustness studies in covariance structure modeling: An overview and a meta-analysis. *Sociological Methods & Research, 26*(3), 329─367.

Hoover, W., & Gough, P. (1990). The simple view of reading. *An Interdisciplinary Journal, 2*(2), 127─160.

Huberty, C. J. (2005). *Mahalanobis distance*. Statistics Reference Online: John Wiley & Sons, Ltd.

Huey, E. B. (1908). *The psychology and pedagogy of reading*: New York: The Macmillan Company.

Huie, M. K. (2010). *Exploring The relationship between oral and orthographic skills in deaf individuals* (Unpublished master's dissertation). State University of New York, New York, USA.

Hulme, C., Goetz, K., Gooch, D., Adams, J., & Snowling, M. J. (2007). Paired-associate learning, phoneme awareness, and learning to read. *Journal of Experimental Child Psychology, 96*(2), 150─166.

Hulme, C., & Snowling, M. (1992). Deficits in output phonology: An explanation of reading failure? *Cognitive Neuropsychology, 9*(1), 47─72.

Hulme, C., Snowling, M., Caravolas, M., & Carroll, J. (2005). Phonological skills are (probably) one cause of success in learning to read: A comment on Castles and Coltheart. *Scientific Studies of Reading, 9*(4), 351─365.

Hulme, C., & Snowling, M. J. (2009). *Developmental disorders of language learning and cognition*. Chichester: John Wiley & Sons.

Iglewicz, B., & Hoaglin, D. C. (1987). Use of boxplots for process evaluation. *Journal of Quality Technology, 19*(4), 180─190.

Irannejad, S., & Savage, R. (2012). Is a cerebellar deficit the underlying cause of reading disabilities? *Annals of Dyslexia, 62*(1), 22─52.

Jackson, N. E., & Butterfield, E. C. (1989). Reading-level-match designs: Myths and realities. *Journal of Literacy Research, 21*(4), 387─412.

Jackson, N. E., & Coltheart, M. (2001). *Routes to reading success and failure: Toward an integrated cognitive psychology of atypical reading* (Vol. 1). New York: Psychology Press.

Jared, D., & O'Donnell, K. (2017). Skilled adult readers activate the meanings of high-frequency words using phonology: Evidence from eye tracking. *Memory & Cognition, 45*(2), 334─346.

Jarrold, C., & Citroen, R. (2013). Re-evaluating key evidence for the development of rehearsal: Phonological similarity effects in children are subject to proportional scaling artifacts. *Developmental Psychology, 49*(5), 837─847.

Jennings, C. D. (2015). Consciousness without attention. *Journal of the American Philosophical Association, 1*(2), 276─295.

Jennings, J. M., Dagenbach, D., Engle, C. M., & Funke, L. J. (2007). Age-related changes and the attention network task: An examination of alerting, orienting, and executive function. *Aging, Neuropsychology, and Cognition, 14*(4), 353─369.

Johnson, M. H. (2002). The development of visual attention: A cognitive neuroscience perspective. In M. H. Johnson, Y. Munakata, & R. O. Gilmore (Eds.), *Brain development and cognition: A reader* (pp. 134─150). Oxford: Blackwell Publishers.

Johnston, R. S., Rugg, M. D., & Scott, T. (1987). Phonological similarity effects, memory span and developmental reading disorders: The nature of the relationship. *British Journal of Psychology, 78*(2), 205─211.

Jones, M., Branigan, H., Parra, M. A., & Logie, R. H. (2013). Cross-modal binding in developmental dyslexia. *Journal of Experimental Psychology: Learning, Memory and Cognition, 39*(6), 1807─1822.

Jöreskog, K. G. (1978). Structural analysis of covariance and correlation matrices. *Psychometrika, 43*(4), 443─477.

Julesz, B., & Hirsh, I. J. (1972). Visual and auditory perception: An essay of comparison. In E. E. David & P. B. Denes (Eds.), *Human communication: A unified view* (pp. 283-340). New York: McGraw-Hill.

Kahneman, D. (1973). *Attention and effort* (Vol. 1063). Englewood Cliffs, New Jersey: Prentice-Hall

Kahneman, D., Beatty, J., & Pollack, I. (1967). Perceptual deficit during a mental task. *Science, 157*(3785), 218─219.

Kamza, A. (2017). Developmental patterns of relationships between inhibitory control and reading skill in early-school children. *L1 Educational Studies in Language and Literature, 17*, 1─23.

Katz, R. B., Shankweiler, D., & Liberman, I. Y. (1981). Memory for item order and phonetic recoding in the beginning reader. *Journal of Experimental Child Psychology*, *32*(3), 474─484.

Katzir, T., Kim, Y.-S., Wolf, M., Morris, R., & Lovett, M. W. (2008). The varieties of pathways to dysfluent reading comparing subtypes of children with dyslexia at letter, word, and connected text levels of reading. *Journal of Learning Disabilities, 41*(1), 47─66.

Kenny, D. A. (1979). *Correlation and causality*. New York: Wiley.

Kenny, D.A. (2011, September 7). Multiple groups [Web log post]. Retrieved from http://davidakenny.net/cm/mgroups.htm

Kenny, D.A. (2015, November 24). Measuring model fit [Web log post]. Retrieved from http://davidakenny.net/cm/fit.htm

Kenny, D. A. (2018, September 25). Effect size of the indirect effect and the computation of power [Web log post]. Retrieved from http://davidakenny.net /cm/mediate.htm

Kenny, D. A., Kaniskan, B., & McCoach, D. B. (2015). The performance of RMSEA in models with small degrees of freedom. *Sociological Methods & Research, 44*(3), 486─507.

Kirby, J. R., Parrila, R. K., & Pfeiffer, S. L. (2003). Naming speed and phonological awareness as predictors of reading development. *Journal of Educational Psychology, 95*(3), 453─464.

Kleiman, G. M. (1975). Speech recoding in reading. *Journal of Verbal Learning and Verbal Behavior, 14*(4), 323─339.

Klein, R. M. (2000). Inhibition of return. *Trends in Cognitive Sciences, 4*(4), 138─147.

Kline, P. (2014). *An easy guide to factor analysis*. UK, USA & Canada: Routledge.

Kline, R. B. (2011). *Convergence of structural equation modeling and multilevel modeling*. New York, NY: The Guilford Press.

Kuppen, S. E., & Goswami, U. (2016). Developmental trajectories for children with dyslexia and low IQ poor readers. *Developmental Psychology, 52*(5), 717─734.

LaBerge, D., Carlson, R. L., Williams, J. K., & Bunney, B. G. (1997). Shifting attention in visual space: Tests of moving-spotlight models versus an activity-distribution model. *Journal of Experimental Psychology: Human Perception and Performance, 23*(5), 1380─1392.

LaBerge, D., & Samuels, S. J. (1974). Toward a theory of automatic information processing in reading. *Cognitive Psychology, 6*(2), 293─323.

Lam, C. M., & Beale, I. L. (1991). Relations among sustained attention, reading performance, and teachers' ratings of behavior problems. *Remedial and Special Education, 12*(2), 40─47.

Lam, S. S.-Y., White-Schwoch, T., Zecker, S. G., Hornickel, J., & Kraus, N. (2017). Neural stability: A reflection of automaticity in reading. *Neuropsychologia, 103*, 162─167.

Lamb, M. R., Robertson, L. C., & Knight, R. T. (1989). Attention and interference in the processing of global and local information: Effects of unilateral temporal-parietal junction lesions. *Neuropsychologia, 27*(4), 471─483.

Landerl, K., & Wimmer, H. (2008). Development of word reading fluency and spelling in a consistent orthography: An 8-year follow-up. *Journal of Educational Psychology, 100*(1), 150─161.

Lavie, N., Beck, D. M., & Konstantinou, N. (2014). Blinded by the load: Attention, awareness and the role of perceptual load. *Philosophical Transactions of the Royal Society B: Biological Sciences, 369*(1641), 1─10.

Lavie, N., Hirst, A., De Fockert, J. W., & Viding, E. (2004). Load theory of selective attention and cognitive control. *Journal of Experimental Psychology: General, 133*(3), 339─354.

Leinenger, M. (2014). Phonological coding during reading. *Psychological Bulletin, 140*(6), 1534─1555.

Lervåg, A., Bråten, I., & Hulme, C. (2009). The cognitive and linguistic foundations of early reading development: A Norwegian latent variable longitudinal study. *Developmental Psychology, 45*(3), 764─781.

Liberman, I., Shankweiler, D., Liberman, A., Fowler, C., & Fisher, F. (1977). Phonetic segmentation and recoding in the beginning reader. In S. Reber & D.L. Scarborough (Eds.), *Towards a psychology of reading* (pp. 207-226). Hillsdale, NJ: Lawrence Erlbaum Associates.

Liberman, I. Y., Shankweiler, D., & Liberman, A. M. (1989). The alphabetic principle and learning to read. In D. Shankweiler & I. Y. Liberman (Eds.), *International Academy for Research in Learning Disabilities monograph series, No. 6. Phonology and reading disability: Solving the reading puzzle* (pp. 1─33). Ann Arbor, MI, US: The University of Michigan Press.

Liew, J. (2012). Effortful control, executive functions, and education: Bringing self-regulatory and social-emotional competencies to the table. *Child Development Perspectives, 6*(2), 105─111.

Livingstone, M. S., Rosen, G. D., Drislane, F. W., & Galaburda, A. M. (1991). Physiological and anatomical evidence for a magnocellular defect in developmental dyslexia. *Proceedings of the National Academy of Sciences of the United States of America, 88*(18), 7943─7947.

Logan, G. D. (2002). An instance theory of attention and memory. *Psychological Review, 109*(2), 376─400.

Luce, R. D. (1986). *Response times: Their role in inferring elementary mental organization (Vol. 8)*. NY, New York: Oxford University Press

Lukatela, G., & Turvey, M. (1991). Phonological access of the lexicon: Evidence from associative priming with pseudohomophones. *Journal of Experimental Psychology: Human Perception and Performance, 17*(4), 951─966.

Lukatela, G., & Turvey, M. T. (1994). Visual lexical access is initially phonological: 1. Evidence from associative priming by words, homophones, and pseudohomophones. *Journal of Experimental Psychology: General, 123*(2), 107‒128.

MacKinnon, D. P., Lockwood, C. M., Hoffman, J. M., West, S. G., & Sheets, V. (2002). A comparison of methods to test mediation and other intervening variable effects. *Psychological Methods, 7*(1), 83‒104.

MacLean, K. A., Ferrer, E., Aichele, S. R., Bridwell, D. A., Zanesco, A. P., Jacobs, T. L., . . . Shaver, P. R. (2010). Intensive meditation training improves perceptual discrimination and sustained attention. *Psychological Science, 21*(6), 829‒839.

Macleod, J. W., Lawrence, M. A., McConnell, M. M., Eskes, G. A., Klein, R. M., & Shore, D. I. (2010). Appraising the ANT: Psychometric and theoretical considerations of the attention network test. *Neuropsychology, 24*(5), 637‒651.

Maltzman, I., & Raskin, D. C. (1965). Effects of individual differences in the orienting reflex on conditioning and complex processes. *Journal of Experimental Research in Personality, 1*(1), 1‒16.

Maris, E., & de Graaff Stoffers, R. (2009). Dual and single route models for beginning readers: A comparison by means of multinomial processing tree models. *Zeitschrift für Psychologie/Journal of Psychology, 217*(3), 159‒174.

Markus, K. A. (2012). Principles and practice of structural equation modeling by Rex B. Kline. *Structural Equation Modeling: A Multidisciplinary Journal, 19*(3), 509‒512.

Marsh, H. W., Muthén, B., Asparouhov, T., Lüdtke, O., Robitzsch, A., Morin, A. J., & Trautwein, U. (2009). Exploratory structural equation modeling, integrating CFA and EFA: Application to students' evaluations of university teaching. *Structural Equation Modeling: A Multidisciplinary Journal, 16*(3), 439‒476.

Marvel, C. L., & Desmond, J. E. (2012). From storage to manipulation: How the neural correlates of verbal working memory reflect varying demands on inner speech. *Brain and Language, 120*(1), 42‒51.

Marzocchi, G. M., Ornaghi, S., & Barboglio, S. (2009). What are the causes of the attention deficits observed in children with dyslexia? *Child Neuropsychology, 15*(6), 567—581.

Matsukura, M., & Vecera, S. P. (2015). Selection of multiple cued items is possible during visual short-term memory maintenance. *Attention, Perception, & Psychophysics, 77*(5), 1625—1646.

Mattingly, I. G. (1972). Reading, the linguistic process, and linguistic awareness. In J. F. Kavanagh & I. G. Mattingly (Eds.), *Language by ear and by eye: The relationships between speech and reading* (pp. 133—147). Cambridge, MA: MIT Press.: ERIC.

McBride-Chang, C. (1999). The ABCs of the ABCs: The development of letter-name and letter-sound knowledge. *Merrill-Palmer Quarterly 45*(2), 285—308.

McCandliss, B. D., Cohen, L., & Dehaene, S. (2003). The visual word form area: Expertise for reading in the fusiform gyrus. *Trends in Cognitive Sciences, 7*(7), 293—299.

McCann, R. S., Folk, C. L., & Johnston, J. C. (1992). The role of spatial attention in visual word processing. *Journal of Experimental Psychology: Human Perception and Performance, 18*(4), 1015—1029.

McDonald, J. J., & Ward, L. M. (1999). Spatial relevance determines facilitatory and inhibitory effects of auditory covert spatial orienting. *Journal of Experimental Psychology: Human Perception and Performance, 25*(5), 1234—1252.

Melby-Lervåg, M. (2012). The relative predictive contribution and causal role of phoneme awareness, rhyme awareness, and verbal short-term memory in reading skills: A review. *Scandinavian Journal of Educational Research, 56*(1), 101—118.

Melby-Lervåg, M., & Hulme, C. (2010). Serial and free recall in children can be improved by training evidence for the importance of phonological and semantic representations in immediate memory tasks. *Psychological Science, 21*(11), 1694—1700.

Melby-Lervåg, M., Lyster, S.-A. H., & Hulme, C. (2012). Phonological skills and their role in learning to read: A meta-analytic review. *Psychological Bulletin, 138*(2), 322—352.

Meltzer, L. (2007). *Executive function in education: From theory to practice*. New York, NY: Guilford Publications.

Menghini, D., Finzi, A., Benassi, M., Bolzani, R., Facoetti, A., Giovagnoli, S., . . . Vicari, S. (2010). Different underlying neurocognitive deficits in developmental dyslexia: A comparative study. *Neuropsychologia, 48*(4), 863─872.

Meschyan, G., & Hernandez, A. (2002). Age of acquisition and word frequency: Determinants of object-naming speed and accuracy. *Memory & Cognition, 30*(2), 262─269.

Meyer, M. S., Wood, F. B., Hart, L. A., & Felton, R. H. (1998). Selective predictive value of rapid automatized naming in poor readers. *Journal of Learning Disabilities, 31*(2), 106─117.

Mezzacappa, E. (2004). Alerting, orienting, and executive attention: Developmental properties and sociodemographic correlates in an epidemiological sample of young, urban children. *Child Development, 75*(5), 1373─1386.

Miellet, S., & Sparrow, L. (2004). Phonological codes are assembled before word fixation: Evidence from boundary paradigm in sentence reading. *Brain and Language, 90*(1-3), 299─310.

Milfont, T. L., & Fischer, R. (2010). Testing measurement invariance across groups: Applications in crosscultural research. *International Journal of Psychological Research, 3*(1), 111─121.

Miočević, M., O'Rourke, H. P., MacKinnon, D. P., & Brown, H. C. (2018). Statistical properties of four effect-size measures for mediation models. *Behavior Research Methods, 50*(1), 285─301.

Mitko, A., Prinzmetal, W., Esterman, M., & List, A. (2015). An EEG study of illusory conjunctions. *Journal of Vision, 15*(12), 894─894.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology, 41*(1), 49─100.

Mondor, T., & Bryden, M. (1991). The influence of attention on the dichotic REA. *Neuropsychologia, 29*(12), 1179─1190.

Mondor, T., & Bryden, M. (1992). On the relation between auditory spatial attention and auditory perceptual asymmetries. *Attention, Perception, & Psychophysics, 52*(4), 393─402.

Moray, N. (1967). Where is capacity limited? A survey and a model. *Acta Psychologica, 27*, 84─92.

Morken, F., Helland, T., Hugdahl, K., & Specht, K. (2017). Reading in dyslexia across literacy development: A longitudinal study of effective connectivity. *NeuroImage, 144*, 92─100.

Morrison, F. J. (1982). The development of alertness. *Journal of Experimental Child Psychology, 34*(2), 187─199.

Munck, I. M. (1979). *Model building in comparative education:Applications of the LISREL method to cross-national survey data.* Stockholm: Almqvist & Wiksell international.

Muter, V., Hulme, C., Snowling, M. J., & Stevenson, J. (2004). Phonemes, rimes, vocabulary, and grammatical skills as foundations of early reading development: Evidence from a longitudinal study. *Developmental Psychology, 40*(5), 665─681.

Muthén, B. (2016, May 4). Re: Over vs just identified models [Online forum comment]. Retrieved from http://www.statmodel.com/discussion/messages/11/22753.html?1462411981

Muthén, B. (2017, May 31). Re: Effect size [Online forum comment]. Retrieved from http://www.statmodel.com/discussion/messages/11/21476.html?1496277332

Muthén, B. (2018a, January 20). Re: Difference testing using chi-square [Online forum comment]. Retrieved from http://www.statmodel.com/discussion/messages/11/8230.html?1516584165

Muthén, B. (2018b, June 20). Re: Over vs just identified models [Online forum comment]. Retrieved from http://www.statmodel.com/discussion/messages/11/22753.html?1462411981

Muthén, L. K. (2010, November 29). RE: Single indicator latent variables! [Online forum comment]. Retrieved from http://www.statmodel.com/discussion/messages/11/596.html?1458568070

Muthén, L. K. (2012, March 31). Re: Standardizing vs. rescaling indicators [Online forum comment]. Retrieved from http://www.statmodel.com/discussion/messages/11/9305.html?1333473182

Muthén, L. K. (2013, November 26). Re: Negative residual variance message? [Online forum comment]. Retrieved from http://www.statmodel.com/discussion/messages/9/17688.html?1385474732

Muthén, B., & Muthén, L. (2008, August 6). Topic 1. Introductory - advanced factor analysis and structural equation modeling with continuous outcomes [Video file]. Retrieved from https://www.statmodel.com/course_materials.shtml

Muthén, B., & Muthén, L. (2018, October 1). Mplus. Retrieved from https://www.statmodel.com/index.shtml

Muthén, L. K., & Muthén, B. O. (2008). *Mplus (Version 5.2)*. Los Angeles, CA: Muthén & Muthén.

Neisser, U. (1976). Cognition and reality: *Principles and implication of cognitive psychology*. San Francisco: Freeman.

Nicolson, R. I., & Fawcett, A. J. (2006). Do cerebellar deficits underlie phonological problems in dyslexia? *Developmental Science, 9*(3), 259─262.

Nicolson, R. I., & Fawcett, A. J. (2007). Procedural learning difficulties: Reuniting the developmental disorders? *TRENDS in Neurosciences*, *30*(4), 135─141.

Nimmo, L. M., & Roodenrys, S. (2004). Investigating the phonological similarity effect: Syllable structure and the position of common phonemes. *Journal of Memory and Language*, *50*(3), 245─258.

Norton, E. S., & Wolf, M. (2012). Rapid automatized naming (RAN) and reading fluency: Implications for understanding and treatment of reading disabilities. *Annual Review of Psychology*, *63*, 427─452.

Oken, B. S., Salinsky, M. C., & Elsas, S. M. (2006). Vigilance, alertness, or sustained attention: Physiological basis and measurement. *Clinical Neurophysiology : Official Journal of the International Federation of Clinical Neurophysiology, 117*(9), 1885─1901.

Pallant, J. (2013). *SPSS survival manual (5th ed.)*. Buckingham: Open University Press.

Panel, N. R., Health, N. I. o. C., & Development, H. (2000). Alphabetics Part II: Phonics instruction. In *Report of the National Reading Panel: Teaching children to read: An evidence-based assessment of the scientific research* *literature on reading and its implications for reading instruction: Reports of the subgroups*. Rockville, MD: NICHD Clearinghouse.

Parasuraman, R., Warm, J. S., & See, J. E. (1998). Brain systems of vigilance. In R. Parasuraman (Ed.), *The attentive brain* (pp. 221─256). Cambridge, MA, US: The MIT Press.

Parrila, R., Kirby, J. R., & McQuarrie, L. (2004). Articulation rate, naming speed, verbal short-term memory, and phonological awareness: Longitudinal predictors of early reading development? *Scientific Studies of Reading, 8*(1), 3─26.

Pelli, D. G. (2008). Crowding: A cortical constraint on object recognition. *Current Opinion in Neurobiology, 18*(4), 445─451.

Perfetti, C. A. (2013). Representations and awareness in the acquisition of reading competence. In L. Rieben & C. Perfetti (Eds.), *Learning to read: Basic research and its implications* (pp. 33-46). New York: Routledge.

Perry, C., Ziegler, J. C., & Zorzi, M. (2007). Nested incremental modeling in the development of computational theories: The CDP+ model of reading aloud. *Psychological Review, 114*(2), 273─315.

Petersen, S. E., & Posner, M. I. (2012). The attention system of the human brain: 20 years after. *Annual Review of Neuroscience, 35*, 73─89.

Plaut, D. C., & Kello, C. T. (1999). The emergence of phonology from the interplay of speech comprehension and production: A distributed connectionist approach. In B. MacWhinney (Ed.), *The emergence of language* (pp. 381─415). Mahwah, NJ: Erlbaum.

Plaut, D. C., McClelland, J. L., Seidenberg, M. S., & Patterson, K. (1996). Understanding normal and impaired word reading: Computational principles in quasi-regular domains. *Psychological Review, 103*(1), 56─115.

Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology, 32*(1), 3─25.

Posner, M. I. (2008). Measuring alertness. *Annals of the New York Academy of Sciences, 1129*(1), 193─199.

Posner, M. I., & Petersen, S. E. (1990). The attention system of the human brain. *Annual Review of Neuroscience, 13*(1), 25─42.

Posner, M. I., Rafal, R. D., Choate, L. S., & Vaughan, J. (1985). Inhibition of return: Neural basis and function. *Cognitive Neuropsychology, 2*(3), 211─228.

Posner, M. I., & Rothbart, M. K. (2007). *Educating the human brain*. Washington DC: American Psychological Association.

Posner, M. I., Rothbart, M. K., & Voelker, P. (2016). Developing brain networks of attention. *Current Opinion in Pediatrics, 28*(6), 720─724.

Pozuelos, J. P., Paz-Alonso, P. M., Castillo, A., Fuentes, L. J., & Rueda, M. R. (2014). Development of attention networks and their interactions in childhood. *Developmental Psychology, 50*(10), 2405─2415.

Preacher, K. J., & Hayes, A. F. (2008). Asymptotic and resampling strategies for assessing and comparing indirect effects in multiple mediator models. *Behavior Research Methods, 40*(3), 879─891.

Preacher, K. J., Rucker, D. D., & Hayes, A. F. (2007). Addressing moderated mediation hypotheses: Theory, methods, and prescriptions. *Multivariate Behavioral Research, 42*(1), 185─227.

Prinz, J. (2012). *The conscious brain*. New York: Oxford University Press.

Pritchard, S. C., Coltheart, M., Palethorpe, S., & Castles, A. (2012). Nonword reading: Comparing dual-route cascaded and connectionist dual-process models with human data. *Journal of Experimental Psychology: Human Perception and Performance, 38*(5), 1268─1288.

Protopapas, A., Altani, A., & Georgiou, G. K. (2013). Development of serial processing in reading and rapid naming. *Journal of Experimental Child Psychology*, *116*(4), 914─929.

Rabe-Hesketh, S., Skrondal, A., & Pickles, A. (2005). Maximum likelihood estimation of limited and discrete dependent variable models with nested random effects. *Journal of Econometrics, 128*(2), 301─323.

Ramus, F. (2003). Developmental dyslexia: Specific phonological deficit or general sensorimotor dysfunction? *Current Opinion in Neurobiology, 13*(2), 212─218.

Ramus, F. (2014). Neuroimaging sheds new light on the phonological deficit in dyslexia. *Trends in Cognitive Sciences, 18*(6), 274─275.

Ramus, F., Rosen, S., Dakin, S. C., Day, B. L., Castellote, J. M., White, S., & Frith, U. (2003). Theories of developmental dyslexia: Insights from a multiple case study of dyslexic adults. *Brain, 126*(4), 841─865.

Ramus, F., & Szenkovits, G. (2008). What phonological deficit? *The Quarterly Journal of Experimental Psychology, 61*(1), 129─141.

Rastle, K. (2015). Visual word recognition. In G. Hickok & S. Small (Eds.), *Neurobiology of language* (pp. 255-264). doi.org/10.1016/B978-0-12-407794-2.00021-3.

Raye, C. L., Johnson, M. K., Mitchell, K. J., Greene, E. J., & Johnson, M. R. (2007). Refreshing: A minimal executive function. *Cortex, 43*(1), 135─145.

Rayner, K. (2009). Eye movements and attention in reading, scene perception, and visual search. *The Quarterly Journal of Experimental Psychology, 62*(8), 1457─1506.

Rayner, K., Pollatsek, A., Ashby, J., & Clifton Jr, C. (2012). *Psychology of reading (2nd ed.)*. New York: Psychology Press.

Raz, A. (2004). Anatomy of attentional networks. *The Anatomical Record Part B: The New Anatomist: An Official Publication of the American Association of Anatomists, 281*(1), 21─36.

Reynolds, J. H., & Desimone, R. (2000). Competative mechanism subserve selective visual attention. In A.P. Marantz, Y. Miyashita & W. O'Neil (Eds.), *Image, Language, Brain: Papers from First Mind Articulation Project Symposium* (pp. 233-247). Cambridge, MA: Massachusetts Institute of Technology.

Reynolds, J. H., & Heeger, D. J. (2009). The normalization model of attention. *Neuron, 61*(2), 168─185.

Reynolds, M., & Besner, D. (2006). Reading aloud is not automatic: Processing capacity is required to generate a phonological code from print. *Journal of Experimental Psychology: Human Perception and Performance, 32*(6), 1303─1323.

Reynolds, M., & Besner, D. (2008). Contextual effects on reading aloud: Evidence for pathway control. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 34*(1), 50─64.

Risko, E. F., Stolz, J. A., & Besner, D. (2010). Spatial attention modulates feature crosstalk in visual word processing. *Attention, Perception, & Psychophysics, 72*(4), 989─998.

Roberts, K. L., Summerfield, A. Q., & Hall, D. A. (2006). Presentation modality influences behavioral measures of alerting, orienting, and executive control. *Journal of the International Neuropsychological Society, 12*(04), 485─492.

Rodríguez, C., van den Boer, M., Jiménez, J. E., & de Jong, P. F. (2015). Developmental changes in the relations between RAN, phonological awareness, and reading in Spanish children. *Scientific Studies of Reading, 19*(4), 273─288.

Rosen, S. (2003). Auditory processing in dyslexia and specific language impairment: Is there a deficit? What is its nature? Does it explain anything? *Journal of Phonetics, 31*(3–4), 509─527.

Rossi, A. F., Bichot, N. P., Desimone, R., & Ungerleider, L. G. (2007). Top–down attentional deficits in macaques with lesions of lateral prefrontal cortex. *Journal of Neuroscience, 27*(42), 11306─11314.

Rubenstein, H., Lewis, S. S., & Rubenstein, M. A. (1971). Evidence for phonemic recoding in visual word recognition. *Journal of Verbal Learning and Verbal Behavior, 10*(6), 645─657.

Rucker, D. D., Preacher, K. J., Tormala, Z. L., & Petty, R. E. (2011). Mediation analysis in social psychology: Current practices and new recommendations. *Social and Personality Psychology Compass, 5*(6), 359─371.

Rueda, M. R., Fan, J., McCandliss, B. D., Halparin, J. D., Gruber, D. B., Lercari, L. P., & Posner, M. I. (2004). Development of attentional networks in childhood. *Neuropsychologia, 42*(8), 1029─1040.

Ruffino, M., Gori, S., Boccardi, D., Molteni, M., & Facoetti, A. (2014). Spatial and temporal attention in developmental dyslexia. *Frontiers in Human Neuroscience, 8*, 331.

Russell, G., Ukoumunne, O. C., Ryder, D., Golding, J., & Norwich, B. (2016). Predictors of word-reading ability in 7-year-olds: Analysis of data from a UK cohort study. *Journal of Research in Reading, 41*(1), 58─78.

Ruthruff, E., Allen, P. A., Lien, M.-C., & Grabbe, J. (2008). Visual word recognition without central attention: Evidence for greater automaticity with greater reading ability. *Psychonomic Bulletin & Review, 15*(2), 337─343.

Sandak, R., Mencl, W. E., Frost, S. J., & Pugh, K. R. (2004). The neurobiological basis of skilled and impaired reading: Recent findings and new directions. *Scientific Studies of Reading, 8*(3), 273─292.

Satorra, A., & Bentler, P. M. (2010). Ensuring positiveness of the scaled difference chi-square test statistic. *Psychometrika, 75*(2), 243─248.

Schechter, C. (2017, March 28). Re: Significant total effects, non-sig direct and indirect effects, why? [Online forum]. Retrieved from https://www.statalist.org/forums/forum/general-stata-discussion/general/1380745-significant-total-effects-non-sig-direct-and-indirect-effects-why

Schermelleh-Engel, K., Moosbrugger, H., & Müller, H. (2003). Evaluating the fit of structural equation models: Tests of significance and descriptive goodness-of-fit measures. *Methods of Psychological Research Online, 8*(2), 23─74.

Seidenberg, M. S. (2005). Connectionist models of word reading. *Current Directions in Psychological Science, 14*(5), 238─242.

Seidenberg, M. S., & McClelland, J. L. (1989). A distributed, developmental model of word recognition and naming. *Psychological Review, 96*(4), 523─568.

Sereno, S. C., & Rayner, K. (2000). Spelling-sound regularity effects on eye fixations in reading. *Perception & Psychophysics, 62*(2), 402─409.

Shaywitz, S. E., & Shaywitz, B. A. (2008). Paying attention to reading: The neurobiology of reading and dyslexia. *Development and Psychopathology, 20*(04), 1329─1349.

Shrout, P. E., & Bolger, N. (2002). Mediation in experimental and nonexperimental studies: New procedures and recommendations. *Psychological Methods, 7*(4), 422─445.

Singleton, C., & Trotter, S. (2005). Visual stress in adults with and without dyslexia. *Journal of Research in Reading*, *28*(3), 365─378.

Sokolov, A. (1972). *Inner Speech and Thought*. New York, London: Plenum Press.

Sokolov, E. N. (1963). Higher nervous functions: The orienting reflex. *Annual Review of Physiology, 25*(1), 545─580.

Spagna, A., Mackie, M.-A., & Fan, J. (2015). Supramodal executive control of attention. *Frontiers in Psychology, 6*, 65.

Speelman, C. P., & Kirsner, K. (2005). *Beyond the learning curve: The construction of mind*. New York: Oxford University Press.

Sperling, G., & Weichselgartner, E. (1995). Episodic theory of the dynamics of spatial attention. *Psychological Review, 102*(3), 503─532.

Spira, E. G., Bracken, S. S., & Fischel, J. E. (2005). Predicting improvement after first-grade reading difficulties: The effects of oral language, emergent literacy, and behavior skills. *Developmental Psychology, 41*(1), 225─234.

Stanovich, K. E. (1980). Toward an interactive-compensatory model of individual differences in the development of reading fluency. *Reading Research Quarterly, 16*(1), 32–71.

Stanovich, K. E., Cunningham, A. E., & Feeman, D. J. (1984). Intelligence, cognitive skills, and early reading progress. *Reading Research Quarterly*(19), 278–303.

Stanovich, K. E., Nathan, R. G., & Zolman, J. E. (1988). The developmental lag hypothesis in reading: Longitudinal and matched reading-level comparisons. *Child Development, 59*(1), 71–86.

Stein, J. (2003). Visual motion sensitivity and reading. *Neuropsychologia, 41*(13), 1785–1793.

Stein, J., & Walsh, V. (1997). To see but not to read; the magnocellular theory of dyslexia. *Trends in Neurosciences, 20*(4), 147–152.

Stern, P., & Shalev, L. (2013). The role of sustained attention and display medium in reading comprehension among adolescents with ADHD and without it. *Research in Developmental Disabilities, 34*(1), 431–439.

Stewart, H. J., & Amitay, S. (2015). Modality-specificity of Selective Attention Networks. *Frontiers in Psychology, 6*.

Stoodley, C. J., & Stein, J. F. (2013). Cerebellar function in developmental dyslexia. *Cerebellum, 12*(2), 267–276.

Sturm, W., & Willmes, K. (2001). On the functional neuroanatomy of intrinsic and phasic alertness. *Neuroimage, 14*(1), S76–S84.

Swanson, H. L., Trainin, G., Necoechea, D. M., & Hammill, D. D. (2003). Rapid naming, phonological awareness, and reading: A meta-analysis of the correlation evidence. *Review of Educational Research, 73*(4), 407–440.

Szenkovits, G., & Ramus, F. (2005). Exploring dyslexics' phonological deficit I: Lexical vs sub-lexical and input vs output processes. *Dyslexia, 11*(4), 253–268.

Tabachnick, B. G. (2013). *Using multivariate statistics (6th ed.)*. Boston: Pearson Education.

Tabachnick, B. G., & Fidell, L. S. (2007). *Using multivariate statistics (5th ed.)*. Boston, MA: Allyn & Bacon/Pearson Education.

Taft, M. (2013). *Reading and the mental lexicon*. London: Psychology Press.

Tallal, P. (1980). Auditory temporal perception, phonics, and reading disabilities in children. *Brain and Language, 9*(2), 182─198.

Tallal, P. (2006). What happens when dyslexic subjects do not meet the criteria for dyslexia and sensorimotor tasks are too difficult even for controls? *Developmental Science, 9*(3), 262─264.

Tallal, P., Miller, S., & Fitch, R. H. (1993). Neurobiological basis of speech: A case for the preeminence of temporal processing. *Annals of the New York Academy of Sciences, 682*(1), 27─47.

Tang, Y.-Y., & Posner, M. I. (2009). Attention training and attention state training. *Trends in Cognitive Sciences, 13*(5), 222─227.

Timmann, D., Drepper, J., Frings, M., Maschke, M., Richter, S., Gerwig, M. e., . . . Kolb, F. (2010). The human cerebellum contributes to motor, emotional and cognitive associative learning. A review. *Cortex, 46*(7), 845─857.

Tomarken, A. J., & Waller, N. G. (2003). Potential problems with" well fitting" models. *Journal of Abnormal Psychology, 112*(4), 578─598.

Torgesen, J. K. (1988). Studies of children with learning disabilities who perform poorly on memory span tasks. *Journal of Learning Disabilities, 21*(10), 605─612.

Torgesen, J. K. (1998). Catch them before they fall. *American Educator, 22*, 32─41.

Torgesen, J. K., Wagner, R. K., Rashotte, C. A., Burgess, S., & Hecht, S. (1997). Contributions of phonological awareness and rapid automatic naming ability to the growth of word-reading skills in second-to fifth-grade children. *Scientific Studies of Reading, 1*(2), 161─185.

Treisman, A. (1996). The binding problem. *Current Opinion in Neurobiology, 6*(2), 171─178.

Treisman, A. (2006). How the deployment of attention determines what we see. *Visual Cognition, 14*(4-8), 411─443.

Treisman, A., & Schmidt, H. (1982). Illusory conjunctions in the perception of objects. *Cognitive Psychology, 14*(1), 107─141.

Treisman, A. M. (1969). Strategies and models of selective attention. *Psychological Review, 76*(3), 282─299.

Treisman, A. M., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology, 12*(1), 97─136.

Trussell, L. O. (1997). Cellular mechanisms for preservation of timing in central auditory pathways. *Current Opinion in Neurobiology, 7*(4), 487─492.

Tucker, L. R., & Lewis, C. (1973). A reliability coefficient for maximum likelihood factor analysis. *Psychometrika, 38*(1), 1─10.

Turkeltaub, P. E., Gareau, L., Flowers, D. L., Zeffiro, T. A., & Eden, G. F. (2003). Development of neural mechanisms for reading. *Nature Neuroscience, 6*(7), 767─773.

Unger, S. M. (1964). Habituation of the vasoconstrictive orienting reaction. *Journal of Experimental Psychology, 67*(1), 11─18.

Valdois, S., Bosse, M. L., & Tainturier, M. J. (2004). The cognitive deficits responsible for developmental dyslexia: Review of evidence for a selective visual attentional disorder. *Dyslexia, 10*(4), 339─363.

van de Sande, E., Segers, E., & Verhoeven, L. (2013). How phonological awareness mediates the relation between children's self-control and word decoding. *Learning and Individual Differences, 26*, 112─118.

Van Orden, G. C. (1987). A ROWS is a ROSE: Spelling, sound, and reading. *Memory & Cognition, 15*(3), 181─198.

Vandenberg, R. J., & Lance, C. E. (2000). A review and synthesis of the measurement invariance literature: Suggestions, practices, and recommendations for organizational research. *Organizational Research Methods, 3*(1), 4─70.

Vellutino, F. R., & Scanlon, D. M. (1989). Some prerequisites for interpreting results from reading level matched designs. *Journal of Reading Behavior, 21*(4), 361─385.

Vidyasagar, T. R., & Pammer, K. (2010). Dyslexia: A deficit in visuo-spatial attention, not in phonological processing. *Trends in Cognitive Sciences, 14*(2), 57─63.

Waechter, S., Besner, D., & Stolz, J. A. (2011). Basic processes in reading: Spatial attention as a necessary preliminary to orthographic and semantic processing. *Visual Cognition, 19*(2), 171─202.

Wagner, R., Torgesen, J., & Rashotte, C. (1994). Development of reading-related phonological processing abilities-new evidence of bidirectional causality from a latent variable longitudinal study. *Developmental Psyhology 30*(1), 73─87.

Wagner, R., Torgesen, J., & Rashotte, C. (1999). *Comprehensive test of phonological processes (CTOPP)*. Austin, TX: Pro-Ed.

Wagner, R. K., & Torgesen, J. K. (1987). The nature of phonological processing and its causal role in the acquisition of reading skills. *Psychological Bulletin, 101*(2), 192–212.

Wagner, R. K., Torgesen, J. K., Rashotte, C. A., & Pearson, N. A. (2013). *CTOPP-2: Comprehensive test of phonological processing*. Austin, TX: Pro-ed.

Walcott, C. M., Scheemaker, A., & Bielski, K. (2010). A longitudinal investigation of inattention and preliteracy development. *Journal of Attention Disorders, 14*(1), 79–85.

Ward, L. M. (1994). Supramodal and Modality-Specific Mechanisms for Stimulus-Driven Shifts of Auditory and Visual Attention. *Canadian Journal of Experimental Psychology/Revue canadienne de psychologie expérimentale, 48*(2), 242–259.

Watzl, S. (2017). *Structuring mind: The nature of attention and how it shapes consciousness*. NY, New York: Oxford University Press.

Weinbach, N., & Henik, A. (2011). Phasic alertness can modulate executive control by enhancing global processing of visual stimuli. *Cognition, 121*(3), 454–458.

Weinbach, N., & Henik, A. (2012). The relationship between alertness and executive control. *Journal of Experimental Psychology: Human Perception and Performance, 38*(6), 1530–1540.

Weinbach, N., & Henik, A. (2013). The interaction between alerting and executive control: Dissociating phasic arousal and temporal expectancy. *Attention, Perception, & Psychophysics, 75*(7), 1374–1381.

White, S., Milne, E., Rosen, S., Hansen, P., Swettenham, J., Frith, U., & Ramus, F. (2006). The role of sensorimotor impairments in dyslexia: A multiple case study of dyslexic children. *Developmental Science, 9*(3), 237–255.

Wiebe, S. A., & McFall, G. P. (2014). Revisiting Executive Function Measurement: Implications for Lifespan Development. *Measurement: Interdisciplinary Research & Perspectives, 12*(3), 115–117.

Wise Younger, J., Tucker-Drob, E., & Booth, J. R. (2017). Longitudinal changes in reading network connectivity related to skill improvement. *NeuroImage, 158*, 90–98.

Witton, C., Richardson, A., Griffiths, T., Rees, A., & Green, G. (1997). Temporal pattern analysis in dyslexia. *British Journal of Audiology, 31*(2), 100‒101.

Witton, C., & Talcott, J. B. (2018). Auditory processing in developmental dyslexia: Some considerations and challenges. In T. Lachmann & T. Weis (Eds.), *Reading and Dyslexia: From Basic Functions to Higher Order Cognition* (pp. 129‒140). Cham: Springer International Publishing.

Wlotko, E. W., Federmeier, K. D., & Kutas, M. (2012). To predict or not to predict: Age-related differences in the use of sentential context. *Psychology and Aging*, *27*(4), 975‒988.

Wolf, E. J., Harrington, K. M., Clark, S. L., & Miller, M. W. (2013). Sample Size Requirements for Structural Equation Models: An Evaluation of Power, Bias, and Solution Propriety. *Educational and Psychological Measurement, 76*(6), 913‒934.

Wolf, M., & Bowers, P. G. (1999). The double-deficit hypothesis for the developmental dyslexias. *Journal of Educational Psychology, 91*(3), 415‒438.

Wolf, M., Bowers, P. G., & Biddle, K. (2000). Naming-speed processes, timing, and reading: A conceptual review. *Journal of Learning Disabilities, 33*(4), 387‒407.

Wolf, M., & Obregón, M. (1992). Early naming deficits, developmental dyslexia, and a specific deficit hypothesis. *Brain and Language, 42*(3), 219‒247.

Wolff, U. (2014). RAN as a predictor of reading skills, and vice versa: Results from a randomised reading intervention. *Annals of Dyslexia*, *64*(2), 151‒165.

Woodcock, R. (2011). *Woodcock reading mastery test (WRMT-III)*. San Antonio, TX: Pearson.

Wright, B. A., Lombardino, L. J., King, W. M., Puranik, C. S., Leonard, C. M., & Merzenich, M. M. (1997). Deficits in auditory temporal and spectral resolution in language-impaired children. *Nature*, *387*(6629), 176‒178.

Wright, R. D., & Ward, L. M. (2008). *Orienting of attention*. New York, NY: Oxford University Press.

Wu, W. (2011). Confronting many-many problems: Attention and agentive control. *Noûs, 45*(1), 50‒76.

Wühr, P., & Heuer, H. (2017). Response preparation, response conflict, and the effects of irrelevant flanker stimuli. *Advances in Cognitive Psychology, 13*(1), 70─82.

Yap, M. J., & Balota, D. A. (2015). Visual Word Recognition. In A. Pollatsek & R. Treiman (Eds.), *The Oxford Handbook of Reading* (pp. 26-43).doi 10.1093/oxfordhb/9780199324576.013.4.

Zhang, J., Hughes, L. E., & Rowe, J. B. (2012). Selection and inhibition mechanisms for human voluntary action decisions. *Neuroimage, 63*(1), 392─402.

Ziegler, J. C., & Goswami, U. (2005). Reading acquisition, developmental dyslexia, and skilled reading across languages: A psycholinguistic grain size theory. *Psychological Bulletin, 131*(1), 3─29.

Ziegler, J. C., Perry, C., & Zorzi, M. (2014). Modelling reading development through phonological decoding and self-teaching: Implications for dyslexia. *Philosophical Transactions of the Royal Society B: Biological Sciences, 369*(1634), 20120397.

Zimny, G. H., Pawlick, G. F., & Saur, D. P. (1969). Effects of stimulus order and novelty on orienting responses. *Psychophysiology, 6*(2), 166─173.

Zorzi, M., Houghton, G., & Butterworth, B. (1998). Two routes or one in reading aloud? A connectionist dual-process model. *Journal of Experimental Psychology: Human Perception and Performance*, *24*(4), 1131─1161.

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Appendix A: The Auditory ANT Pilot Study

Introduction

This appendix describes a pilot study of the child auditory ANT with a typically developing sample of primary aged children (aged 6 to 11 years).

Aims

The pilot study for this auditory ANT is intended to develop a child appropriate measure that assesses the alerting, orienting, and executive attention network in audition, as the previously developed cVANT (Rueda et al., 2004). This is achieved by confirming (1) the difficulty level of selected approaches to testing the attention network in audition, and (2) the ability of the task to generate significant alerting, orienting, and executive attention effects in audition.

Experiment 1

Experiment 1 examined whether informative cues improved performance in a two-alternative forced choice pitch discrimination task (aANT-PD), which required participants to determine whether the target pitch was high or low. The ISI was fixed to 400 ms. In assessing the alerting and orienting effects, significant auditory cue benefits were expected, because the double and spatial cues, respectively, would provide a warning about target presentation, thus enhance performance. For the executive effect, significantly faster RTs in the congruent compared to incongruent flanker conditions were predicted, because incongruent flankers would provide greater distraction to pitch judgments, imposing higher demands on executive attention to ignore the concurrent flanker, compared to the congruent flanker. Neutral conditions were included to assess the degree to which stimuli in the non-attending ear might disrupt task performance.

To also assess auditory orienting attention with a more conventional methodology that involves attentional shifts to different locations on each trial, a separate pitch discrimination task with informative cuing was included. This is referred to as an auditory single orienting task (aSOT-PD). To maintain as much similarity with the aANT-PD, the ISI was fixed to 400 ms. Significantly faster RTs in the valid compared to invalid cue conditions were predicted, because greater costs and benefits are associated with orienting from an invalid cue, and to valid cues, respectively.

Method

Participants

Participants comprised 24 children, aged 6‒11 years (*M* age = 8.5 years, *SD* = 1.7 years, 14 males). The parents of all participants reported that their child/children had normal hearing and had normal or corrected-to-normal vision. All participants, except two, were right-handed. Written consent was obtained from all participants and their parents. The study was conducted in accordance with the ethical guidelines of the Curtin University Human Research Ethics Committee.

Apparatus and Stimuli

The development of the auditory stimuli for the aANT-PD were the same as described in the method chapter (Chapter 3) of this thesis. Auditory stimulus RTs were recorded by an Acer Aspire E5-521 (15. 6" monitor) personal computer installed with DmDx software (Forster & Forster, 2003), respectively. Auditory stimuli were presented from a wireless stereo SONY headset (Model No CECHYA-0086).

In the aANT-PD, target stimuli were 400 ms (SPL of 76.99 dB) in duration and were either high (870 or 890 Hz) or low (270 or 275 Hz) pitched pure tones or sine waves with a ramped onset and offset to avoid audible clicks. Simultaneous presentation of two high or two low frequency tones, one to each ear (e.g., 270 Hz left & 275 Hz right, or 870 Hz left & 890 Hz right), created the congruent trials. The small difference in frequency between left and right tones during congruent trials prevented the perceptual integration of tones into a single sound (Blauert & Lindemann, 1986; Roberts et al., 2006). That is, the tones were heard as different sounds that were either both high or low in frequency. The simultaneous presentation of one high and one low frequency tone, one to each ear (e.g., 270 Hz left & 870 Hz right, or 275 Hz left & 890 Hz right), created the incongruent trials. To simultaneously present two tones, those tones were combined into a single stereo sound file, one for the left channel, for left ear presentation, and the other for the right channel, for right ear presentation. All auditory stimuli were therefore stereo sound files. Stereo sound files were also used for target tones presented to one ear only (i.e., in the neutral condition), but with the channel in the opposite ear silenced. Two dichotically presented tones with similar mid-level frequency combined into a single stereo wave file (i.e., 560 Hz left & 600 Hz right, or 600 Hz left & 560 Hz right), created the double cue stimuli, two dichotically equivalent tones (i.e., 560 Hz left & 560 Hz right, or 600 Hz left & 600 Hz right) created the central cue stimuli, and monaurally presented mid-frequency tones just to the left or right ear (e.g., 560 Hz left, or 600 Hz right), with the opposite ear silenced, created the spatial cue stimuli. All cue tones were 100 ms in duration. Cue tones were passed through a hamming filter creating a smoothed pulse-like sound, to ensure the cues were perceptually distinct from the targets. Both target and cue stimuli had sampling frequencies of 44100 Hz with 16-bit resolution.

Procedure

Tasks were counterbalanced with the aSOT-PD being administered, in alternate participants, directly before or after the aANT-PD. Participants were tested individually in a quiet room at their home or community centre.

aANT-PD. Figure A.1 illustrates the configuration of the aANT-PD, cue conditions, target conditions, and an example of the procedure. Participants were instructed to respond as quickly and accurately as possible to identify the pitch of target tones delivered to the target ear. They were informed that sometimes target tones were preceded by an auditory cue. On two of the experimental blocks, participants attended only to the target tone from the left ear and ignored any tones from the right ear. On the remaining two blocks, they attended only to the target tone in the right ear and ignored tones from the left ear. For each ear, one block comprised only no cue and double cue conditions (for the alerting effect); the other block comprised only spatial (monaural cue signal in the target ear) and central cue conditions (for the orienting effect). Within each experimental block there were 48 trials. Each trial represented one of six conditions in each block, two cue conditions by three congruency conditions.

Each trial started with a visual fixation point, "+", presented mid-screen for 1000 ms, followed by one of four cue conditions, a 400 ms fixation period, and then the target presentation with flanker (for congruent and incongruent trials). The fixation point disappeared at the end of the target tone. The "+" did not function as a cue to the auditory target, to maintain eyes fixation and to prevent them from shifting to different locations of the sound stimuli. In the neutral condition, target tones were presented alone (either low or high frequency) in the target ear. In the congruent condition, the flanker tone (in the non-target ear) had the same pitch as the target tone (i.e., either high or low pitch tones presented simultaneously).

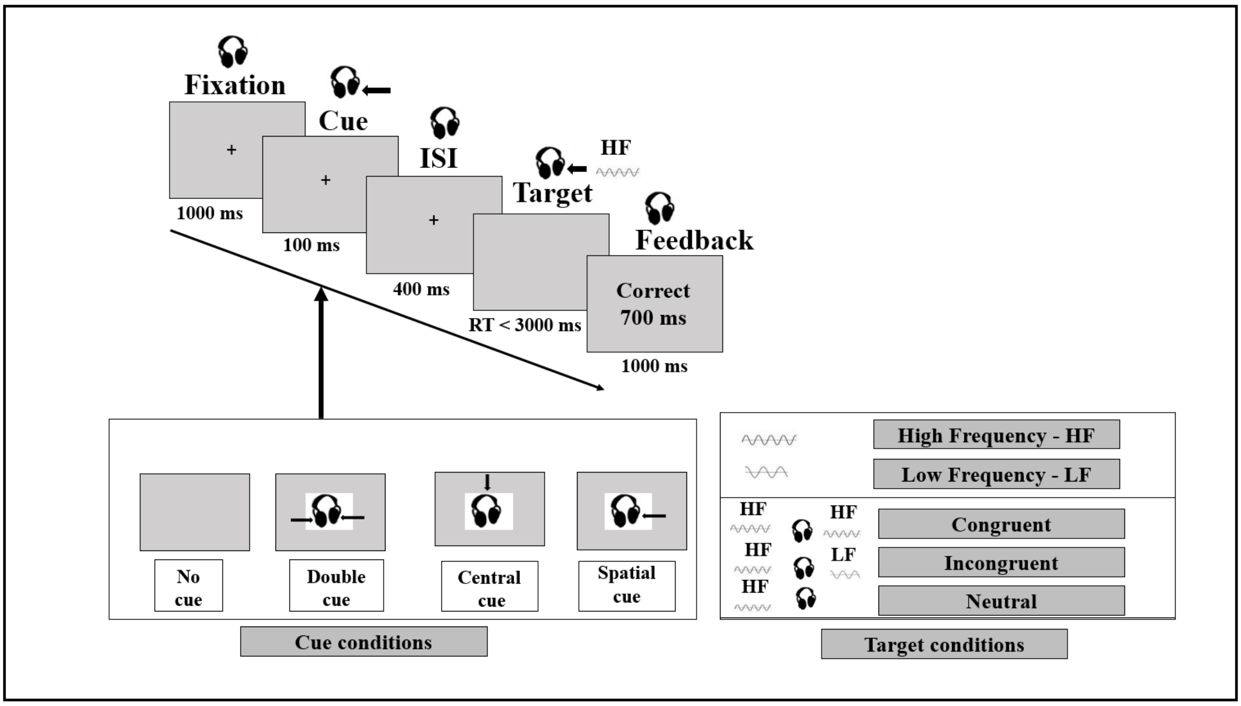


Figure A.1. The configuration of the aANT-PD.

In the incongruent condition, the flanker tone differed in pitch from the target tone (e.g., high tone to the target ear and low tone to the non-target ear, simultaneously). Participants were given a maximum of 3,000 ms to respond before the subsequent trial started. Responses were made via the keyboard using the vertically displaced "Y" (high tone) and "V" (low tone) keys. Accuracy and RTs were measured from target tone onset. In both practice and experimental blocks, visual feedback, indicating accuracy ("correct" or "incorrect") and RT were provided. Throughout the experiment, the background colour was grey.

A short break was provided after each experimental block and the experimenter manually commenced subsequent blocks using the space bar until all blocks were completed. The experimental task comprised 192 trials across 4 experimental blocks. Each experimental block lasted for 7 minutes. A block of 10 practice trials lasting 1 minute per block, preceded each experimental block. The entire task lasted for approximately 35 minutes.

aSOT-PD. Figure A.2 illustrates the configuration of the aSOT-PD, cue conditions, target conditions, and an example of the procedure. Under speeded instructions, participants indicated the pitch of a target tone in the same way as the aANT-PD by pressing one of two buttons. They were informed that a cue always preceded target tones. After a fixation period, one of two validity conditions (valid or invalid cue) was presented, followed by target presentation. In the valid condition, target tones were presented in the same ear as the cue. In the invalid condition, target tones were presented in the opposite ear of the cue. The responses keys were the same as the aANT-PD. The aSOT-PD comprised 80 trials across 2 experimental blocks, each comprising 40 trials (28 valid trials and 12 invalid trials). Each experimental block took approximately 5 minutes to complete, with a break between each block. A block of 12 practice trials (8 valid and 4 invalid trials), which took approximately 1 minute to complete, preceded the experimental blocks. For both the aANT-PD and aSOT-PD, target pitch and location, and cue/validity type were equally and randomly presented within practice and experimental blocks.

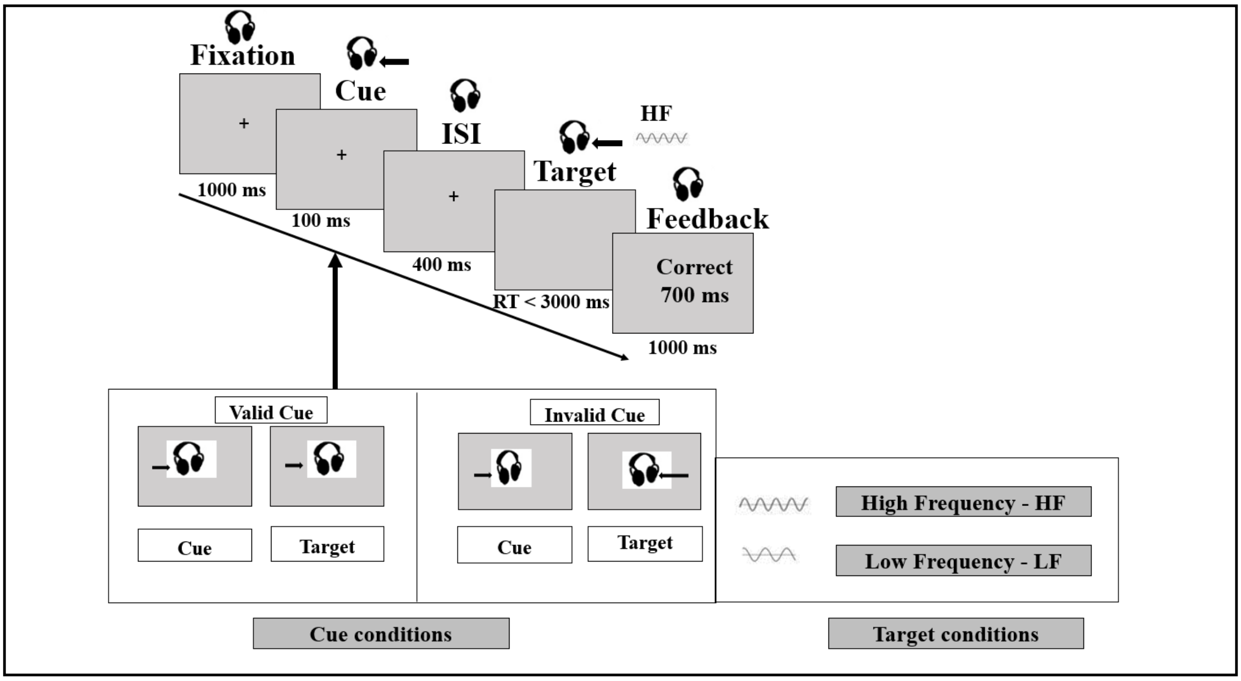


Figure A.2. The configuration of the aSOT-PD.

Results

Errors, where participants pressed the wrong button or failed to respond within the response period (25.7% of trials for the aANT-PD, and 12.4% of trials for the aSOT-PD), and RT outliers, defined as RTs less than 200 ms and scores falling 2 standard deviations above or below the mean within each condition (3.8% of trials for aANT-PD, and 4.5% of trials for the aSOT-PD), were excluded when calculating the mean RT for each condition for each participant. The data for the aANT-PD and aSOT-PD were pooled across target location (left ear or right ear) and tone (high vs. low pitch), since preliminary analysis showed these effects to be negligible. For the aANT-PD, 12 participants did not meet the 75% accuracy criterion and were therefore excluded from further analysis. Of those 12 children, three were aged 6 years, four were aged 7 years, two were aged 8 years, two were aged 10 years and one was aged 11 years. For the aSOT-PD, 3 children did not meet the 75% accuracy criterion. For the aANT-PD, ANOVA and follow-up analyses was the same as reported in the method chapter (Chapter 3) of the current thesis. For the aSOT-PD, paired sample *t*-test was used to examine the validity effect. The alpha level was .05 and effect sizes are reported using partial eta squared (η_p^2) or Cohen's *d*, where appropriate.

Attention Network Effects

Table A.1 provides the mean RTs in each condition of the aANT-PD, along with marginal means. ANOVA showed a main effect of cue, $F(3, 33) = 13.44$, $p < .001$, $\eta_p^2 = .55$. There was also a main effect of congruency, $F(2, 22) = 45.20$, $p < .001$, $\eta_p^2 = .80$. The interaction between cue and congruency was not significant, $F(3.32, 36.54) = 0.55$ $p = .77$, $\eta_p^2 = .05$.

Planned contrasts between the no cue and double cue conditions showed auditory alerting effects with an advantage for the double cue condition (212 ms), $F(1, 11) = 56.53$, $p < .001$, $\eta_p^2 = .84$. A contrast between the central cue and spatial cue conditions showed no significant auditory spatial-cue benefits (29 ms numerical benefit for the central cue condition), $F(1, 11) = 1.37$, $p = .27$, $\eta_p^2 = .11$. Finally, a contrast between the incongruent and congruent flanker conditions revealed auditory executive attention effects (287 ms), $F(1, 11) = 44.96$, $p < .001$, $\eta_p^2 = .80$.

The analysis of errors found no main effect of cue, $F(3, 33) = 0.34$, $p = .80$, $\eta_p^2 = .03$. There was a main effect of congruency, $F(2, 22) = 23.34$, $p < .001$, $\eta_p^2 = .68$. For the aANT-PD, there were significantly more errors in the incongruent (M = 23.7% ± 4.3%) compared with congruent conditions (M = 6.9% ± 1.5%). The cue by congruency interaction was not significant, $F(6, 66) = 1.66$, $p = .15$, $\eta_p^2 = .13$.

Table A.1: Mean RT in Milliseconds and Standard Deviations for the aANT-PD

	Cue Type				
Congruency Type	No Cue	Double	Central	Spatial	Total Mean
aANT-PD					
Neutral	1273 (101)	1094 (99)	995 (78)	1010 (82)	1093 (85)
Congruent	1233 (95)	1030 (88)	1004 (92)	1030 (90)	1074 (82)
Incongruent	1544 (117)	1292 (98)	1281 (112)	1327 (122)	1361 (105)
Total Mean	1350 (100)	1138 (90)	1093 (89)	1122 (93)	

Validity effects (aSOT)

A paired sample *t*-test showed no significant validity effects in the aSOT-PD, $t(20) = 0.92$, $p = .37$, $d = .20$. The mean of the valid cue condition was 826 ms (SD = 244 ms), and the mean of the invalid condition was 848 ms (SD = 242 ms).

Findings

The aANT-PD produced auditory alerting and auditory executive effects, but no auditory orienting effect. Moreover, the error rate was high and half of the participants had to be excluded from the analysis. While the aSOT-PD was less difficult, compared with the aANT-PD, it also failed to produce a significant orienting effect in audition.

Experiment 2

Previous studies that have developed aANTs (in adult populations) have fixed their ISIs (e.g., Roberts et al., 2006; Spagna et al., 2015). This might have encouraged responses based on the temporal structure of the experiment, regardless of spatially valid auditory cues (Festa-Martino, Ott, & Heindel, 2004). Therefore, in Experiment 2, the aANT-PD variable ISI was developed, replicating the aANT-PD in

Experiment 1, but with ISIs of 150, 450, and 750 ms. Significant RT benefits for auditory spatially valid cue conditions were predicted. The same participants also completed the aSOT-PD variable ISI to test for validity effects on pitch discrimination, replicating the aSOT-PD in Experiment 1, but with variable ISI.

Method

Participants

Twelve children, aged 7—11 years (*M* age = 9.2 years, *SD* = 1.6 years, 5 males) volunteered to participate. The parents of all participants reported that their child/children had normal hearing and had normal or corrected-to-normal vision. All participants were right-handed and none had participated in the previous experiment.

Apparatus and Stimuli

This was the same as Experiment 1.

Procedure

The design and procedure for the aANT-PD and the aSOT-PD variable ISIs were the same as Experiment 1, except that the ISI was equally set to 150, 450, or 750 ms across 144 trials (aANT-PD variable ISI), including 36 trials across four experimental blocks. For the aSOT-PD variable ISI, the number of trials remained the same as Experiment 1.

Results

Exclusion criteria for errors and outliers, and RT mean calculation approach were the same as Experiment 1. Errors (21.4% of trials for the aANT-PD variable ISI, and 12.5% of trials for the aSOT-PD variable ISI) and RT outliers (4.6% of trials for the aANT-PD variable ISI, and 5.6% of trials for the aSOT-PD variable ISI), were excluded. For the aANT-PD variable ISI, 3 (aged 7, 8, and 10) participants were excluded from the analysis for performing below the 75% accuracy requirement. For the aSOT-PD variable ISI, 1 participant did not meet the 75% accuracy requirement.

Attention Network Effects

A three-way repeated measures ANOVA was first conducted, examining cue, congruency, and ISI effects on mean RT. Table A.2 provides the mean RTs in each (cue by congruency) condition, along with marginal means. There was a main effect of cue, $F(3, 15) = 32.99$, $p < .001$, $\eta_p^2 = .87$, congruency, $F(1.02, 5.09) = 13.48$, $p = .01$, $\eta_p^2 = .73$, and ISI, $F(2, 10) = 21.99$, $p < .001$, $\eta_p^2 = .82$. The interactions between cue and congruency, $F(3.06, 15.31) = 0.79$, $p = .59$, $\eta_p^2 = .14$, cue and ISI, $F(2.04, 10.17) = 0.82$, $p = .56$, $\eta_p^2 = .14$, congruency and ISI, $F(4, 20) = 1.22$, $p = .33$, $\eta_p^2 = .20$, and cue, congruency, and ISI, $F(3.71, 18.53) = 1.75$, $p = .08$, $\eta_p^2 = .26$, were not significant (Greenhouse-Geisser adjustment where applicable).

Planned contrasts between the no cue and double cue conditions revealed an auditory alerting effect (127 ms), $F(1, 8) = 60.86$, $p < .001$, $\eta_p^2 = .91$. A contrast between the central and spatial cue conditions showed no auditory orienting effect (10 ms), $F(1, 8) = 0.11$, $p = .75$, $\eta_p^2 = .02$. Finally, a contrast between the incongruent and congruent conditions revealed an auditory executive effect (309 ms), $F(1, 8) = 16.53$, $p = .01$, $\eta_p^2 = .77$.

The analysis of errors found no main effect of cue, $F(3, 15) = 0.55$, $p = .65$, $\eta_p^2 = .10$, or ISI, $F(2, 10) = 0.58$, $p = .58$, $\eta_p^2 = .10$. There was a main effect for congruency, $F(2, 10) = 13.80$, $p = .001$, $\eta_p^2 = .73$, with significantly more errors in the incongruent ($M = 25.7\% \pm 6.6\%$) than the congruent condition ($M = 5.2\% \pm 2.5\%$). The interactions between cue and congruency, $F(1.97, 16.15) = 0.16$, $p = .99$, $\eta_p^2 = .03$, cue and ISI, $F(2.44, 12.19) = 0.53$, $p = .78$, $\eta_p^2 = .10$, congruency and ISI, $F(4, 20) = 0.69$, $p = .61$, $\eta_p^2 = .12$, and cue, congruency, and ISI, $F(3.17.15.85) = 0.79$, $p = .66$, $\eta_p^2 = .14$, were not significant (Greenhouse-Geisser adjustment where applicable).

Table A.2: Mean RT in Milliseconds and Standard Errors for the aANT-PD Variable ISI in Experiment 2

	Cue Type				
Congruency Type	No Cue	Double	Central	Spatial	Total Mean
aANT-PD					
Neutral	817 (51)	682 (47)	670 (50)	677 (45)	719 (42)
Congruent	796 (36)	724 (50)	670 (56)	694 (54)	721 (44)
Incongruent	1162 (84)	989 (79)	1002 (93)	968 (106)	1030 (88)
Total Mean	925 (37)	798 (51)	790 (55)	780 (49)	

Cue and ISI effects. To clarify the role of ISI in auditory orienting, a set of planned two-way repeated measures ANOVAs was conducted, examining the orienting (central vs. spatial cue conditions) and ISI effects on mean RT separately for each level of congruency (see Table A.3 for mean RTs).

In the neutral condition, there was no main effect of cue, $F(1,8) = 3.12$, $p = .12$, $\eta_p^2 = .28$, but the effect was marginally significant for ISI, $F(2, 16) = 3.11$, $p = .07$, $\eta_p^2 = .28$. The interaction between cue and ISI, $F(2, 16) = 1.59$, $p = .23$, $\eta_p^2 = .17$, was not significant. Subsequent planned comparisons, as Table A.3 illustrates, found a statistically significant RT difference between central and spatial cue conditions, with spatial cues producing faster RT, at the 150 ms ISI, $F(1, 8) = 4.13$, $p = .04$, $\eta_p^2 = .34$, but not the 450 ms, $F(1, 8) = 0.07$, $p = .80$, $\eta_p^2 = .01$, or the 750 ms, $F(1, 8) = 1.61$, $p = .24$, $\eta_p^2 = .17$, ISIs.

In the congruent condition, there was no main effect of cue, $F(1, 8) = 0.82$, $p = .39$, $\eta_p^2 = .09$, or ISI, $F(2, 16) = 2.02$, $p = .17$, $\eta_p^2 = .20$. The interaction between cue and ISI, $F(2, 16) = 1.11$, $p = .35$, $\eta_p^2 = .12$, was not significant.

In the incongruent condition, the main effect of cue, $F(1, 8) = 0.08$, $p = .79$, $\eta_p^2 = .01$, was not significant. The main effect for ISI, $F(2, 16) = 3.38$, $p = .06$, $\eta_p^2 = .33$, was marginally significant. The interaction between cue and ISI, $F(2, 16) = 1.15$, $p = .34$, $\eta_p^2 = .14$, was not significant. Although, subsequent planned comparisons showed no statistically significant RT difference between central and spatial cue conditions, for each ISI, there were numerical spatial cue benefits at the 450 ms ISI, but not at the 150 ms or 750 ms ISI, as Table A.3 illustrates.

Table A.3: Mean RT in Milliseconds and Standard Errors at Each ISI for each Level of Congruency in the aANT-PD Variable ISI in Experiment 2

Congruency Type & ISI	Central Cue	Spatial Cue	Difference Score
Neutral			
150 ms	954 (114)	809 (81)	145*
450 ms	781 (90)	799 (82)	-18
750 ms	805 (78)	758 (76)	47
Total Mean	847 (89)	789 (70)	58
Congruent			
150 ms	840 (87)	816 (78)	24
450 ms	752 (84)	793 (90)	-41
750 ms	784 (78)	822 (72)	-38
Total Mean	792 (81)	810 (77)	-18
Incongruent			
150 ms	1077 (129)	1161 (82)	-84
450 ms	1050 (98)	928 (113)	122
750 ms	963 (68)	1041 (126)	-78
Total Mean	1030 (81)	1043 (98)	-13

Note. *Difference score was significant at the .05 level (2-tailed).

The analysis of errors found no main effect of cue, $F(1, 7) = 0.62$, $p = .46$, $\eta_p^2 = .08$, or ISI, $F(2,14) = 0.09$, $p = .92$, $\eta_p^2 = .01$. There was a main effect of congruency, $F(2, 14) = 11.98$, $p = .001$, $\eta_p^2 = .63$. The interactions between cue and congruency, $F(2, 14) = 0.01$, $p = .99$, $\eta_p^2 = .01$, cue and ISI, $F(2, 14) = 0.39$, $p = .68$, $\eta_p^2 = .05$, congruency and ISI, $F(4, 28) = 0.27$, $p = .90$, $\eta_p^2 = .04$, and cue, congruency, and ISI, $F(4, 28) = 0.84$, $p = .51$, $\eta_p^2 = .11$, were not significant.

Validity Effects

A paired samples *t*-test with mean RT averaged across ISI showed no significant validity effect, $t(10) = 0.90$, $p = .39$, $d = .27$, with 766 ms as the mean of the valid condition (SD = 253 ms), and 775 ms for the invalid condition (SD = 249 ms). A two-way repeated measures ANOVA was conducted, examining the effect of cue validity (valid vs. invalid) and ISI (150, 450, and 750 ms) on mean RT. There was no main effect of validity, $F(1, 10) = 0.11$, $p = .75$, $\eta_p^2 = .01$, but a main effect of ISI, $F(2, 20) = 4.31$, $p = .03$, $\eta_p^2 = .30$, and the interaction between validity and ISI was marginally significant, $F(2, 20) = 3.11$, $p = .06$, $\eta_p^2 = .24$.

Table A.4 provides the RT means and difference scores for the valid and invalid cue conditions at each ISI level. Planned comparisons showed a significant validity effect for the 450 ms ISI (64 ms), $F(1, 10) = 9.90$, $p = .01$, $\eta_p^2 = .50$, but not for the 150 ms, $F(1, 10) = 0.50$, $p = .50$, $\eta_p^2 = .05$, or 750 ms, $F(1, 10) = 2.16$, $p = .17$, $\eta_p^2 = .18$, ISIs.

Table A.4: Mean RT in Milliseconds and Standard Errors at Each ISI in the aSOT-PD variable ISI in Experiment 2

ISI	Valid	Invalid	Difference Score
150 ms	817 (91)	789 (84)	-28
450 ms	744 (75)	808 (73)	64*
750 ms	756 (78)	734 (73)	-22
Total	772 (80)	777 (75)	5

Note. *Difference score is significant at the .05 level (2-tailed).

Table A.5 provides the difference scores for error data between the valid and invalid cue conditions at each ISI level in the aSOT-PD. An analysis of error data found no main effect of validity, $F(1, 10) = 2.23$, $p = .16$, $\eta_p^2 = .19$, or ISI, $F(2,20) = 0.40$, $p = .68$, $\eta_p^2 = .04$. The interaction between validity and ISI was significant, $F(2, 20) = 4.27$, $p = .03$, $\eta_p^2 = .30$. Planned comparisons showed a significant validity effect in error data for the 450 ms ISI, $F(1, 10) = 0.00$, $p = 1.00$, $\eta_p^2 = .00$, but not the 150 ms, $F(1, 10) = 0.50$, $p = .50$, $\eta_p^2 = .05$, or 750 ms, $F(1, 10) = 1.38$, $p = .27$, $\eta_p^2 = .12$, ISIs.

Table A.5: Error Data (Percentage) and Standard Errors at Each ISI in the aSOT-PD variable ISI in Experiment 2

ISI	Valid	Invalid	Difference Score
150 ms	9.1 (2.8)	9.0 (3.4)	-0.1
450 ms	4.0 (1.5)	11.4 (2.6)	7.4*
750 ms	8.0 (3.3)	5.7 (2.6)	-2.3
Total	7.0 (2.0)	8.7 (2.3)	1.7

Note. *Difference score was significant at the .05 level (2-tailed).

Findings

The number of participants excluded for low accuracy improved from Experiment 1. However, the aANT-PD variable ISI produced alerting and executive effects, but no orienting effect, when the analysis was conducted across all levels of cue and congruency. Thus, this finding replicates Experiment 1. However, there was evidence of a pattern for spatial cue advantage under restricted conditions (neutral at the 150 ms ISI). Similarly, a spatial cue effect was only observed under restricted conditions in the aSOT-PD, variable ISI (450 ms ISI).

Experiment 3

Experiment 3 developed an auditory spatial localisation ANT (aANT-SL), where responses were based on identifying the location (ear) of a target tone. To measure the aANT-SL alerting and orienting effects, the same cueing protocol for Experiment 1 was adopted. Faster RTs for informative, warning (double and spatial) conditions compared with non-informative (none and central) conditions was predicted. The congruency manipulation, to measure the executive effect, involved presenting two successive tones separated by a short interval, with the first tone, the target, and the second tone, the flanker (congruent or incongruent). Faster responses for congruent flanker conditions, compared with incongruent conditions, was predicted.

Method

Participants

Participants comprised 20 primary-aged children, aged 6─10 years (*M* age = 7.8 years, *SD* = 1.4 years, 10 males). Parent reports indicated that all participants had normal hearing and normal or corrected-to-normal vision. All participants were right-handed and none participated in the previous experiments. As before, ethics protocols were applied.

Apparatus and Stimuli

Apparatus and cue stimuli for the aANT-SL were the same as Experiments 1 and 2. The model of the headphone was changed to Logitech (Headset H151).

aANT-SL (Game). Using the Praat software (Boersma & Weenink, 2016), auditory target stimuli were created by sequencing two monaurally presented tones (the same as the target tones used in earlier experiments, with one channel silenced), separated by a 200 ms silence interval. The tones were either high (870Hz) or low (270Hz) in frequency. The first and second tones (matched in frequency) were the target and flanker tones, respectively. The congruency manipulation was achieved by having the target and flanker tones in the same left or right channel (congruent condition), or in different channels (incongruent condition). For the neutral condition, the sound files had the target tone only in either right or left channel, with the following flanker tone silenced.

Procedure

Participants were administered the attention task in a quiet room at their school or home. All testing was completed in one 15-minute session.

aANT-SL (Game). Figure A.3 illustrates the configuration of the aANT-SL (Game), cue conditions, target conditions, and an example of the procedure. Participants were informed that the task was a secret spy game and they needed to listen for a secret code. They were informed that the secret code would either be a high or low tone. Participants were advised that sometimes, they would hear one tone and at other times, they would hear two tones. They were instructed that when two tones were heard, the secret code was only the first tone. Participants were informed that sometimes, secret codes were preceded by a cue. They were told that sometimes the cue predicted where the secret code would appear. Responses were made via the keyboard using the “E” (left ear) and “I” (right ear) keys, with the instruction to respond as quickly and accurately as possible. For the no cue and double cue conditions (to measure the alerting effect), the ISI was fixed to 750 ms (previous research, for example, Morrison (1982) showed that longer ISIs elicit greater alerting effects), whereas for the central and spatial cue conditions (to measure the orienting effect), the ISI was fixed to 150 ms to reduce any effect of response priming.

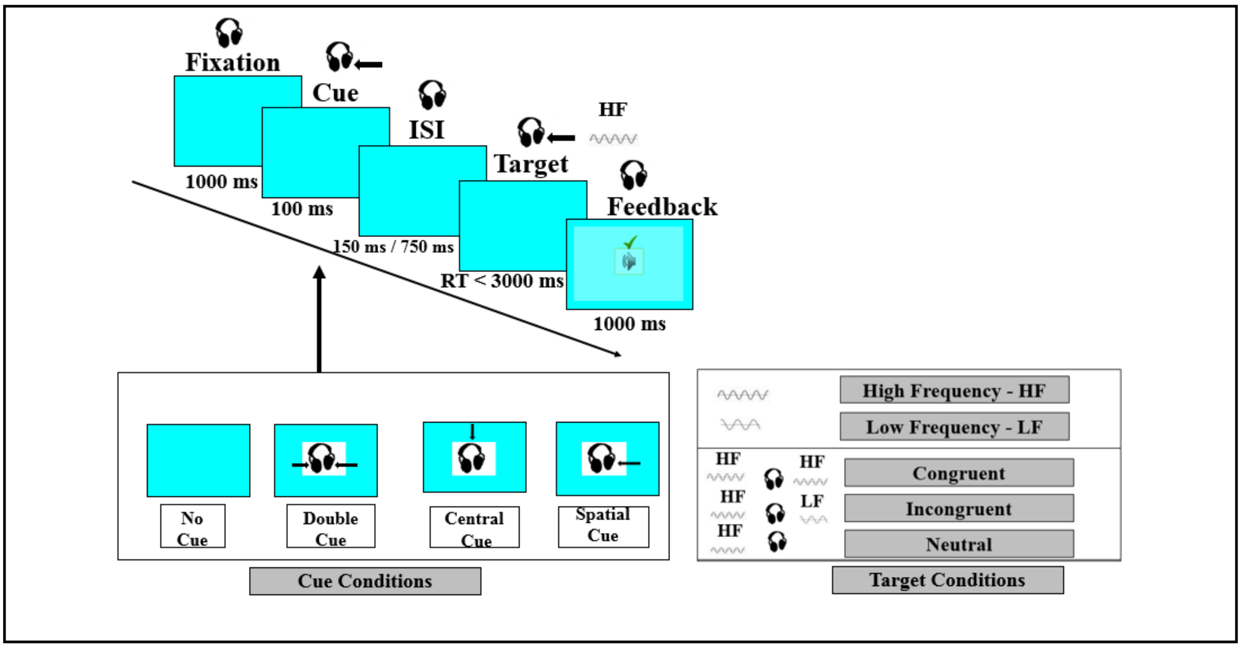


*Figure A.3.*The configuration of the aANT-SL (Game).

The aANT-SL (Game) consisted of a total of 12 practice trials and three experimental blocks of 48 trials in each. Each trial represented one of 12 conditions in equal proportion: four cues (no cue, double cue, central cue, and spatial cue) X three target types (congruent, incongruent, and neutral). For each trial a fixation screen was presented, followed 1,000 ms later by one of four cue conditions (no cue, double cue, central cue, or spatial cue), then a fixation period of either 150 or 750 ms, depending on cue condition, and then the target with or without a flanker. RT was measured from target onset. Visual feedback was presented only in practice blocks. The task took 15─20 minutes to be completed. Throughout the experiment, the background colour was magenta.

Results

RT for the aANT-SL (Game) was pooled across target location (left or right ear). Exclusion criteria for errors and outliers were the same as Experiment 1. Eight children were excluded from the auditory analyses for performing below the 75% requirement. Of those 8 children, 6 were within the 6 to 7 year-old group. Errors (21.7% of trials) and RT outliers (3.9% of trials), were excluded when calculating the mean RT for each condition for each participant. Mean RT and error rate data were analysed in similar fashion to Experiments 1 and 2 using repeated measures ANOVA.

Attention Network Effects

Table A.6 provides the mean RTs in each condition, with marginal means for the aANT-SL (Game). There was no main effect of cue, $F(3,33) = 1.65$, $p = .20$, $\eta_p^2 = .13$, but there was a main effect of congruency, $F(2,22) = 38.69$, $p < .001$, $\eta_p^2 = .78$. The interaction between cue and congruency was not significant, $F(6, 96) = 0.70$, $p = .65$, $\eta_p^2 = .06$. Planned comparison between the no cue and double cue conditions showed no auditory alerting effect (30 ms numerical benefit for double cue condition), $F(1, 11) = 1.38$, $p = .26$, $\eta_p^2 = .11$. A comparison between the central and spatial cue conditions showed no auditory orienting effect (40 ms advantage for the spatial cue condition), $F(1, 11) = 3.70$, $p = .08$, $\eta_p^2 = .25$. A comparison between incongruent and congruent conditions showed an auditory executive effect (197 ms), $F(1, 11) = 55.36$, $p < .001$, $\eta_p^2 = .83$.

Table A.6: Mean RT in Milliseconds and Standard Errors for the aANT-SL (Game) in Experiment 3

	Cue Type				
Congruency Type	No Cue	Double	Central	Spatial	Total Mean
aANT-SL					
Neutral	1038 (41)	1023 (42)	1090 (52)	1022 (43)	1043 (38)
Congruent	1099 (39)	1050 (34)	1113 (58)	1060 (48)	1080 (39)
Incongruent	1305 (50)	1279 (64)	1263 (54)	1263 (71)	1277 (56)
Total Mean	1147 (38)	1117 (40)	1155 (47)	1115 (50)	

The analysis of error data found a main effect of cue, $F(3, 33) = 5.49$, $p = .004$, $\eta_p^2 = .33$. Participants made more errors in the central ($M = 23.4\% \pm 3.6\%$) than spatial ($M = 13.2\% \pm 2.4\%$) cue conditions There was also a main effect of congruency, $F(2, 22) = 14.07$, $p < .001$, $\eta_p^2 = .56$. Participants made more errors in the incongruent ($M = 24.7\% \pm 3.2\%$) than congruent ($M = 12.2\% \pm 2.5\%$) conditions. The interaction between cue and congruency was significant, $F(6, 66) = 3.23$, $p = .01$, $\eta_p^2 = .23$. Simple effect analysis showed that there were no significant cue differences in the neutral and congruent conditions. In contrast, in the incongruent conditions, there were significantly fewer errors ($p < .001$) when incongruent conditions were preceded by no cue (*M* = 16.7% ± 4.1%), compared with central cues (*M* = 39.6% ± 3.4%). There were also significantly fewer errors in the double cue (*M* = 22.2% ± 5.3%, *p* = .002) and spatial cue (*M* = 20.1% ± 4.4%, *p* = .001) conditions, compared with the central cue conditions.

Findings

The number of participants excluded for low accuracy improved from Experiment 1. However, the aANT-SL (Game) produced no auditory alerting or auditory orienting effect, only an auditory executive effect.

Experiment 4

Experiment 4 developed a more child-friendly version of the aANT-SL (cAANT-SL). Therefore, this experiment was the same as Experiment 3, but used a dog bark stimulus instead of pure tones. This change was implemented to ensure that children remained engaged with the task.

Method

Participants

Participants comprised 55 primary-aged children, aged 6–11 years (*M* age = 8.2 years, *SD* = 1.6 years, 29 males). Parent reports indicated that all participants had normal hearing and normal or corrected-to-normal vision. All participants were right-handed and none participated in the previous experiments. As before, ethics protocols were applied.

Apparatus and Stimuli

Apparatus and cue stimuli for the cAANT-SL were the same as Experiment 3. The design of the task was the same except that a dog bark was used as the ‘secret code’ instead of tones. The cAANT-SL was used in the current doctoral research and its configuration is illustrated in Figure 3.5 in the method section of Chapter 3.

Procedure

Participants were tested in a quiet room at their school or home. All testing was completed in one 15-minute session.

Results

RTs were pooled across target location (left or right ear). Exclusion criteria for errors and outliers were the same as Experiment 1. Errors (10.7% of trials) and RT outliers (4.1% of trials), were excluded when calculating the mean RT for each condition for each participant. Mean RT and error rate data were analysed in similar fashion to Experiments 1 and 2 using repeated measures ANOVA. Only 4 children (all aged 6 years) were excluded from the auditory analyses for performing below the 75% requirement.

Attention Network Effects

Table A.7 provides the mean RTs in each condition with marginal means for the cAANT-SL. There was a main effect of cue, $F(3, 150) = 5.92$, $p = .001$, $\eta_p^2 = .11$, and congruency, $F(2, 100) = 84.95$, $p < .001$, $\eta_p^2 = .63$. The interaction between cue and congruency was not significant, $F(6, 300) = 1.91$, $p = .31$, $\eta_p^2 = .02$. Planned comparison between the no cue and double cue conditions showed an auditory alerting effect (23 ms), $F(1, 50) = 4.34$, $p = .04$, $\eta_p^2 = .08$. A comparison between the central and spatial cue conditions showed an auditory orienting effect (41 ms), $F(1, 50) = 15.66$, $p < .001$, $\eta_p^2 = .24$. A comparison between incongruent and congruent conditions showed an auditory executive effect (110 ms), $F(1, 50) = 53.52$, $p < .001$, $\eta_p^2 = .52$.

Analysis of error data found a main effect of cue, $F(3, 150) = 4.55$, $p = .004$, $\eta_p^2 = .08$, and congruency, $F(2, 100) = 46.67$, $p < .001$, $\eta_p^2 = .48$. The interaction between cue and congruency was not significant, $F(6, 300) = 1.18$, $p = .32$, $\eta_p^2 = .02$. Participants made more errors in the central ($M = 16.3\% \pm 2.1\%$) than spatial ($M = 11.0\% \pm 1.6\%$) cue conditions.

Table A.7: Mean RT in Milliseconds and Standard Errors for the cAANT-SL in Experiment 4

	Cue Type				
Congruency Type	No Cue	Double	Central	Spatial	Total Mean
Neutral	985 (28)	995 (33)	1027 (33)	979 (32)	996 (30)
Congruent	1106 (30)	1056 (37)	1092 (36)	1057 (35)	1078 (33)
Incongruent	1207 (47)	1177 (45)	1204 (45)	1164 (42)	1188 (43)
Total Mean	1099 (33)	1076 (37)	1108 (36)	1067 (35)	

Findings

The number of participants excluded for low accuracy was low and this version (i.e., cAANT-SL) designed for children elicited alerting, orienting, and executive attention effects in audition.

General Conclusion

To date, previous studies have only developed an auditory ANT for adults (Rueda et al., 2004). Therefore, there has been a sparse focus on the development of a singular task that is able to examine the alerting, orienting, and executive components of auditory attention in children. The present series of Experiments in this pilot study aimed to fill this gap by examining different approaches to assessing attention networks in audition. Together, these experiments showed that, generally, auditory alerting and executive control effects might not be heavily dependent upon task demand. Conversely, a sound localisation (cAANT-SL) approach (tailored specifically for children), in comparison with pitch discrimination (aANT-PD and aSOT-PD), provides a better option to assess auditory orienting attention. That said, given the high errors and absence of auditory orienting in the aANT-PD, assessing spatial orienting in a pitch discrimination task seems to be significantly difficult, and this approach is likely to prevent the application of that model for a single aANT. Further research will benefit from examining the impact of ISI variation in the cAANT-SL to gain a better understanding of orienting in audition and more broadly, alerting and executive attention networks.

Appendix B: Information Letters and Consent Forms

This appendix contains information letters and consent forms for primary school principals, parents/guardians of participants, and study participants.

Pilot Study Parent/Guardian Information Letter

Curtin University

School of Psychology and Speech Pathology

Samantha-Kaye.D. Christie
PhD Student
School of Psychology and Speech Pathology
Curtin University
GPO Box U 1987, Perth
Western Australia, 6845

Dear Parent/Guardian

Developing a Task to Assess Auditory Attention and Reading Speed

My name is Samantha-Kaye Christie and I am a PhD student at Curtin University. I am conducting a research project that aims to give us a better understanding of processes in the brain that help children learn to read more accurately and efficiently. To achieve this aim, this project will assess auditory attention in typically developing children. I am also developing a second task to assess reading speed in children.

I would like to invite your child to participate in my study.

Who is eligible to participate?

This project will involve children in mainstream primary schools in Years 1 to 6. All children participating should have no diagnosed intellectual or cognitive impairment or other developmental condition (e.g., autism, ADHD), have normal or corrected vision and hearing, and English as a first language. Parents or caregivers will be asked about these criteria when completing the consent form to check each child is eligible for the study.

What does participation in the research project involve?

Upon receiving consent from you, your child will participate in one 30-minute testing session in which their auditory attention will be assessed. They will wear headphones and hear sounds (e.g., tones) of different frequencies at a comfortable volume. They will then be asked to press a button depending on whether the tone they hear is either high or low in frequency (or if the sound is coming from their left ear or right ear). In another session, I will ask them to quickly read some words that appear on a computer screen. During this task, their voices will be recorded on a laptop.

What are the benefits of this research for my child's education, and are there any associated risks?

The results of this study will lead to a better understanding of attention processes in children. Moreover, along with the reading speed task, this knowledge is important in order to develop methods to help improve reading accuracy and efficiency. We anticipate no risks from participating in this study.

Does my child have to take part?
No. You do not have to give permission for your child to take part in this project. If you would like your child to take part, I have included a consent form for you to sign. I have also included a consent form for your child.

What if either of us was to change our mind?
If you give permission, but then change your mind, you may withdraw your child or yourself, or your child may withdraw themselves, at any time without consequence. If you both decide to withdraw from the study, all of your information and your child's information will be destroyed immediately. If the project has already been published at the time a participant decides to withdraw, their contribution to research data, however, cannot be removed from the publication.

What will happen to the information collected, and is privacy and confidentiality assured?
The information collected from you about your child, his/her name, your name, and any personal information will be removed and a code will be assigned. Information is stored this way so that, if you or your child decide to take part and then withdraw from the project, I can find your information and your child's information and destroy it. The results of this project will be published, but no personal information about you or your child will be used.

The data that we will collect from you and your child, will be stored in a locked cupboard and a password protected folder on the computer at Curtin University that can only be accessed by my supervisors (Dr Neville Hennessey, Dr Suze Leitao and Dr Robert Kane) and me. All assessment records will be stored until your child reaches 25 years of age, after which it will be destroyed according to the Curtin University Functional Records Disposal Authority protocol.

How do I know that the people involved in this research have all the appropriate documentation to be working with children?
Under the Working with Children (Criminal Record Checking) Act 2004, researchers that work with children must pass a Working with Children Check. Upon request, I can you with evidence of my current Working with Children Check.

Is this research approved?
Approval has been received from the Curtin University Human Research Ethics Committee (**Approval Code: HR04/2016**). Any questions or verification of approval for this study can be obtained by contacting the Committee.
Address: Curtin University Human Research Ethics Committee, c/o Office of Research and Development, Curtin University, GPO Box U1987, Perth, 6845.
Telephone: 9266 9223 Email: hrec@curtin.edu.au

Who do I contact if I wish to discuss the project further?
Please do not hesitate to contact either myself or my research supervisors if you have any questions about the study. I can be contacted by phone on 040 650 1119 or by email s.christie@postgrad.curtin.edu.au. Alternatively, you may wish to contact one of my supervisors, Dr Neville Hennessey (email: N.Hennessey@curtin.edu.au, Phone: 9266 2553), Dr Suze Leitao (email: S.Leitao@exchange.curtin.edu.au, Phone: 9266 7620) or Dr Robert Kane (email: R.T.kane@curtin.edu.au; phone: 9266 7515).

How do my child and I become involved in this project?
If you would like to take part, I have included a short questionnaire and consent form for you to complete and sign. Once all questions have been answered to your satisfaction, and you and your child are both willing to take part, please both complete the attached **Consent Forms.**

Thank you.

Regards,

Samantha-Kaye Christie
PhD Student
Curtin University

Dr Suze Leitao
Speech Pathologist
Supervisor and Senior Lecturer
Curtin University

Dr Neville Hennessey
Supervisor and Senior Lecturer
Curtin University

Dr Robert .T. Kane
Supervisor and Senior Lecturer
Curtin University

Pilot Study Parent/Guardian Consent Form

School of Psychology and Speech Pathology

Developing a Task to Assess Auditory Attention

Consent Form for Parent/Guardian

- I have read this document and I understand the aims and procedures of this project.
- I have been given the opportunity to ask any questions, and these have been answered.
- I am willing for my child to become involved in the research project, as described.
- I have talked to my child about the project, and he/she wishes to take part, as indicated by his/her completion of the child consent form.
- I understand that participation in this project is completely voluntary.
- I understand that both my child and I are free to withdraw from participation at any time, without consequence.
- I give permission for the contribution that my child and I make to this research to be used in conference talks and published in a scientific journal, provided that we are not identified in any way.
- I understand that all data and personal records will be kept confidential and can only be accessed by the researchers on this project.

Name of Child (please print): ______________________________________

Child's Date of birth (please print): _____ / _____ / ________

Name of Parent/Guardian (please print): ____________________________________

Signature of Parent/Guardian: ____

Available dates and times for testing:

____

____

Date (DD/MM/YYYY): _____ / _____ / ________

Please answer the following questions

1. Does your child have an intellectual or cognitive impairment? Yes ☐ No ☐

   If yes, please, state if there is a specific diagnosis and who (what profession) made the diagnosis. This information will be kept confidential.

   ____

2. Has your child ever been assessed with any vision impairments? If yes, has this been corrected? (e.g. wearing glasses)

   ____

3. Has your child been assessed with any hearing problems? If yes, has this been corrected? (e.g. wearing hearing aid).

   ____

4. Is English the main language spoken by your child? Please identify any other languages spoken at home.

   ____

5. Has your child been diagnosed with any developmental disorder? (E.g. autism, dyslexia, attention deficit disorder)? Yes ☐ No ☐

If yes, please give details regarding type of disorder and when it was diagnosed.

____

Pilot Study Participant (Child) Information Letter

Curtin University

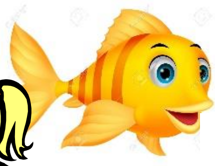
School of Psychology and Speech Pathology

Participant Information Script

Hello,

My name is Samantha. I have a project that you might like to help me with.

The project is about getting to understand how people pay attention to pictures and sounds. It is also about fast people can read words.



Would you like to help me? If you would like to help, we will do some quick activities. You will do activities looking at some fishes and pressing a button to tell me if a fish is looking left or right and listening to some sounds and then telling me if the sound is high or low (or coming from your left or right ear). You will also read some words very quickly on a computer screen.

When I am finished I will write up my results. When I do this, I will not write or tell anyone your name.

I will not tell anyone what you say while helping me with the project, unless I need to tell someone like your mother or father (e.g. if you tell me that someone has hurt you).

You can change your mind about being in this project anytime. If you change your mind, I will destroy your information from the project.

Please talk to your parents about this research project and ask them any questions.

If you would like to help with the project, please draw a circle around the tick on the next page. If you do not want to be part of this project- that is OK too.

Even if you want to help me now but want to stop later, that is OK. You can tell your parents and they will let me know.

Please let your parent know and read and sign the consent form below. This letter is for you to keep.

You can also ask me any questions about the project.

Thank you for listening to my idea.

Samantha-Kaye Christie
PhD Student
Curtin University

Pilot Study Participant (Child) Consent Form

School of Psychology and Speech Pathology

Participant Consent Form

- I know I have a choice whether or not I want to do this project.
- I know that I can stop whenever I want to. I know I will not get into trouble if I want to stop.
- I know that I will be doing some different activities (like looking at pictures, listening to sounds through some headphones, reading some words very quickly) to help with this project.
- I know that I need to draw a circle around the tick on this page and sign my name on the line before I can help with the project.

YES	**NO**
I would like to help with the project	Not this time

Your name: ________________________________

Today's date: ____ / ____ / ________

Study 1 Principal Information Letter

School of Psychology and Speech Pathology

Samantha-Kaye.D. Christie
PhD Student
School of Psychology and Speech Pathology
Curtin University
GPO Box U 1987, Perth
Western Australia, 6845
Ph: +61 8 9266 2553

Dear Principal

An investigation of the relationship between attention, verbal skills, behaviour regulation and reading

My name is Samantha-Kaye Christie and I am a PhD student at Curtin University. I am conducting a research project that aims to give us a better understanding of processes in the brain that help children learn to read more accurately and efficiently. To achieve this aim, this project will assess the relationship between attention, verbal skills associated with phonological processing, behaviour regulation capacity, and reading skills in typically developing children. I will also look at how this relationship changes over a 12-month period and compare typically developing children with children who have a diagnosis of dyslexia.

I am currently approaching primary schools to recruit 260 typically developing children across Years 1 and 2, and Years 4 and 5. I would like to invite your school to take part.

Who is eligible to participate?
All children participating should have no diagnosed intellectual or cognitive impairment or other developmental condition (e.g., autism, ADHD), have normal or corrected vision and hearing, and English as a first language. Parents or caregivers will be asked about these criteria when completing the consent form to check each child is eligible for the study. In Phase 2 of this project I will re-assess each child on some of the measures 12 months later.

What does participation in the research project involve?

Upon receiving consent from their parents, each student will then be assessed using the following tasks:

1. *Test of Non-Verbal Intelligence-4 (TONI-4).* This is a short 10 minute screening test that will allow us to describe the non-verbal abilities of the sample of children in the study.
2. The Word Identification and Passage Comprehension subtests of the *Woodcock Reading Mastery Test- III (WRMT*-3). Together the subtests provide a short 10 minute screen of reading ability that will allow us to describe the range of reading abilities in our sample.
3. *Castles & Coltheart Reading Test 2: A Modified Version (CC2-MV).* This test provides the key reading outcome measures in the study. It assesses development of lexical knowledge in a child's reading system and their decoding skills, both in terms of accuracy and speed. This will take approximately 20 minutes.
4. *Comprehensive Test of Phonological Processing (C-TOPP),* which assesses verbal processes such as an understanding of speech sounds and memory. This will take 30 minutes.
5. *Visual Attention Network Test* and *Auditory Attention Network Test*, which assess ability to attend to visual images and sounds. Each task will take approximately 30 minutes with breaks.
6. In addition, parents will be asked to complete the *Behavior Rating Inventory of Executive Function (BRIEF),* which assesses their child's executive function (e.g. ability to control impulses and regulate behaviour). This will take up to 10 minutes.

A year from now, I will follow up the students and their new teacher and re-administer the second phase of tests (as listed in points 3-5 above).

I would be most grateful for your assistance in the following areas. As the Principal, I am requesting:

- your assistance in providing my research information sheet, consent forms to all the parents/guardians of students throughout Years 1 and 2 and Years 4 and 5.
- your permission to ask the teachers to collect and provide me with the consent forms from the parents/ guardians who choose to participate. Parents/ guardians and teachers will have the opportunity to discuss any questions they may have with me.
- your permission to come to your school to carry out all testing. Each student will be assessed by the researcher over a period of no more than 3 sessions with each session lasting no more than 50 minutes. The last session should only be 30 minutes. As such, I am requesting the possibility of being provided with a designated room in which to test students. Students will be offered breaks as required.

If granted permission for your school to participate in the current study, all testing for the first study will begin taking place at the school during Terms 2 to 4, 2016 and follow-up testing will take place one year later in Terms 2 to 4, 2017.

What are the benefits of this research for the students' education and the school?

The results of this study will lead to a better understanding of how a range of factors including attention and verbal skills interact and together play a role in reading outcomes in children. This knowledge is important in order to develop methods to help improve reading accuracy and efficiency. I will be able to provide parents with a non-diagnostic summary of their child's performance if they request it. Parents will be encouraged to speak with their child's teacher or school if there any concerns about their child's results. If difficulties are identified by any of the formal assessments indicating cause for concern, parents will be provided with referral information on follow-up services. If the child's test results mean that the child cannot be included in the study, then, because these assessments are administered in the first session, I will exclude the child from that point to avoid unnecessary testing. Where it might also be important to share results with the child's teacher (e.g., if the child's reading is well below normal), I will also seek parent consent to inform the School as appropriate. In this way the project will also aid in providing possible intervention strategies, if needed. A summary report of the overall research project will also be provided to the Department of Education, as well as to all participating schools.

To what extent is participation voluntary, and what are the implications of withdrawing participation?

Participation in this study is completely voluntary. All potential participants and their parents are advised of this in the information letters. If you would like your school to take part, I have included a consent form for you to sign.

If parents/guardians give permission for their child to participate in the research, they may withdraw their child, or the child may withdraw themselves, from participation at any time without consequence. If a child is withdrawn from participating in the study, all information and data will be destroyed immediately. The decision about whether to participate, or to participate and then withdraw, of any participant will not affect the relationship with the research team or Curtin University.

What will happen to the information collected, and is privacy and confidentiality assured?

The information collected (e.g. names, personal information, school name) will be removed and a code will be assigned. Participant information is stored this way so that, if they decide to take part and then withdraw from the project, I can find the information and destroy it. The results of this project will be published, but no personal information will be used. However, this personal information may be provided in a situation where the research team must legally report this information, such as to the Department of Education Child Protection Policy.

The data will be stored in a locked cupboard and a password protected folder on the computer at Curtin University that can only be accessed by my supervisors (Dr Neville Hennessey, Dr Suze Leitao and Dr Robert Kane) and me. All assessment records will be stored until children are 25 years of age, after which it will be destroyed according to the Curtin University Functional Records Disposal Authority protocol.

Are there any risks associated with participation?
The research assessments, tasks and procedures are age-appropriate, typically used in common research and psychological practice and are enjoyed by most children. The assessment sessions will include breaks as needed. Data collection is being conducted by a trained primary level educator who has worked with this population for over five years so it is not anticipated that students will experience any discomfort or stress. The time that the child will spend out of class will be kept to a minimum and suited to their level of attention.

Do all members of the research team who will be having contact with children have their Working with Children Check?
Yes. Under the Working with Children (Criminal Record Checking) Act 2004, individuals undertaking research that involves contact with children must pass a Working with Children Check. I have attached evidence of my current Working with Children Check.

Is this research approved?
Approval has been received from the Curtin University Human Research Ethics Committee (**Approval Code: HR04/2016**). Any questions or verification of approval for this study can be obtained by contacting the Committee.
Address: Curtin University Human Research Ethics Committee, c/o Office of Research and Development, Curtin University, GPO Box U1987, Perth, 6845.
Telephone: 9266 9223 Email: hrec@curtin.edu.au

This study has also been approved by the Western Australian Department of Education (DoE)-D16/0277635.If you wish to contact the DoE, you are able to email: ResearchandPolicy@education.wa.edu.au

Who do I contact if I wish to discuss the project further?
Please do not hesitate to contact either myself or my research supervisors if you have any questions about the study. I can be contacted by phone on 040 650 1119 or by email s.christie@postgrad.curtin.edu.au. Alternatively, you may wish to contact one of my supervisors, Dr Neville Hennessey (N.Hennessey@curtin.edu.au), Dr Suze Leitao (S.Leitao@curtin.edu.au) or Dr Robert Kane (R.T.kane@curtin.edu.au).

How do I indicate my willingness for the school to be involved in this project?
If you have had all questions about the research project answered to your satisfaction, and are willing for your school to participate, please contact me, the principal researcher, Ms Samantha-Kaye Christie at s.christie@postgrad.curtin.edu.au, to speak further about the project and how it can be best implemented.

Thank you.

Regards,

Samantha-Kaye Christie
PhD Student
Curtin University

Dr Suze Leitao
Speech Pathologist
Supervisor and Senior Lecturer
Curtin University

Dr Neville Hennessey
Supervisor and Senior Lecturer
Curtin University

Dr Robert .T. Kane
Supervisor and Senior Lecturer
Curtin University

Study 1 Principal Consent Form

Curtin University

An investigation of the relationship between attention, verbal skills, behaviour regulation and reading

Consent Form for Principal

- I have read this document and I understand the aims and procedures of this project.
- I have been given the opportunity to ask any questions, and these have been answered.
- I am willing for my school to become involved in the research project, as described.
- I understand that participation in this project is completely voluntary.
- I understand that students and their parents are free to withdraw from participation at any time, without affecting the foundation's relationship to Curtin University.
- I give permission for the contribution that my school will make to this research to be used in conference talks and published in a journal, provided that this school, the children and their parents are not identified in any way (unless permission is provided).

Name of Principal (please print): ______________________________________

Signature of Principal: ____

Date (DD/MM/YYYY):_____ / _____ / ________

Reliable email contact details: ____

Study 1 Parent/Guardian Information Letter

School of Psychology and Speech Pathology

Samantha-Kaye.D. Christie
PhD Student
School of Psychology and Speech Pathology
Curtin University
GPO Box U 1987, Perth
Western Australia, 6845

Dear Parent/Guardian

An investigation of the relationship between attention, verbal skills, behaviour regulation and reading

My name is Samantha-Kaye Christie and I am a PhD student at Curtin University. I am conducting a research project that aims to give us a better understanding of processes in the brain that help children learn to read more accurately and efficiently. To achieve this aim, this project will assess the relationship between attention, verbal skills, behaviour regulation and reading skills in typically developing children. I will also look at how this relationship changes over a 12-month period and compare typically developing children with children who have a diagnosis of developmental dyslexia.

I would like to invite both you and your child to participate in my study as part of the typically developing child sample.

Who is eligible to participate?

Phase 1 of this project will involve 260 children in mainstream primary schools in Years 1 and 2 and Years 4 and 5, as well as their parents. All children participating should have no diagnosed intellectual or cognitive impairment or other developmental condition (e.g., autism, ADHD), have normal or corrected vision and hearing, and English as a first language. Parents or caregivers will be asked about about these criteria when completing the consent form to check each child is eligible for the study. In Phase 2 of this project I will re-assess each child on some of the measures 12 months later.

What does participation in the research project involve?

Upon receiving consent from you, your child in Phase 1 will participate in three testing sessions to be conducted at your child's Primary School. These sessions will be spaced out across a 3 to 4-week period to minimise any disruption to your child's ongoing education. In the first session your child will participate in short tasks that evaluate thinking and reasoning, word reading accuracy, reading comprehension, and verbal skills (phonological processing). This session should take no more than 50 minutes in total. The second session will assess reading speed and visual attention. Your child will sit in front of a computer and read words aloud or respond by pressing a button to indicate the direction of an arrow on the screen. This session will take no more than 45 minutes. In the final session, I will assess auditory attention. Your child will wear headphones and hear the sound of a friendly dog barking. They will be asked to press a button depending on whether the dog bark is coming from their left or right ear. This session will take no more than 30 minutes. For some tasks I need to make an audio recording of your child's response (e.g., when naming words) so that I can score their performance at a later point in time.

In 2017 there will be only two sessions. This is because most assessments in the first session will not be re-administered. In particular, in Phase 2 I will re-assess your child's verbal skills, reading accuracy and speed, visual attention and auditory attention.

I would also like to get further information on your child's capacity to regulate or control their behaviour in order to include this as a factor in my analysis. The value of my research lies in being able to consider a broad range of factors that might relate to reading outcomes. I am, therefore, asking for your consent as a parent or guardian to complete a short questionnaire about your child’s behaviour (about 10 minutes in total). You will receive the questionnaire in the mail with a pre-paid return envelope.

If you grant permission for you and your child to participate as described above, the first testing will take place at the school during Term 2 to 4, 2016. Because I will have to contact you a year from now to check your child can still participate in Phase 2 in 2017, I will request your contact details at the end of the consent form attached.

What are the benefits of this research for my child’s education and the school, and are there any associated risks?

The results of this study will lead to a better understanding of how a range of factors including attention and verbal skills interact and together play a role in reading outcomes in children. This knowledge is important in order to develop methods to help improve reading accuracy and efficiency. Although participation in the study will not directly benefit your child's reading, I will be able to provide you with a summary of your child's performance if you request that on the consent form.

There are minimal risks associated with this study. Each session includes regular breaks in between tasks. Also, children generally find the tasks interesting and enjoyable and I will endeavour to keep the overall testing time to a minimum. If a child, however, shows any discomfort or signs of distress within a session I will cease the testing immediately and return the child to his or her class room. All formal testing is non-diagnostic in that test scores do not in themselves provide a diagnosis of a developmental problem. If difficulties are identified by any of the formal assessments indicating cause for concern (e.g., in relation to reading, verbal skills, or regulation of behaviour), you will be provided with referral information on follow-up services. If your child's test results mean that he/she cannot be included in the study, then, because these assessments are administered in the first session, I will exclude them from that point to avoid unnecessary testing. Where this information might also be important to share with your child's teacher, I will also seek your consent to inform the School as appropriate. In this way the project will also aid in providing possible intervention strategies, if needed.

Does my child have to take part?
No. You do not have to give permission for your child to take part in this project. If you would like your child to take part, I have included a consent form for you to sign. I have also included a consent form for your child. Please talk to your child about the activities and let them know that they do not need to take part if they do not want to. Please have your child sign their consent form if they do want to take part.

Your decision about whether to take part in this project will not change your family’s relationship with your child’s school.

What if either of us was to change our mind?
If you give permission, but then change your mind, you may withdraw your child or yourself, or your child may withdraw themselves, at any time without consequence. If you both decide to withdraw from the study, all of your information and your child’s information will be destroyed immediately. If the project has already been published at the time a participant decides to withdraw, their contribution to research data, however, cannot be removed from the publication.

What will happen to the information collected, and is privacy and confidentiality assured?
The information collected from you about your child, his/her name, your name, and any personal information will be removed and a code will be assigned. Information is stored this way so that, if you or your child decide to take part and then withdraw from the project, I can find your information and your child’s information and destroy it. The results of this project will be published, but no personal information about you or your child will be used. However, this personal information may be provided in a situation where the research team must legally report this information, such as to the Department of Education Child Protection Policy. Your child’s information, your name or the name of your child’s school will not be provided at any other time. When the study is complete, I can provide you with a summary of the research findings. This will be sent to your preferred contact details, which you can provide on the consent form.
The data that we will collect from you and your child, including audio recordings, will be stored in a locked cupboard and a password protected folder on the computer at Curtin University that can only be accessed by my supervisors (Dr Neville Hennessey, Dr Suze Leitao and Dr Robert Kane) and me. All assessment records will be stored until your child reaches 25 years of age, after which it will be destroyed according to the Curtin University Functional Records Disposal Authority protocol.

How do I know that the people involved in this research have all the appropriate documentation to be working with children?
Under the Working with Children (Criminal Record Checking) Act 2004, researchers that work with children must pass a Working with Children Check. I have provided the Principal of your child's school with evidence of my current Working with Children Check.

Is this research approved?
Approval has been received from the Curtin University Human Research Ethics Committee (**Approval Code: HR04/2016**). Any questions or verification of approval for this study can be obtained by contacting the Committee.
Address: Curtin University Human Research Ethics Committee, c/o Office of Research and Development, Curtin University, GPO Box U1987, Perth, 6845.
Telephone: 9266 9223 Email: hrec@curtin.edu.au

This study has also been approved by the Western Australian Department of Education (DoE)-D16/0277635.If you wish to contact the DoE, you are able to email: ResearchandPolicy@education.wa.edu.au

Who do I contact if I wish to discuss the project further?
Please do not hesitate to contact either myself or my research supervisors if you have any questions about the study. I can be contacted by phone on 040 650 1119 or by email s.christie@postgrad.curtin.edu.au. Alternatively, you may wish to contact one of my supervisors, Dr Neville Hennessey (email: N.Hennessey@curtin.edu.au, Phone: 9266 2553), Dr Suze Leitao (email: S.Leitao@exchange.curtin.edu.au, Phone: 9266 7620) or Dr Robert Kane (email: R.T.kane@curtin.edu.au; phone: 9266 7515).

How do my child and I become involved in this project?
If you would like to take part, I have included a short questionnaire and consent form for you to complete and sign.
Please make sure that you:

- Talk to your child about what taking part in the project involves before you both decide;
- Take up my offer to ask any questions you may have about the project.

Once all questions have been answered to your satisfaction, and you and your child are both willing to take part, please both complete the attached **Consent Forms**, and return them to your child's school teacher within two weeks from the date of receipt.

Thank you.

Regards,

Samantha-Kaye Christie
PhD Student
Curtin University

Dr Neville Hennessey
Supervisor and Senior Lecturer
Curtin University

Dr Robert .T. Kane
Supervisor and Senior Lecturer
Curtin University

Dr Suze Leitao
Speech Pathologist
Supervisor and Senior Lecturer
Curtin University

Study 1 Parent/Guardian Consent Form

Curtin University

School of Psychology and Speech Pathology

An investigation of the relationship between attention, verbal skills and reading

Consent Form for Parent/Guardian

- I have read this document and I understand the aims and procedures of this project.
- I have been given the opportunity to ask any questions, and these have been answered.
- I am willing for my child to become involved in the research project, as described.
- I am willing to complete a checklist as explained in the letter.
- I have talked to my child about the project, and he/she wishes to take part, as indicated by his/her completion of the child consent form.
- I understand that participation in this project is completely voluntary.
- I understand that both my child and I are free to withdraw from participation at any time, without affecting my family's relationship with my child's teacher or my child's school.
- I give permission for the contribution that my child and I make to this research to be used in conference talks and published in a scientific journal, if we are not identified in any way.
- I understand that an audio recording will be made of my child's verbal responses for scoring.
- I understand that all data and personal records will be kept confidential and can only be accessed by the researchers on this project.
- I understand that a non-diagnostic summary of findings from the research can be made available to me.

Please also tick the box to give permission for the following:

☐ I would like to be provided with a summary of my child's results in a non-diagnostic report (please provide your preferred delivery address)

____

____

Name of Child (please print): ___________________________________

Child's Date of birth (please print): _____ / _____ / ________

Name of Parent/Guardian (please print): _________________________________

Signature of Parent/Guardian: _______________________________________

Contact Details (email address and telephone number for future study and details about receiving a summary of the results of the study when it is completed, as explained above):

____

Date (DD/MM/YYYY):_____ / _____ / ________

Please answer the following questions

1. Does your child have an intellectual or cognitive impairment? Yes ☐ No ☐
   If yes, please, state if there is a specific diagnosis and who (what profession) made the diagnosis. This information will be kept confidential.

   ____

2. Has your child ever been assessed with any vision impairments? If yes, has this been corrected? (e.g. wearing glasses)

   ____

3. Has your child been assessed with any hearing problems? If yes, has this been corrected? (e.g. wearing hearing aid).

4. Is English the main language spoken by your child? Please identify any other languages spoken at home.

5. Has your child been diagnosed with any developmental disorder? (E.g. autism, dyslexia, attention deficit disorder)? Yes ☐ No ☐

If yes, please give details regarding type of disorder and when it was diagnosed.

Study 1 Participant (Child) Information Letter

Curtin University

School of Psychology and Speech Pathology

Participant Information Script

Hello,

My name is Samantha. I have a project that you might like to help me with.

The project is about getting to understand how people pay attention to pictures and sounds and also about how people read.

Would you like to help me? If you would like to help, we will do some quick activities this Term. You will do activities like reading, looking at some fishes and pressing a button to tell me if a fish is looking left or right and listening to some sounds and then telling me if the sound is high or low.

I may ask you if you would do some more activities with me another time. I will also use the information you give me in another research project that I am doing.

When I am finished I will write up my results. When I do this, I won't write or tell anyone your name or the name of your school.

I will not tell anyone what you say while helping me with the project, unless I need to tell someone like your teacher (e.g. if you tell me that someone has hurt you).

You can change your mind about being in this project during that time. If you change your mind, I will destroy your information from the project.

Please talk to your parents/guardians about this research project and ask them any questions.

If you would like to help with the project, please draw a circle around the tick on the next page. If you <u>do not</u> want to be part of this project- that is OK too.

Even if you want to help me now but want to stop later, that is OK. You can tell your parents or teacher and they will let me know.

Please let your parents/guardians know and read and sign the consent form below. This letter is for you to keep.

You can also ask me any questions about the project.

Thank you for listening to my idea.

Samantha-Kaye Christie
PhD Student
Curtin University

Study 1 Participant (Child) Consent Form

School of Psychology and Speech Pathology

Participant Consent Form

- I know I have a choice whether or not I want to do this project.
- I know that I can stop whenever I want to. I know I will not get into trouble if I want to stop.
- I know that I will be doing some different activities (like looking at pictures, listening to sounds through some headphones, reading some words) to help with this project.
- I know that I need to draw a circle around the tick on this page and sign my name on the line before I can help with the project.

YES	**NO**
I would like to help with the project	Not this time

Child's name: ________________________________

Today's date: ____ / ____ / ________

Study 2 Parent/Guardian Information Letter

School of Psychology and Speech Pathology

Samantha-Kaye. D. Christie
PhD Student
School of Psychology and Speech Pathology
Curtin University
GPO Box U 1987, Perth
Western Australia, 6845

Dear Parent/Guardian

An investigation of the relationship between attention, verbal skills, behaviour regulation and reading

My name is Samantha-Kaye Christie and I am a PhD student at Curtin University. Last year you gave consent for your child to participate in my research project, which is aimed at having a better understanding of processes in the brain that help children learn to read more accurately and efficiently. My project includes a second phase that involves re-assessing the same children 12 months later. Seeing how reading skills improve over time in relation to other factors, such as attention, verbal skills and behaviour regulation, is an important way of understanding the causal relationships between these factors and reading outcomes. I am grateful for this continued support from your child's school, and all the parents and children in the study. The purpose of this letter is simply to inform parent or guardians again of this second phase of the project, which was described in the original information sheet, and to give parents a brief update on my progress so far. There is also the option, if you do not want your child to participate in Phase 2, or your child does not want to participate, to complete the attached form and return that to me using the reply paid envelope within 2 weeks from receiving this letter, so that I know not to re-assess your child.

What does participation in Phase 2 of the research project involve?
Your child will participate in two testing sessions to be conducted at your child's Primary School. These sessions will be spaced out across a 2 to 3-week period to minimise any disruption to your child's ongoing education. In the first session your child will participate in short tasks that evaluate word reading speed and accuracy and may include testing of verbal skills (phonological processing). Your child will sit in front of a computer and read words aloud on the screen. There may also be a second in which your child's visual and auditory attention will be assessed. Your child will sit in front of a computer and press a button to indicate the direction of an arrow and do another task where they wear headphones and hear tones of different frequencies at a comfortable volume. They will be asked to press a button depending

on whether the sound they hear is coming from their left or right ear. This session will take no more than 50 minutes. For some tasks I need to make an audio recording of your child's response (e.g., when naming words) so that I can score their performance at a later point in time.

I would also like to get further information on your child's capacity to regulate or control their behaviour to include this as a factor in my analysis. The value of my research lies in being able to consider a broad range of factors that might relate to reading outcomes. I am, therefore, hoping that you will agree as a parent or guardian to complete another short questionnaire about your child’s behaviour (about 10 minutes in total). You will receive the questionnaire in the mail with a pre-paid return envelope.

What are the benefits of this research for my child’s education and the school, and are there any associated risks?

The results of this study will lead to a better understanding of how a range of factors including attention and verbal skills interact and together play a role in reading outcomes in children. This knowledge is important in order to develop methods to help improve reading accuracy and efficiency. Although participation in the study will not directly benefit your child's reading, I will be able to provide you with a summary of your child's performance if you request that on the consent form.

There are minimal risks associated with this study. Each session includes regular breaks in between tasks. Also, children generally find the tasks interesting and enjoyable and I will endeavour to keep the overall testing time to a minimum. If a child, however, shows any discomfort or signs of distress within a session I will cease the testing immediately and return the child to his or her class room.

Does my child have to take part?

No. You do not have to agree for your child to continue to take part in this project. Please talk to your child about the activities and let them know that they do not need to take part if they do not want to. Please complete and sign the attached form and return to me if I am not to re-assess your child.

Your decision about whether to take part in Phase 2 will not change your family’s relationship with your child’s school.

What if either of us was to change our mind?

If you give permission, but then change your mind, you may withdraw your child or yourself, or your child may withdraw themselves, from the whole study at any time without consequence. If you both decide to withdraw from the whole study, all of your information and your child’s information from 2016 and 2017 will be destroyed immediately. If the project has already been published at the time a participant decides to withdraw, their contribution to research data, however, cannot be removed from the publication.

What will happen to the information collected, and is privacy and confidentiality assured?

The information collected from you about your child, his/her name, your name, and any personal information will be removed and a code will be assigned. Information is stored this way so that, if you or your child decide to take part and then withdraw from the project, I can find your information and your child's information and destroy it. The results of this project will be published, but no personal information about you or your child will be used. However, this personal information may be provided in a situation where the research team must legally report this information, such as to the Department of Education Child Protection Policy. Your child's information, your name or the name of your child's school will not be provided at any other time. When the study is complete, I can provide you with a summary of the research findings. This will be sent to your preferred contact details, which you can provide on the consent form.

The data that we will collect from you and your child, including audio recordings, will be stored in a locked cupboard and a password protected folder on the computer at Curtin University that can only be accessed by my supervisors (Dr Neville Hennessey, Dr Suze Leitao and Dr Robert Kane) and me. All assessment records will be stored until your child reaches 25 years of age, after which it will be destroyed according to the Curtin University Functional Records Disposal Authority protocol.

How do I know that the people involved in this research have all the appropriate documentation to be working with children?

Under the Working with Children (Criminal Record Checking) Act 2004, researchers that work with children must pass a Working with Children Check. I have provided the Principal of your child's school with evidence of my current Working with Children Check.

Is this research approved?

Approval has been received from the Curtin University Human Research Ethics Committee (**Approval Code: HR04/2016**). Any questions or verification of approval for this study can be obtained by contacting the Committee.
Address: Curtin University Human Research Ethics Committee, c/o Office of Research and Development, Curtin University, GPO Box U1987, Perth, 6845.
Telephone: 9266 9223 Email: hrec@curtin.edu.au

This study has also been approved by the Western Australian Department of Education (DoE)-D16/0277635.If you wish to contact the DoE, you are able to email: ResearchandPolicy@education.wa.edu.au

Who do I contact if I wish to discuss the project further?

Please do not hesitate to contact either myself or my research supervisors if you have any questions about the study. I can be contacted by phone on 040 650 1119 or by email s.christie@postgrad.curtin.edu.au. Alternatively, you may wish to contact one of my supervisors, Dr Neville Hennessey (email: N.Hennessey@curtin.edu.au, Phone: 9266 2553), Dr Suze Leitao (email: S.Leitao@exchange.curtin.edu.au, Phone: 9266 7620) or Dr Robert Kane (email: R.T.kane@curtin.edu.au; phone: 9266 7515).

How do my child and I become involved in this project?
If you would like to take part, I have included a short questionnaire and consent form for you to complete and sign.
Please make sure that you:

- Talk to your child about what taking part in the project involves before you both make a decision;
- Take up my offer to ask any questions you may have about the project.

Once all questions have been answered to your satisfaction, and you and your child are both willing to take part, please both complete the attached **Consent Forms**, and return them to your child's school teacher within two weeks from the date of receipt**.**

Thank you.

Regards,

Samantha-Kaye Christie
PhD Student
Curtin University

Dr Suze Leitao
Speech Pathologist
Supervisor and Senior Lecturer
Curtin University

Dr Neville Hennessey
Supervisor and Senior Lecturer
Curtin University

Dr Robert .T. Kane
Supervisor and Senior Lecturer
Curtin University

Study 2 Parent/Guardian Consent Form

Curtin University

School of Psychology and Speech Pathology

An investigation of the relationship between attention, verbal skills, behaviour regulation and reading

Notification to Not Participate in Phase 2 for Parent/Guardian

If you prefer that your child does not participate in Phase 2 of the above study, please tick the box:

☐ I would like for both my child and myself to opt-out of the follow-up assessments for the above study.

Name of Child (please print): ___________________________________

Child's Date of birth (please print): _____ / _____ / ________

Name of Parent/Guardian (please print): ___________________________________

Signature of Parent/Guardian: ____

Date (DD/MM/YYYY): _____ / _____ / ________

PLEASE RETURN THIS FORM VIA THE REPLY-PAID ENVELOPE AS SOON AS YOU CAN SO THAT I KNOW NOT TO RE-ASSESS YOUR CHILD.

Study 2 Participant (Child) Information Letter

Curtin University

School of Psychology and Speech Pathology

Participant Information Script

Hello,

Hi again. Thank you for helping with my research project last year. As we spoke about last year, there are two parts to my project. You did the first part last year and I want to find out if you would be happy to do the second part with me.

The project is about getting to understand how people pay attention to pictures and sounds and also about how people read.

Would you like to help me? If you would like to help, we will do some quick activities, similar to what we did last year. You will do activities like reading some words as quickly and correctly as you can. I may also ask you to look at some fishes and pressing a button to tell me if a fish is looking left or right and listening to some sounds and then telling me if the sound is coming from your left or right ear.

When I am finished I will write up my results. When I do this, I won't write or tell anyone your name or the name of your school.

I will not tell anyone what you say while helping me with the project, unless I need to tell someone like your teacher (e.g. if you tell me that someone has hurt you).

You can change your mind about being in this project during that time. If you change your mind, I will destroy your information from the project.

Please talk to your parents/guardians about this research project and ask them any questions.

If you would like to help again with the project, please draw a circle around the tick on the next page. If you do not want to be part of this project- that is OK too.

Even if you want to help me now but want to stop later, that is OK. You can tell your parents or teacher and they will let me know.

Please let your parents/guardians know and read and sign the consent form below. This letter is for you to keep.

You can also ask me any questions about the project.

Thank you for listening to my idea.

Samantha-Kaye Christie
PhD Student
Curtin University

Study 2 Participant (Child) Consent Form

School of Psychology and Speech Pathology

Participant Consent Form

- I know I have a choice whether or not I want to do this project.

- I know that I can stop whenever I want to. I know I will not get into trouble if I want to stop.

- I know that I will be doing some different activities (like looking at pictures, listening to sounds through some headphones, reading some words) to help with this project.

- I know that I need to draw a circle around the tick on this page and sign my name on the line before I can help with the project.

YES

I would like to help with the project

NO

Not this time

Child's name: ________________________________

Today's date: ____ / ____ / ________

Study 3 Information Sheet for Director of Language Centre

School of Psychology and Speech Pathology

Samantha-Kaye.D. Christie
PhD Student
School of Psychology and Speech Pathology
Curtin University of Technology
GPO Box U 1987, Perth
Western Australia, 6845

Dear Director of XXX

An investigation of the relationship between attention, verbal skills, behaviour regulation and reading

My name is Samantha-Kaye Christie and I am a PhD student at Curtin University. I am conducting a research project that aims to give us a better understanding of processes in the brain that help children learn to read more accurately and efficiently. To achieve this aim, this project will assess the relationship between attention, verbal skills associated with phonological processing, behaviour regulation capacity, and reading skills in typically developing children. I will also look at how this relationship changes over a 12-month period and compare typically developing children with children who have a diagnosis of dyslexia.

I would like to invite the DSF to take part in this study through recruiting students' with developmental dyslexia via your organisation. I am seeking a total of 50 children aged 9 to 10 years (e.g., in years 4 and 5) with developmental dyslexia to take part. I am expecting this recruitment to be undertaken in 2017.

What does participation in the research project involve and are there any risks?
I am asking DSF to advertise my study through sending out the attached flyer. Parents who are interested in taking part will directly indicate their interest to me and be provided with a consent form. With consent, I will access previous records of their child's non-verbal cognitive ability, reading, screening of hearing and vision, and any information indicating whether they have ADHD and data on the languages spoken. If assessments have not been previously conducted, or results are no longer current, I will invite students to be assessed using the following tests in up to three sessions:

1. *Test of Non-Verbal Intelligence-4 (TONI-4).* This is a short 10-minute screening test that will allow us to describe the non-verbal abilities of the sample of children in the study.
2. The Word Identification and Passage Comprehension subtests of the *Woodcock Reading Mastery Test- III (WRMT*-3). Together the subtests provide a short 10-minute screen of reading ability that will allow us to describe the range of reading abilities in our sample.
3. *Castles & Coltheart Reading Test 2: A Modified Version (CC2-MV)*, This test provides the key reading outcome measures in the study. It assesses development of lexical knowledge in a child's reading system and their decoding skills, both in terms of accuracy and speed. This will take approximately 20 minutes.
4. *Comprehensive Test of Phonological Processing (C-TOPP).* This will take 30 minutes.
5. *Attention Network Test* and *Auditory Attention Network Test*, which assess ability to attend to visual images and sounds. Each task will take approximately 30 minutes with breaks.
6. In addition, parents will be asked to complete the *Behavior Rating Inventory of Executive Function (BRIEF),* which assesses their child's executive function (e.g. ability to control impulses and regulate behaviour). This will take up to 10 minutes.

With your permission, testing will take place in a quiet room at the DSF outside of school hours, or at the students' home. Students will be offered breaks as required.

If granted permission for your organisation to participate in the current study, all testing will take place during Terms 3 and 4, 2017.

What are the benefits of this research for the child's education and the school?
The results of this study will lead to a better understanding of visual and auditory attention development. Understanding how attention develops is important as these processes provide one with the ability to concentrate on and gain essential skills such as learning how to read or improving reading ability. In turn, this will minimise the impact of poor reading or reading difficulties on the academic, social and psychological outcomes among children with dyslexia.

The data that are collected have the potential to identify difficulties with students' attention processes, as well as their cognitive ability. Parents will be confidentially informed via phone call, if their child has scored below the cut-off points for their age group on the Test of Non-Verbal Intelligence-4 (TONI-4) or have scored over the clinical cut-offs for their age group on the Behaviour Rating Inventory of Executive Function (BRIEF). The research team will provide them with referral options for further advice and assistance from psychologists and speech pathologists. In this way the project will also aid in providing possible intervention strategies for identified difficulties.

A summary report of the overall research project will also be provided to the DSF.

To what extent is participation voluntary, and what are the implications of withdrawing participation?
Participation in this study is completely voluntary. All potential participants and their parents are advised of this in the information letters. If you would like your organisation to take part, I have included a consent form for you to sign.

If parents/guardians give permission for their child to participate in the research, they may withdraw their child, or the child may withdraw themselves, from participation at any time without consequence. If a child is withdrawn from participating in the study, all information and data will be destroyed immediately. If the project has already been published at the time a participant decides to withdraw, their contribution to research data cannot be removed from the publication. The decision about whether to participate, or to participate and then withdraw, of any participant will not affect the relationship with the research team or Curtin University.

What will happen to the information collected, and is privacy and confidentiality assured?
The information collected (e.g. names, personal information, school name) will be removed and a code will be assigned. Participant information is stored this way so that, if they decide to take part and then withdraw from the project, I can find the information and destroy it. The results of this project will be published, but no personal information will be used. However, this personal information may be provided in a situation where the research team must legally report this information, such as to the Department of Education Child Protection Policy.

The data will be stored in a locked cupboard and a password protected folder on the computer at Curtin University that can only be accessed by my supervisors (Dr Neville Hennessey, Dr Suze Leitao and Dr Robert Kane) and me. All assessment records will be stored until children are 25 years of age, after which it will be destroyed according to the Curtin University Functional Records Disposal Authority protocol.

Are there any risks associated with participation?
The research assessments, tasks and procedures are age-appropriate, typically used in common research and psychological practice and are enjoyed by most children. The assessment sessions will include breaks as needed. The time that the child will spend in the assessments will be kept to a minimum and suited to their level of attention. Data collection is being conducted by a trained primary level educator who has worked with this population for over five years, so it is not anticipated that students' will experience any discomfort or stress. Testing time will be reduced if parents give consent to access results for their child on equivalent measures if available.

Do all members of the research team who will be having contact with children have their Working with Children Check?

Yes. Under the Working with Children (Criminal Record Checking) Act 2004, individuals undertaking research that involves contact with children must pass a Working with Children Check. I have attached evidence of my current Working with Children Check.

Is this research approved?
Approval has been received from the Curtin University Human Research Ethics Committee (**Approval Code: HR04/2016**). Any questions or verification of approval for this study can be obtained by contacting the Committee.

Address: Curtin University Human Research Ethics Committee, c/o Office of Research and Development, Curtin University, GPO Box U1987, Perth, 6845.
Telephone: 9266 9223
Email: hrec@curtin.edu.au

This study has also been approved by the Western Australian Department of Education (DoE)-D16/0277635.If you wish to contact the DoE, you are able to email: ResearchandPolicy@education.wa.edu.au

Who do I contact if I wish to discuss the project further?
Please do not hesitate to contact either myself or my research supervisors if you have any questions about the study. I can be contacted by phone on 040 650 1119 or by email s.christie@postgrad.curtin.edu.au. Alternatively, you may wish to contact one of my supervisors, Dr Neville Hennessey (N.Hennessey@curtin.edu.au), Dr Suze Leitao (S.Leitao@exchange.curtin.edu.au) or Dr Robert Kane (R.T.kane@curtin.edu.au).

How do I indicate my willingness for the school to be involved in this project?

If you have had all questions about the research project answered to your satisfaction, and are willing for your organisation to participate, please complete the **Consent Form** attached. Please return this to me via the enclosed stamped and addressed envelope within two weeks from the date of receipt if you would like to be involved.

Thank you.

Regards,

Samantha-Kaye Christie
PhD Student
Curtin University

Dr Suze Leitao
Speech Pathologist
Supervisor and Senior Lecturer
Curtin University

Dr Neville Hennessey

Speech Pathologist
Supervisor and Senior Lecturer
Curtin University

Dr Robert .T. Kane
Supervisor and Senior Lecturer
Curtin University

Study 3 Consent Form for Director of Language Centre

An investigation of the relationship between attention, verbal skills, behaviour regulation and reading

Consent Form for Director at XXX

- I have read this document and I understand the aims and procedures of this project.
- I have been given the opportunity to ask any questions, and these have been answered.
- I am willing for XXX to become involved in the research project, as described.
- I understand that participation in this project is completely voluntary.
- I understand that students and their parents are free to withdraw from participation at any time, without affecting the foundation's relationship to Curtin University.
- I give permission for the contribution that XXX will make to this research to be used in conference talks and published in a journal, provided that XXX, the children and their parents are not identified in any way.

Name of Director (please print): ______________________________________

Signature of Director: ____

Date (DD/MM/YYYY):_____ / _____ / ________

Reliable email contact details: ____

Study 3 Information Sheet for Parent/Guardian

Curtin University

School of Psychology and Speech Pathology

Samantha-Kaye.D. Christie
PhD Student
School of Psychology and Speech Pathology
Curtin University
GPO Box U 1987, Perth
Western Australia, 6845

Dear Parent/Guardian

An investigation of the relationship between attention, verbal skills, behaviour regulation and reading

My name is Samantha-Kaye Christie and I am a PhD student at Curtin University. I am conducting a research project that aims to give us a better understanding of processes in the brain that help children learn to read more accurately and efficiently. To achieve this aim, this project will assess the relationship between attention, verbal skills, behaviour regulation and reading skills in typically developing children who are at different stages of reading development. I will also compare typically developing children with children who have a diagnosis of dyslexia.

I am current recruiting up to 50 students with dyslexia, aged 9 to 10 years as well as their parents. I would like to invite both you and your child to participate in data collection.

What does participation in the research project involve?

With your consent, I will access previous records and reports of your child's non-verbal cognitive ability, reading and phonological processing skills from DSF. The following assessments will then be administered in person:

1. *Castles & Coltheart Reading Test 2: A Modified Version (CC2-MV)*, which assesses word knowledge and decoding in terms of both accuracy and speed. Each child reads aloud words and non-words that appear on a computer screen. This will take 15 minutes.
2. *Visual Attention Network Task* and *Auditory Attention Network Task*, which assess ability to attend to images and sounds. Your child will sit in front of a computer and indicate by pressing a button the direction of an arrow on the screen, and whether a dog bark that is presented through headphones at a

comfortable volume is coming from the left or right ear. Each task will take no more than 20 minutes with breaks.

As part of the above assessments I need to make an audio recording of your child's response (e.g., when naming words) so that I can score their performance at a later point in time.

I will also invite you to complete the following:

3. The *Behavior Rating Inventory of Executive Function (BRIEF),* which assesses your child’s behavioural regulation. This will take up to 10 minutes to complete.

If assessments of non-verbal cognitive ability and a standardised test of reading ability have not been previously administered to your child, or the results are no longer current, then I will also need to administer the following two assessments. By using results already available for the same or equivalent tests, however, the assessment time for your child can be reduced.

4. *Test of Non-Verbal Intelligence-4 (TONI-4).* This is a short 10-minute screening test that will allow us to describe the non-verbal abilities of the sample of children in the study.
5. The Word Identification and Passage Comprehension subtests of the *Woodcock Reading Mastery Test- III (WRMT*-3). Together the subtests provide a short 10-minute screening of reading ability that will allow us to describe the range of reading abilities in our sample.

The research assessments, tasks and procedures are age-appropriate, typically used in common psychological practice and are enjoyed by most children. Data collection is being conducted by a trained primary level educator who has worked with this population for over five years, so it is not anticipated that your child will experience any discomfort or stress.

What are the benefits of this research?

The results of this study will lead to a better understanding of how a range of factors including attention and verbal skills interact and together play a role in reading outcomes in children. This knowledge is important in order to develop methods to help improve reading accuracy and efficiency. I will be able to provide you with a summary of your child's performance. With your consent, this information can also be provided to the DSF or your child's school, if you feel this is appropriate. You can also request a summary report of the overall research project, which can be provided when the study is complete.

Does my child have to take part?

No. You do not have to give permission for your child to take part in this project. If you would like your child to take part, I have included a consent form for you to sign. I have also included a consent form for your child. Please have your child sign the consent form if they do want to take part. Your decision about whether to take part in this project will not change your family's relationship with the DSF or Curtin University.

What if either of us was to change our mind?
If you give permission, but then change your mind, you may withdraw your child or yourself, or your child may withdraw themselves, at any time without consequence. If you both decide to withdraw from the study, all of your information/ child's information will be destroyed immediately.

What will happen to the information collected, and is privacy and confidentiality assured?
The information collected from you about your child, his/her name, your name, and any personal information will be removed and a code will be assigned. Information is stored this way so that, if you or your child decide to take part and then withdraw from the project, I can find your information and your child's information and destroy it. The results of this project will be published, but no personal information about you or your child will be used. However, this personal information may be provided in a situation where the research team must legally report this information, such as to the Department of Education Child Protection Policy. Your child's information, your name will not be provided at any other time.

All data, including audio recordings, will be stored in a locked cupboard and a password protected folder on the computer at Curtin University that can only be accessed by my supervisors (Dr Neville Hennessey, Dr Suze Leitao and Dr Robert Kane) and me. All assessment records will be stored until your child reaches 25 years of age, after which it will be destroyed according to the Curtin University Functional Records Disposal Authority protocol.

How do I know that the people involved in this research have all the appropriate documentation to be working with children?
Under the Working with Children (Criminal Record Checking) Act 2004, researchers that work with children must pass a Working with Children Check. I have provided the Director of the DSF with evidence of my current Working with Children Check.

Is this research approved?
Approval has been received from the Curtin University Human Research Ethics Committee (**Approval Code: HR04/2016**). Any questions or verification of approval for this study can be obtained by contacting the Committee. Address: Curtin University Human Research Ethics Committee, c/o Office of Research and Development, Curtin University, GPO Box U1987, Perth, 6845. Telephone: 9266 9223 Email: hrec@curtin.edu.au

This study has also been approved by the Western Australian Department of Education (DoE)-D16/0277635.If you wish to contact the DoE, you are able to email: ResearchandPolicy@education.wa.edu.au

Who do I contact if I wish to discuss the project further?
Please do not hesitate to contact either myself or my research supervisors if you have any questions about the study. I can be contacted by phone on 040 650 1119 or by email s.christie@postgrad.curtin.edu.au. Alternatively, you may wish to contact one of my supervisors, Dr Neville Hennessey (N.Hennessey@curtin.edu.au), Dr Suze Leitao (S.Leitao@exchange.curtin.edu.au) or Dr Robert Kane (R.T.kane@curtin.edu.au).

How do my child and I become involved in this project?
If you would like to take part, I have included a consent form for you to sign. Please make sure that you:

- Talk to your child about what taking part in the project involves before you both make a decision;
- Take up my offer to ask any questions you may have about the project.

Once all questions have been answered to your satisfaction, and you and your child are both willing to take part, please both complete the attached **Consent Forms**.

Thank you.

Regards,

Samantha-Kaye Christie
PhD Student
Curtin University

Dr Neville Hennessey
Supervisor and Senior Lecturer
Curtin University

Dr Robert .T. Kane
Supervisor and Senior Lecturer
Curtin University

Dr Suze Leitao
Speech Pathologist
Supervisor and Senior Lecturer
Curtin University

Study 3 Parent/Guardian Consent Form

School of Psychology and Speech Pathology

An investigation of the relationship between attention, verbal skills, behaviour regulation and reading

Consent Form for Parent/Guardian

- I have read this document and I understand the aims and procedures of this project.
- I have been given the opportunity to ask any questions, and these have been answered.
- I am willing for my child to become involved in the research project, as described.
- I am willing to complete the checklists as explained in the letter.
- I have talked to my child about the project, and he/she wishes to take part, as indicated by his/her completion of the child consent form.
- I understand that participation in this project is completely voluntary.
- I understand that both my child and I are free to withdraw from participation at any time, without affecting my family’s relationship with my child’s teacher or my child’s school/DSF.
- I understand that an audio recording will be made of my child's verbal responses for scoring.
- I understand that all data and personal records will be kept confidential and can only be accessed by the researchers on this project.
- I give permission for the contribution that my child and I make to this research to be used in conference talks, further analyses, published in a journal, provided that we are not identified in any way.

- If available, I give permission for the researcher to access previous records of my child's non-verbal cognitive ability, reading scores and phonological processing scores.
- I understand that a non-diagnostic summary of findings from the research can be made available to me.

Please also tick the box to give permission for the following:

☐ I would like to be provided with a summary of my child's results in a non-diagnostic report (please provide your preferred delivery address)

____

____

Name of Child (please print): ______________________________________

Date of birth (please print): _____ / _____ / ________

Name of Parent/Guardian (please print): _____________________________________

Signature of Parent/Guardian: ____

Date (DD/MM/YYYY):_____ / _____ / ________

<u>Please answer the following questions</u>

1. Does your child have an intellectual or cognitive impairment? Yes ☐ No ☐

   If yes, please, state if there is a specific diagnosis and who (what profession) made the diagnosis. This information will be kept confidential.

   ____

2. Has your child ever been assessed with any vision impairments? If yes, has this been corrected? (e.g. wearing glasses)

   ____

3. Has your child been assessed with any hearing problems? If yes, has this been corrected? (e.g. wearing hearing aid).

4. Is English the main language spoken by your child? Please identify any other languages spoken at home.

5. Has your child been diagnosed with any other developmental disorders? (E.g. autism, attention deficit disorder)? Yes ☐ No ☐

If yes, please give details regarding type of disorder and when it was diagnosed.

6. Is your child right-handed or left-handed and do they have any musical background?

Study 3 Information Sheet for (Child) Participant

School of Psychology and Speech Pathology

Participant Information Sheet

Hello,

My name is Samantha. I have a project that you might like to help me with.

The project is about getting to understand how people pay attention to pictures and sounds and also about how people read.

Would you like to help me? If you would like to help, we will do some quick activities this Term. You will do activities like reading, looking at some fishes and pressing a button to tell me if a fish is looking left or right and listening to some sounds and then telling me if the sound is coming from your left or right ear.

When I am finished I will write up my result. When I do this, I won't write or tell anyone your name or the name of your school. I will not tell anyone what you say while helping me with the project, unless I need to tell someone like your teacher (e.g. if you tell me that someone has hurt you).

You can change your mind about being in this project during that time. If you change your mind, I will destroy your information from the project.

Please talk to your parents/guardians about this research project and ask them any questions.

If you would like to help with the project, please draw a circle around the tick on the next page. If you do not want to be part of this project- that is OK too. Please let your parents/guardians know and read and sign the consent form below. This letter is for you to keep.

Even if you want to help me now but want to stop later, that is OK. You can tell your parents or teacher and they will let me know.

You can also ask me any questions about the project. Thank you for listening to my idea.

Samantha-Kaye Christie
PhD Student
Curtin University

Study 3 Consent Form for (Child) Participant

Curtin University

School of Psychology and Speech Pathology

PARTICIPANT CONSENT

1. Are you happy to talk with me about your dyslexia?

2. Would you like to help me with some activities (like reading, looking at some fishes and listening to some sounds)?

3. You can stop at any time.

4. What you tell me will be kept strictly confidential.

5. You can ask me or your parents about any other question you have.

Yes	No

6. I know that I need to draw a circle around the tick on this page and sign my name on the line before I can help with the project.

YES | **NO**

I would like to help with the project | Not this time

My name: ________________________________

Today's date: ____ / ____ / ________

Appendix C: An Example of the Non-Diagnostic Report

Curtin University

School of Psychology and Speech Pathology

Examining the relationship between attention, phonological processing and reading

Results from study conducted in Term 1, 2017

Student: ___________________________________ **Year/ Class**: ________

Date of Testing: ____________________________

Thank you for allowing your child to take part in my research project.
Your child was assessed on the following tasks and his/her results are summarised below.

<u>Test of Non-Verbal Cognitive Ability Task</u>
Test of Non-Verbal Intelligence Task
This task measures non-verbal cognitive ability in a simple format. It assesses the ability to determine a pattern and requires a child to indicate their answer by using a gesture such as pointing.
Your child's performance on this task was:
Scaled Score = (Average Range = 8-19)
Description: below cut-off score/below average range/within average range/above average range

<u>Reading Tasks</u>
Woodcock Reading Mastery Test – Word Identification
This task assesses the ability to read words
Your child's performance on this task was:
Scaled Score = (Average Range = 7 – 14)
Description: below cut-off score/below average range/within average range/above average range

Woodcock Reading Mastery Test – Passage Comprehension
This task assesses the ability to read a sentence or short passage and then use a variety of comprehension and vocabulary skills in identifying a missing word.
Your child's performance on this task was:
Scaled Score = (Average Range = 7 -14)
Description: below cut-off score/below average range/within average range/above average range

<u>Executive Function Task</u>
Behaviour Inventory of Executive Function – Global Executive Function

This task asks questions about your child's executive function (e.g. ability to control impulses, ability to tolerate change) in daily situations such as at home, school and while with friends.
Your child's performance on this task was:
Scaled Score = (Average Range = Below 65)
Description: below cut-off score/below average range/within average range/above average range

Phonological Processing Tasks
Comprehensive Test of Phonological Processing – Phonological Awareness
This task assesses the ability to understand speech sounds. It comprises activities such as taking away a sound from the beginning, middle or end of a word and say the word that remains, e.g. say 'cupboard' without 'cup', say 'cup' without 'c'. Another task includes the ability to select words with the same initial and final sounds e.g. say which of the following words start with the same sound 'foot, feel, pot'.

Your child's performance on this task was:
Scaled Score = (Average Range = 85 – 100)
Description: below cut-off score/below average range/within average range/above average range

Comprehensive Test of Phonological Processing – Phonological Memory
This task assesses the ability to repeat a series of numbers accurately and to repeat non-words accurately (e.g. say the word 'gop').
Your child's performance on this task was:
Scaled Score = (Average Range = 85 – 100)
Description: below cut-off score/below average range/within average range/above average range

Comprehensive Test of Phonological Processing – Rapid Automatized Naming
This task assesses the ability to rapidly name numbers and letters.
Your child's performance on this task was:
Scaled Score = (Average Range = 85 – 100)
Description: below cut-off score/below average range/within average range/above average range

In summary: The assessments identified your child as having scored below the cut-off, and having some difficulty with:

- Non-Verbal Cognitive Ability
- Executive Functioning

It is recommended that you discuss this with your child's teacher and possibly seek further assessment with a Speech Pathologist or Psychologists. I have attached a list of such services and their contact details. (For children with dyslexia, this was only included if there are any identified difficulties that is not expected for a child with dyslexia).

You have permission to share these results with your child's school if you wish.
Kind Regards,

Samantha-Kaye Christie	Dr Suze Leitao	Dr Neville Hennessey
PhD Student	Speech Pathologist	Psychologist
Curtin University	Supervisor	Supervisor
s.christie@postgrad.curtin.edu.au	Curtin University	Curtin University

Dr Robert Kane
Psychologist
Supervisor
Curtin University

Appendix D: The Reading Speed Task Pilot Study

Introduction

This appendix presents a pilot study of the reading speed task with a typically developing sample of primary aged early (Years 1 and 2) and later (Years 4 and 5) stage readers. The pilot study used the reading speed task developed during this doctoral research.

Aims

This pilot study intended to develop an appropriate word reading speed task that contained words comprising the same number of syllables as the standardised word reading (CC2) task (Castles et al., 2009) that was used in this doctoral research. This is achieved by confirming the difficulty level of selected words based on the responses from a typically developing sample, comprising primary aged early (6 to 7 year-old) and later (9 to 10 year-old) stage readers.

Method

Participants. In this study four groups of children participated: two (Years 1 and 2) groups of typically developing children at the early stages of reading and two (Years 4 and 5) groups of typically developing children at the later stages of reading. The study population used consisted of 40 participants divided into four groups, including 5 boys and 5 girls in Year 1 (mean age 6.8 years, *SD* = .35 years), 6 boys and 4 girls in Year 2 (mean age 7.5 years, *SD* = .37 years), 4 boys and 6 girls in Year 4 (mean age 9.5 years, *SD* = .56 years), 4 boys and 6 girls in Year 5 (mean age 10.5 years, *SD* = .33 years). All children had normal hearing and normal or corrected-to-normal vision.

See Tables D.1 (early stage) and D.2 (later stage) for the descriptive characteristics of participants, regarding word reading performance. Reading performance was tested in all children by a standardised reading test, namely the Woodcock-WI test (Woodcock, 2011). Participants with a background of reading difficulties were excluded as including them would affect error reliability in the reading speed task.

Table D.1: Means and Standard Deviations for WI in Early Stage (Years 1 and 2) Readers

	Early (Year 1) (*N* = 10)		Early (Year 2) (*N* = 10)	
Variable	*Mean WI*	*SD*	*Mean WI*	*SD*
WI accuracy	123.20	15.38	127.90	13.82

Note. WI = word identification.

Table D.2: Means and Standard Deviations for WI in Later Stage (Years 4 and 5) Readers

	Later (Year 4) (*N* = 10)		Later (Year 5) (*N* = 10)	
Variable	*Mean WI*	*SD*	*Mean WI*	*SD*
WI accuracy	116.90	15.98	117.40	16.62

Note. WI = word identification.

Apparatus and Stimuli

Table D.3 outlines the final list of words comprising the reading speed task.

Table D.3: Final List of Exception Words and Non-Words using in the Reading Speed Task

Words	Word Type
some	Exception
most	Exception
many	Exception
people	Exception
would	Exception
great	Exception
year	Exception
house	Exception
thought	Exception
school	Exception
enough	Exception
night	Exception
look	Exception
group	Exception
among	Exception
become	Exception
door	Exception
half	Exception
money	Exception
love	Exception

front	Exception
mother	Exception
move	Exception
talk	Exception
plag	Nonsense
blan	Nonsense
inmall	Nonsense
parden	Nonsense
thub	Nonsense
flad	Nonsense
pexus	Nonsense
somad	Nonsense
goma	Nonsense
drapple	Nonsense
drig	Nonsense
scrain	Nonsense
fostel	Nonsense
crod	Nonsense
prad	Nonsense
strill	Nonsense
sarm	Nonsense
fent	Nonsense
talk	Nonsense
blart	Nonsense
clent	Nonsense
fland	Nonsense
jawl	Nonsense
cland	Nonsense
kerth	Nonsense

Procedure and Data Analysis

Children were recruited through local community groups. All words were randomly presented using the DmDx software (Forster & Forster, 2003). Words were presented with Arial 36-point font. Mean RTs for each word type, for each participant, was calculated. Removal of errors and outliers, and calculation of mean RT and error, were performed using SPSS Statistics 24 (Corp, 2016).

Results

Two participants were excluded from the analysis based on poor reading ability. Reaction latencies from all test trials were trimmed to exclude errors and outlying responses. Errors were defined as incorrect pronunciations, which were assigned a score of ‘0’. Correct pronunciations were assigned a score of ‘1’. Outliers were defined as scores lower than 200 and greater than 6000 ms. Scores that fell 2 standard deviations below the mean were also excluded. Therefore, errors (11.5% of trials among early stage Year 1 readers, 7.7% of trials among early stage Year 2 readers, 5.4% of trials among later stage Year 4 readers, and 4.4% of trials among Year 5 later stage readers) and RT outliers (6.5% of trials among early stage Year 1 readers, 2.9% of trials among early stage Year 2 readers, 1.7% of trials among later stage Year 4 readers, and 5.0% of trials among Year 5 later stage readers), were excluded when calculating the mean RT for each word type condition for each participant.

The histograms for both exception and non-word reading speed for each year group were normally distributed, with skewness and kurtosis scores in the suggested ranges of ±2 and ±7, respectively (Tabachnick, 2013). Descriptive statistics for RTs and errors by reading group are reported in Tables D.4 and D.5.

Table D.4: Mean RTs (Standard Deviations) for Word Type and Errors

	Early (Year 1) (*N* = 10)		Early (Year 2) (*N* = 10)	
Variable	*Mean RT (ms)*	*Error (%)*	*Mean RT (ms)*	*Error (%)*
Exception words	926 (252)	5.8 ± 5.3	721 (123)	1.3 ± 2.0
Non-words	1133 (411)	17.1 ± 11.5	883 (213)	14.2 ± 7.7

Note. ms = milliseconds

Table D.5: Mean RTs (Standard Deviations) for Word Type and Errors

	Early (Year 4) (*N* = 10)		Early (Year 5) (*N* = 10)	
Variable	*Mean RT (ms)*	*Error (%)*	*Mean RT (ms)*	*Error (%)*
Exception words	627 (36)	3.3 ± 3.3	691 (219)	0.8 ± 1.8
Non-words	726 (75)	7.5 ± 7.0	791 (264)	7.9 ± 8.9

Note. ms = milliseconds

General Conclusion

Given the low error rates for each word type at each stage of reading, the reading speed task and the words that it comprises is an appropriate measure to determine reading speed in early and later stage readers. Therefore, this task was used in the current research, to assess the relationship between attention, phonological processing, and reading speed.

Appendix E: Copyright Permission

8/7/2018 RightsLink Printable License

ELSEVIER LICENSE
TERMS AND CONDITIONS

Aug 07, 2018

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Expected completion date	Oct 2018
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Appendix F: Confirming the Pattern of T1 Attention and T1 Phonological Processing Data in Study 2

The means, ranges, and standard deviations for the standardised and RT measures in Study 2 of this thesis are reported in Table F.1. This includes the T1 CTOPP phonological processing scores, for early and later stage readers. RT measures include T1 data for the cVANT and cAANT-SL. A series of independent samples *t*-tests were conducted on phonological processing scores, and repeated measures ANOVA was used in the analysis of the data from the ANTs.

Phonological processing. As Table F.1 illustrates, mean performance for each phonological processing subtest fell within a typically developing (average) range for both early and later stage readers. Later stage readers had significantly lower standardised scores, $t(124) = 2.85$, $p = .01$, $d = .25$, and raw scores, $t(124) = 5.02$, $p < .001$, $d = .45$, on the phonological awareness task, compared with early stage readers. Similarly, later stage readers had significantly lower standardised, $t(124) = 2.40$, $p = .02$, $d = .21$, and raw, $t(124) = 2.42$, $p = .02$, $d = .22$, phonological memory scores compared with early stage readers. Finally, there were no significant group differences in RAN standardised, $t(124) = 0.72$, $p = .47$, $d = .06$, and raw, $t(124) = 0.72$, $p = .47$, $d = .07$, scores.

Table F.1: Means and Standard Deviations of Phonological Processing and Attention Network Effects for Early and Later Stage Readers in Study 2

	Early (*n* = 64)		Later (*n* = 62)	
	M (min, max)	*SD*	*M* (min, max)	*SD*
Phon.Processing				
Phon. aware SS	112.45 (91,136)	11.33	106.48 (82, 130)	12.15
Phon. aware raw	27.33 (17,44)	7.06	22.16 (14, 30)	4.05
Phon. memory SS	104.88 (79, 139)	14.34	99.98 (61, 127)	13.17
Phon. memory raw	21.63 (13, 33)	4.78	19.65 (7, 29)	4.41
RAN SS	102.95 (67, 139)	14.29	104.69 (76, 139)	12.71
RAN Raw	20.98 (9, 33)	4.76	21.56 (12, 33)	4.24
cVANT Effects				
Alerting (ms)	68 (- 46, 182)	47	53 (-51, 160)	42
Orienting (ms)	40 (-79, 152)	57	49 (-67, 208)	44
Executive (ms)	93 (-11, 188)	48	70 (-47, 237)	43
cAANT-SL Effects				
Alerting (ms)	-14 (-295, 304)	109	34 (-145, 246)	78

Orienting (ms)	57 (-188, 418)	120	32 (-110, 202)	74
Executive (ms)	152 (-187, 469)	129	111 (-79, 322)	93

Note. Phon. aware = phonological awareness; SS = standard score; raw = raw score; Phon. memory = phonological memory; RAN = rapid automatised naming.

Visual attention. Table F.2 provides the mean RTs in each condition of the cVANT, along with marginal means for early and later stage readers. ANOVA showed a main effect of cue for both early, $F(3, 189) = 56.86$, $p < .001$, $\eta_p^2 = .47$, and later, $F(3, 183) = 77.20$, $p < .001$, $\eta_p^2 = .56$, stage readers. There was also a main effect of congruency for early, $F(2, 126) = 152.70$, $p < .001$, $\eta_p^2 = .71$, and later, $F(2, 122) = 132.98$, $p < .001$, $\eta_p^2 = .69$, stage readers. The interaction between cue and congruency was significant for early, $F(6, 366) = 2.44$, $p = .03$, $\eta_p^2 = .04$, but not for later, $F(6, 414) = 1.82$, $p = .09$, $\eta_p^2 = .03$, stage readers.

Table F.2: Mean RT in Milliseconds and Standard Deviations in the cVANT for Early (*n* = 64) and Later Stage (*n* = 62) Readers

	Cue Type				
Congruency Type	No Cue	Double	Central	Spatial	Total Mean
Early Stage					
Neutral	889 (127)	819 (141)	857 (139)	798 (132)	841 (118)
Congruent	918 (118)	817 (128)	843 (120)	805 (121)	846 (105)
Incongruent	991 (125)	948 (154)	957 (126)	915 (148)	953 (122)
Total Mean	933 (108)	861 (126)	886 (113)	839 (117)	
Later Stage					
Neutral	717 (102)	655 (97)	675 (107)	627 (104)	668 (93)
Congruent	727 (104)	664 (101)	685 (110)	643 (96)	680 (96)
Incongruent	787 (106)	753 (106)	759 (99)	701 (106)	750 (96)
Total Mean	744 (97)	691 (94)	706 (98)	657 (95)	

Note. RT difference between the no cue and double cue conditions = alerting effect;
RT difference between the central and spatial cue conditions = orienting effect;
RT difference between incongruent and congruent conditions = executive effect.

Planned contrast between the no cue and double cue conditions revealed significant visual alerting benefits, with an advantage for the double cue condition, for both the early (72 ms), $F(1, 63) = 83.85$, $p < .001$, $\eta_p^2 = .57$, and later (53 ms), $F(1, 61) = 95.88$, $p < .001$, $\eta_p^2 = .61$, stage readers. A contrast between the central cue and spatial cue conditions showed visual significant spatial-orienting benefits for the spatial cue condition for both early (47 ms), $F(1, 63) = 35.78$, $p < .001$, $\eta_p^2 = .36$, and later (49 ms), $F(1, 61) = 75.15$, $p < .001$, $\eta_p^2 = .55$, stage readers. Finally, a contrast between the incongruent and congruent flanker conditions revealed that visual executive control benefits were significant for early (107 ms), $F(1, 63) = 252.98$, $p < .001$, $\eta_p^2 = .80$, and later (70 ms), $F(1, 61) = 164.92$, $p < .001$, $\eta_p^2 = .73$, stage readers.

Error analysis in the cVANT for early stage readers. Table F.4 provides the mean error percentages in each condition of the cVANT, along with marginal means, for early and later stage readers. The analysis of errors for early stage readers in the cVANT found no main effect of cue, $F(3, 189) = 0.79$, $p = .50$, $\eta_p^2 = .01$. There was however a main effect of congruency, $F(2, 126) = 15.14$, $p < .001$, $\eta_p^2 = .19$. There were significantly more errors in the incongruent ($M = 13.7\% \pm 1.8\%$) compared with the neutral ($M = 10.0\% \pm 1.3\%$, $p = .001$) and congruent ($M = 8.6\% \pm 1.4\%$, $p < .001$) flanker conditions. The difference in error percentage between neutral and congruent conditions was marginally significant ($p = .054$). The cue by congruency interaction was not significant, $F(6, 378) = 0.73$, $p = .63$, $\eta_p^2 = .01$.

Error analysis in the cVANT for later stage readers. The analysis of errors for later stage readers in the cVANT found no main effect of cue, $F(3, 183) = 0.71$, $p = .55$, $\eta_p^2 = .01$. There was however a main effect of congruency, $F(2, 122) = 9.99$, $p < .001$, $\eta_p^2 = .14$. There were significantly more errors in the incongruent ($M = 6.4\% \pm 0.9\%$) compared with the neutral ($M = 4.7\% \pm 0.6\%$, $p = .03$) and congruent ($M = 3.7\% \pm 0.5\%$, $p < .001$) flanker conditions. The difference in error percentage between neutral and congruent conditions was significant ($p = .02$). The cue by congruency interaction was not significant, $F(6, 366) = 0.85$, $p = .53$, $\eta_p^2 = .01$.

Table F.3: Mean Error Percentage Data and Standard Deviations for the cVANT in Early (*n* = 64) and Later (*n* = 62) Stage Readers

	Cue Type				
Congruency Type	No Cue	Double	Central	Spatial	Total Mean
Early Stage					
Neutral	10.8 (12.2)	8.9 (12.6)	11.1 (14.1)	9.4 (11.9)	10.0 (10.7)
Congruent	8.5 (13.3)	8.9 (12.9)	9.4 (13.1)	7.9 (13.3)	8.6 (10.8)
Incongruent	13.9 (16.2)	15.1 (17.2)	13.2 (17.2)	12.6 (14.1)	13.7 (14.0)
Total Mean	11.1 (11.5)	10.9 (12.0)	11.2 (12.8)	10.0 (11.0)	

Later Stage					
Neutral	5.8 (7.3)	4.7 (6.3)	4.2 (6.9)	4.0 (5.6)	4.7 (4.6)
Congruent	4.6 (7.0)	3.2 (4.9)	3.8 (5.4)	3.1 (5.7)	3.7 (3.8)
Incongruent	5.9 (8.3)	5.9 (9.1)	6.7 (10.0)	7.1 (10.0)	6.4 (6.5)
Total Mean	5.4 (5.4)	4.6 (5.0)	4.9 (5.5)	4.7 (5.0)	

Auditory attention. Table F.3 provides the mean RTs in each condition of the cAANT-SL, along with marginal means, for early and later stage readers. ANOVA showed a main effect of cue for both early, $F(3, 186) = 6.61$, $p < .001$, $\eta_p^2 = .10$, and later, $F(3, 180) = 7.52$, $p < .001$, $\eta_p^2 = .11$, stage readers. There was also a main effect of congruency for early, $F(2, 124) = 126.12$, $p < .001$, $\eta_p^2 = .67$, and later, $F(2, 120) = 141.05$, $p < .001$, $\eta_p^2 = .70$, stage readers. The interaction between cue and congruency was not significant for both early stage readers $F(6, 372) = 1.90$, $p = .08$, $\eta_p^2 = .03$, and later stage readers, $F(6, 360) = 1.09$, $p = .37$, $\eta_p^2 = .02$.

Table F.4: Mean RT in Milliseconds and Standard Deviations in the cAANT-SL for Early (*n* = 64) and Later Stage (*n* = 62) Readers

	Cue Type				
Congruency Type	No Cue	Double	Central	Spatial	Total Mean
Early Stage					
Neutral	1128 (160)	1190 (177)	1187 (198)	1136 (197)	1160 (158)
Congruent	1241 (153)	1247 (223)	1269 (197)	1200 (199)	1239 (184)
Incongruent	1416 (209)	1389 (254)	1408 (251)	1347 (260)	1390 (211)
Total Mean	1261 (179)	1275 (199)	1288 (185)	1228 (217)	
Later Stage					
Neutral	965 (168)	962 (214)	969 (196)	942 (184)	960 (184)
Congruent	1060 (183)	1019 (220)	1049 (213)	1015 (210)	1036 (201)
Incongruent	1178 (249)	1128 (267)	1155 (277)	1124 (263)	1146 (250)
Total Mean	1068 (189)	1037 (230)	1058 (226)	1027 (213)	

Note. RT difference between the no cue and double cue conditions = alerting effect;
RT difference between the central and spatial cue conditions = orienting effect;
RT difference between incongruent and congruent conditions = executive effect.

Planned contrasts between the no cue and double cue conditions revealed no significant auditory alerting benefits (-14 ms, faster mean RT for the no cue condition), $F(1, 63) = 1.20$, $p = .28$, $\eta_p^2 = .02$, for early stage readers. However, there were significant auditory alerting benefits for later stage readers (31 ms), $F(1, 61) =$

10.54, p = .002, η_p^2= .15. A contrast between the central cue and spatial cue conditions showed significant auditory spatial-orienting benefits for the spatial cue condition for both early (60 ms), F(1, 63) = 16.18, p < .001, η_p^2= .21, and later stage (31 ms), F(1, 61) = 10.58, p = .002, η_p^2 = .15, readers. Finally, a contrast between the incongruent and congruent flanker conditions revealed that auditory executive control benefits were significant for both early (151 ms), F(1, 63) = 87.39, p < .001, η_p^2 = .59, and later stage (110 ms), F(1, 61) = 87.26, p < .001, η_p^2 = .59, readers.

Error analysis in the cAANT-SL for early stage readers. Table F.5 provides the mean error percentages in each condition of the cAANT-SL, along with marginal means, for early and later stage readers. The analysis of errors for early stage readers in the cAANT-SL found a main effect of cue, F(3, 189) = 35.36, p < .001, η_p^2 = .36, and congruency, F(2, 126) = 29.72, p < .001, η_p^2 = .32. The difference between errors in the no cue (M = 11.9% ± 1.5%) and double cue (M = 23.0% ± 2.3%) conditions was significant (p < .001). There were significantly (p < .001) more errors in the central cue (M = 25.6% ± 2.1%) compared with the spatial cue (M = 17.5% ± 1.6%) conditions. The difference in errors between the no cue and spatial cue conditions was significant (p < .001). The difference in errors between double and spatial cue conditions was significant (p < .001). There was also a significant error difference between the no cue and central cue conditions (p < .001), as well as between the double and central cue conditions (p = .05).There were significantly more errors in the incongruent (M = 25.0% ± 1.9%) compared with the neutral (M = 17.2% ± 1.8%, p < .001) and congruent (M = 16.3% ± 1.8%, p < .001) flanker conditions. The difference in error percentage between neutral and congruent conditions was not significant (p = .32). The cue by congruency interaction was not significant, F(6, 378) = 0.73, p = .62, η_p^2 = .01.

Error analysis in the cAANT-SL for later stage readers. The analysis of errors for later stage readers in the cAANT-SL found a main effect of cue, F(3, 180) = 15.07, p < .001, η_p^2 = .20, and congruency, F(2, 120) = 32.50, p < .001, η_p^2 = .35. The difference between errors in the no cue (M = 6.0% ± 0.8%) and double cue (M = 9.7% ± 1.4%) conditions was significant (p < .001). There were significantly (p < .001) more errors in the central cue (M = 11.8% ± 1.4%) compared with the spatial cue (M = 6.9% ± 1.0%) conditions. The difference in errors between the no cue and spatial cue conditions was not significant (p = .20). The difference in errors between double and spatial cue conditions was significant (p = .01). There was also a significant error difference between the no cue and central cue conditions (p < .001), as well as between the double and central cue conditions (p = .02). There were significantly more errors in the incongruent (M = 12.9% ± 1.4%) compared with the neutral (M = 7.0% ± 1.1%, p < .001) and congruent (M = 5.9% ± 0.8%, p < .001) flanker conditions. The difference in error percentage between neutral and congruent conditions was not significant (p = .15). The cue by congruency interaction was not significant, $F(6, 360) = 0.42$, p = .86, η_p^2 = .01.

Table F.5: Mean Error Percentage Data and Standard Deviations for the cAANT-SL in Early (*n* = 64) and Later (*n* = 62) Stage Readers

	Cue Type				
Congruency Type	No Cue	Double	Central	Spatial	Total Mean
Early Stage					
Neutral	9.4 (14.2)	21.6 (20.9)	23.8 (20.0)	13.9 (14.5)	17.2 (14.7)
Congruent	8.9 (13.1)	19.4 (20.9)	23.0 (19.6)	13.9 (16.3)	16.3 (14.1)
Incongruent	17.6 (14.6)	27.9 (20.3)	30.0 (21.2)	24.7 (17.6)	25.0 (15.0)
Total Mean	11.9 (12.0)	23.0 (18.0)	25.6 (16.7)	17.5 (14.7)	
Later Stage					
Neutral	3.8 (6.4)	8.2 (12.5)	10.7 (14.2)	5.3 (8.3)	7.0 (8.6)
Congruent	3.0 (5.5)	7.4 (11.8)	8.6 (10.2)	4.8 (6.7)	5.9 (6.7)
Incongruent	11.1 (12.4)	13.7 (14.4)	16.3 (15.9)	10.5 (12.7)	12.9 (11.1)
Total Mean	6.0 (6.0)	9.7 (10.6)	11.8 (11.1)	6.9 (7.6)	