Curtin School of Allied Health

Cross-linguistic Effects on Spoken Picture Naming in Bilingual People with Aphasia

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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.

Human Ethics

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 March 2014. The proposed research study received human research ethics approval from the Curtin University Human Research Ethics Committee (EC00262), Approval Number (HRE2017-0274). Furthermore, ethics approval for this study was obtained by the ethics committee of Bielefeld University in Germany (EUB 2020-137-Am), and the South Metropolitan Health Service Human Research Ethics Committee (RGS0000003763).

Signature:
Date: 29/06/2023

Abstract

Bilingualism is the norm rather than the exception across the globe, more than half of the world's population knows and uses more than one language. While there is a consensus about the steps of word retrieval, and while it is known that one language can activate the other in a bilingual speaker, little is known about the psycholinguistic mechanisms of how two or more languages in a language system influence and interact with each other. This project aimed to explore factors that might hinder or facilitate spoken word form access and word recovery in bilingual speakers with aphasia (language breakdown after stroke) to expand existing language theories. Insights gained can in turn inform bilingual language assessment and ultimately enhance speech pathology services regarding practice guidelines for bilingual aphasia.

During the scope of this PhD project, word materials for five different language combinations were developed that can be used for future research when exploring assessment and treatment in bilingual speakers with aphasia.

The project consisted of three large-scale spoken picture naming experiments including eight bilingual speakers with aphasia with five different language combinations (language combinations: Dutch-German, Polish-German, English-German, English-Italian, English-French) and ten monolingual speakers with aphasia (English or German). Bilingual participants named 347+ pictures in each of their available languages, and monolingual participants named 423+ pictures. Each of the three studies was based on a case-series design, (bilingual participants, n = 8; monolingual participants, n = 10), a commonly used approach in cognitive neuropsychology that includes in-depth data collection for each individual.

Study 1 explored spoken naming accuracy and error types *within* and *across* languages in bilingual speakers with aphasia. This was achieved by taking into account the participants' bilingual profile (language age of acquisition, language dominance) and item factors (seven lexical variables: Spoken word form frequency, syllable lengths, phoneme length, item age of acquisition, familiarity, imageability, and visual complexity). Quantitative data analyses McNemar's Test, Fisher's Exact Test, Regression Analysis) were conducted. Results showed a higher accuracy for seven participants in their dominant language, regardless of whether the dominant language was their first or second language. Additionally, different distributions of error types across languages were found for seven participants, originating from their different bilingual language profiles (e.g., language proficiency). Further regression analyses showed a facilitatory effect of different linguistic properties (word length, item age of acquisition, imageability) on accuracy. The data of Study 1 underpin the influence of the individual bilingual language profile on lexical access in bilingual speakers with aphasia.

Building on Study 1, Study 2 specifically expanded its investigation to the influence of similar-sounding words (phonological neighbours). As for Study 1, we used the dependent variable spoken naming accuracy to explore the influence of phonological neighbourhood within and across languages in bilingual speakers with aphasia. Phonological neighbours differ from the target word in a single phoneme and can occur within languages (e.g., target *cat*, phonological neighbour *mat*) and across languages (e.g., target *shower*, phonological neighbour in German *Bauer* [German for farmer]). For this study, eight bilingual and ten monolingual speakers with aphasia were assessed. Logistic regression analyses with five experimental predictors (phonological neighbourhood) and seven control predictors (lexical variables) revealed that high within-language phonological neighbourhood increased accuracy in five bilingual speakers for their non-dominant language, while phonological neighbourhood effects for the monolingual speakers were only observed for one participant. Our data therefore suggest that facilitation effects across languages based on word similarity are limited, but bilingual speakers seem to benefit from within neighbourhood effects when the non-dominant language was used. Dominant languages did not seem to benefit (which also explains the null effect for the monolingual speakers).

Study 3 focussed on a special word group, compound words, defined as a word consisting of two or more free-standing morphemes (e.g., bedroom). As for Study 1 and Study 2, accuracy, error rate and specific error types in spoken picture naming within and across languages were the main dependent variables. A Fisher's Exact Test revealed a higher naming accuracy in compound words for the dominant language for six participants. Further, language mixing errors in compound words were analysed by identifying three main types of language mixing errors when bilingual participants responded to compound words: (i) substitution of the first constituent (e.g., target: Schlafzimmer [German for bedroom], response: bedzimmer [influenced by bedroom]), (ii) substitution of the second constituent (e.g., target: Ellenbogen [German for elbow], response: Ellenbow [influenced by elbow]) and (iii) literal translation errors (e.g., target: méduse [French word for jellyfish], response: poisson de gellée [literal translation of the non-target language compound word jellyfish into the target language French]). Language mixing errors occurred in both or one of the available languages in six participants, however always in their non-dominant language. In addition, logistic regression analysis showed that phonological similarity across languages had an influence on language mixing errors in only one participant. Overall, the findings of Study 3 suggest that non-selective language activation processes are at play.

In sum, a consistent finding for Study 1 and Study 2 was that picture naming accuracy was higher in their dominant language, whereas naming errors that were influenced by the other language were usually observed in the speaker's non-dominant language. This was observed regardless of whether the dominant language was the speaker's first or second language. However, Study 2 showed a higher accuracy for targets with higher phonological neighbourhood in five bilingual participants within their non-dominant language only, while monolinguals showed hardly any effects of phonological neighbourhood within their language.

Overall, the findings of this thesis emphasise that it is important to consider bilingual factors, like language dominance, and the linguistic features of each language to understand the complexity of a language breakdown across all languages spoken by the individual. Current standardised aphasia assessments and current language production theories (e.g., serial vs interactive) do not accommodate for such an in-depth bilingual investigation that considers all languages equally.

An overarching outcome of this PhD project are comprehensive word materials (347+ items for each language) for five different language combinations (Dutch-German, Polish-German, English-German, English-Italian, English-French) and two monolingual word lists German and English). The item lists, which are controlled for specific linguistic variables within and across languages, have been developed during the course of this project. All of these materials are freely available via the Open Science Framework database readily available to be used for future bilingual aphasia studies. Additionally, this thesis puts forward a comprehensive in-depth error coding guide that can help to capture the specific breakdown across languages which in turn may help to diagnose and plan treatment for people with bilingual aphasia. Again, this error coding guide is freely available via the Open Science Framework database. We hope that these materials can be useful for further much-needed bilingual explorations and can serve as a reference point for future bilingual aphasia studies that may expand to other language combinations. We encourage future research on language combinations across scripts that are notoriously understudied in bilingual aphasia.

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(1) Dell, G. S., Martin, N., & Schwartz, M. F. (2007). A case-series test of the interactive two-step model of lexical access: Predicting word repetition from picture naming☆. *Journal of Memory and Language*, *56*(4), 490–520. https://doi.org/10.1016/j.jml.2006.05.007

(2) Dijkstra, T., Wahl, A., Buytenhuijs, F., Van Halem, N., Al-Jibouri, Z., De Korte, M., & Rekké, S. (2019). Multilink: A computational model for bilingual word recognition and word translation. *Bilingualism: Language and Cognition*, *22*(04), 657–679. https://doi.org/10.1017/S1366728918000287

(3) Green, D. W. (1998). Mental control of the bilingual lexico-semantic system. *Bilingualism: Language and Cognition*, *1*(2), 67–81. https://doi.org/10.1017/S1366728998000133

(4) Levelt, W. J. M., Roelofs, A., & Meyer, A. S. (1999). A theory of lexical access in speech production. *Behavioral and Brain Sciences*, *22*(01). https://doi.org/10.1017/S0140525X99001776

Acknowledgement of Country

We acknowledge that Curtin University works across hundreds of traditional lands and custodial groups in Australia, and with First Nations people around the globe. We wish to pay our deepest respects to their ancestors and members of their communities, past, present, and to their emerging leaders. Our passion and commitment to work with all Australians and peoples from across the world, including our First Nations peoples are at the core of the work we do, reflective of our institutions' values and commitment to our role as leaders in the Reconciliation space in Australia.

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General Appendices

List of Abbreviations

ASCII	American Standard Code for Information Interchange
BAT	Bilingual Aphasia Test
BwA	Bilingual Speaker with Aphasia
DUT	Dutch
ENG	English
EUB	Ethics committee of Bielefeld University in Germany
FRE	French
GER	German
HRE	Ethics committee of Curtin University Perth
ICF	International Classification of Functioning, Disability, and Health
IPA	International Phonetic Alphabet
ITA	Italian
L1	First language
L2	Second language
LEAP-Q	Language Experience and Proficiency Questionnaire
LEMO	Lexikon modellorientiert
MwA	Monolingual speaker with aphasia
PND	Phonological neighbourhood density
PNF	Phonological neighbourhood frequency
POL	Polish
RGS	South Metropolitan Health Service Human Research Ethics Committee
VIF	Variance inflation factor
X-SAMPA	Extended Speech Assessment Methods Phonetic alphabet
WAB	Western Aphasia Battery

Chapter 1:

General Introduction

Despite bilingualism being the norm rather than the exception across the globe, practice guidelines to support bilingual speakers in the event of language breakdown after stroke (aphasia) are scarce. Spoken word finding difficulties are one of the main symptoms in people with aphasia (e.g., Nickels & Howard, 1995) and are therefore most commonly targeted in speech pathology interventions. Hence, spoken word production is a key area of concern to understand how language organisation varies in bilingual speakers compared to monolingual speakers. Only if we understand in greater depth the mechanisms that underpin bilingual lexical processes and the factors that influence them, will we be able to deliver more fine-tuned assessment and treatment materials that enhance bilingual clinical services.

This project will do exactly that – aiming to investigate word processing within and across languages in bilingual speakers with aphasia; consider influencing lexical factors; and add new pieces to the bilingual evidence base that in turn can expand bilingual language theory, even though only at a small scale. It is hoped that ultimately these additions to the bilingual puzzle can also enhance bilingual speech pathology services.

The Global Bilingual Population

The bilingual population is increasing with 50% of the world's population already being bilingual (Grosjean, 2021). According to the Australian Bureau of Statistics (2017), 21% of the Australian population speaks more than one language at home. Similarly, 27% of the German population has an immigrant background that brings a diverse language repertoire (German Bureau of Statistics, 2022).

Historically, bilingual speakers were defined by their fluency and proficiency levels when speaking the languages available to them. However, this approach overlooked that the majority of bilingual speakers have varying degrees of fluency across their acquired languages depending on the context of each language spoken; driven by when, how often, and why a language is used. Grosjean et al. (2013) therefore defines a speaker as bilingual[1] as soon as a person speaks more than one language, regardless of how often, when, and why each language is used.

Bilingual speakers can be further described by the following key aspects: age of acquisition for each language, proficiency of both languages, dominance, the context of

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[1] The term bilingual will be used as a label for bilingual and multilingual, hence, covers all speakers that know or use more than one language.

language exposure (e.g., full immersion versus classroom learning), and the linguistic similarities between languages (e.g., distant versus close).

(1) *Age of acquisition* captures the age at which a language has been learned. If the language was acquired before the age of 12, much of the literature refers to this as ‘early’ exposure and anything thereafter as late. However, this binary distinction is not always useful, as a language acquired early can be less proficiently spoken compared to a language acquired later, especially when living in the country of their second language. However, a commonly used cut-off in the literature marking an early vs late distinction is the age of 12 (e.g., Akbari, 2014). The concept of language age of acquisition is also linked to the terminology ‘simultaneous’ (early) versus ‘sequential’ (late[r]) bilingual speaker (e.g., Paradis, 2010). Simultaneous bilingual speakers learn two or more languages concurrently, while sequential bilingual speakers learn their second language (L2) after they acquired their first language (L1). It is important to note that L2 acquisition can occur either early or late in life, hence, can be learned before the age of 12).

(2) *Language proficiency* reflects the level of competence across the linguistic domains of each language spoken. This is reflected in the ease of production and comprehension of each available language across modalities (speaking, listening, reading, and writing) (Stankovic et al., 2022).

(3) *Language dominance*: The definition and concept of language dominance vary across research. While some studies ascertain language dominance by evaluating language proficiency (e.g., Genesee et al., 1995), others define it by language use and exposure (e.g., Argyri and Sorace, 2007) or the environmental languages (e.g., Polinksy, 2008). Hence, language dominance in bilingual individuals is a multifactorial concept and can be defined in various ways. In recent years, this topic has received increasing attention (Montrul, 2015; Hamann et al., 2019). In this thesis, language dominance is defined as a multifactorial construct that entails language proficiency, language use and exposure, and biographical factors such as the environmental language, age of acquisition, and language of residence. This definition is in line with previous research (e.g., Birdsong et al., 2012; Dunn & Fox Tree, 2009).

(4) *The context of exposure* outlines the circumstances, in which the L2 has been learned (acquired) (e.g., full L2 immersion when living in the country of L2) (Stankovic et al., 2022).

(5) *Linguistic similarities* can vary among the available languages, ranging from closely related to more distant languages depending on language typologies (structural and functional properties of languages) (e.g., German-English versus Mandarin-English). (e.g., Fromkin et al., 2018).

Ageing Population and Aphasia

An increasing bilingual population predicts an increasing bilingual aging population, who will experience the same age-related diseases that the monolingual population experiences, just with different challenges and therefore different needs. According to the United Nations, people over 60 are the fastest-growing age group and it can be predicted, that one in six people globally (16%) will be 65 or older in 2050 (United Nations, 2019). These numbers are already a reality for Australia, approximately 4.2 million people (16% of Australia's total population) were aged 65 and over in 2020 (Australian Institute of Health and Welfare, 2023).

An aging population will experience age-related cognitive decline as well as associated cardiovascular diseases, for example a stroke, which might lead to a language impairment such as aphasia.

Aphasia is an acquired language disorder caused by brain injury (e.g., through stroke, brain tumours, head traumas), affecting all language modalities (speaking, understanding, reading, and writing) at all linguistics levels (semantics, phonology, morphology, syntax; see e.g., Schneider et al., 2021). Spoken word finding difficulties are almost always a prominent symptom, but modalities and linguistic levels can be affected to different extents, resulting in heterogeneous language impairments based on severity and level of breakdown (Schneider et al., 2021). Heterogeneity is further exacerbated when speakers are bilingual, placing greater demands on assessment and treatment practices.

Bilingual Aphasia

The clinical profiles of aphasia in monolingual and bilingual speakers share similarities. However, bilingual speakers with aphasia hold a bilingual language profile. As a result, impairment patterns, recovery patterns, and error types that are not necessarily observed in monolingual individuals with language impairment may occur. In addition, the impact of aphasia might be different on the languages spoken, hence, specific aphasia symptoms might differ across a person's available languages (Cargnelutti et al., 2019).

Impairment and Recovery Patterns in Bilingual Speakers with Aphasia

Bilingual speakers with aphasia can experience different types of language *impairment across their available languages* (see for example, Khachatryan et al., 2016):

(1) Parallel impairment: Languages are impaired at a comparable level.

(2) Differential impairment: In comparison, one language is more severely impaired than the other.

(3) Antagonistic impairment: The deficit decreases in one language, the deficit increase in the other language.

(4) Blended mixed impairment: Interference between the available languages (mixing and switching symptoms).

(5) Selective impairment: Only one language is impaired.

Additionally, *recovery patterns across the available languages* can differ among bilingual speakers with aphasia (see Table 1).

Table 1

Recovery Patterns in Aphasia in Bilingual Speakers

Recovery pattern	Language characteristics
Parallel recovery	Both languages recover to their relative abilities before the onset of aphasia. If one language was stronger before the onset of the stroke, it will become stronger again over time post-stroke.
Differential recovery	One language recovers better than the other; the performance in the languages differs from the premorbid abilities.
Antagonistic recovery	Initially, only one language is available, but as the other language begins to recover, the initially available language disappears.
Alternating antagonism	Like the pattern above, however, the availability of languages alternates within cycles that can range from 24 hours to several months.
Blending recovery	Uncontrolled mixing of words and grammatical constructions from two or more languages. The occurring mixing symptoms cannot be controlled when a speaker attempts to speak in only one language (unrelated to the common code-switching in bilingual speakers).

Selective aphasia	Loss of language abilities in one language with no measurable deficit in the other language.
Successive recovery	Recovery of one language before the other language(s) recover(s).

Note. Table adapted from Lorenzen & Murray (2008), Fabbro (1999)

Error Types in Bilingual Speakers with Aphasia

Error types related to lexical retrieval difficulties in bilingual speakers with aphasia do not differ from the ones that have been observed in monolingual speakers with a language disorder (e.g., Fabbro, 2001). These different error types have been examined in detail over the last decades and can include semantic errors (e.g., target *cat*, response *dog*), phonological errors (e.g., target *fish*, response *fush*), no responses, neologisms (e.g., target *bed*, response *ucsenchail*), semantic-phonological error (e.g., target *apple*, response *banuna*) and many more (please refer to e.g., Schwartz et al. [1994] for an overview of these different error types).

It is important to note that these typical error types can also occur in the non-target language when a bilingual speaker names a picture. Again, these well-known error types can include semantic errors in the non-target language (e.g., English target *cat*, response *Hund* [German for dog]), or phonological errors in the non-target language (e.g., English target *desk*, response *Tusch* [German word Tisch [desk] with a phonological error]) etc.

Due to the bilingual language profile, bilingual speakers exhibit error types that are specifically related to their bilingualism. These error types include language mixing, language switching, and translation errors (Cargnelutti et al., 2019; Fabbro, 2001; Fabbro, 1999).

Language mixing errors occur when an individual produces a word that includes part of the target language and the non-target language (English target *pear*, response *pearne* [response includes part of German non-target *Birne* [*pear*]pear). Conversely, language switching errors involve the shift to another language between utterances and sentences (e.g., English target language: *I'm writing a letter to my mum.* Switch to German non-target language: *Sie hat morgen Geburtstag).* This code switch only constitutes an error when the listener does not speak the non-target language or the switch was not intended by the speaker (e.g., Albert & Obler, 1978; Fabbro, 1999; Paradis, 1977). Translation errors are defined as difficulties with translation from one language to the other. Among translation errors, different difficulties can be observed, for example, the inability to translate (ability to respond in each language, but inability to translate from one language into the other) or the occurrence of spontaneous translation (translation of written or spoken language without prompting but inability to translate on demand) (e.g., Khachatryan et al., 2016).

Word Finding Difficulties in Monolingual Word Processing Models

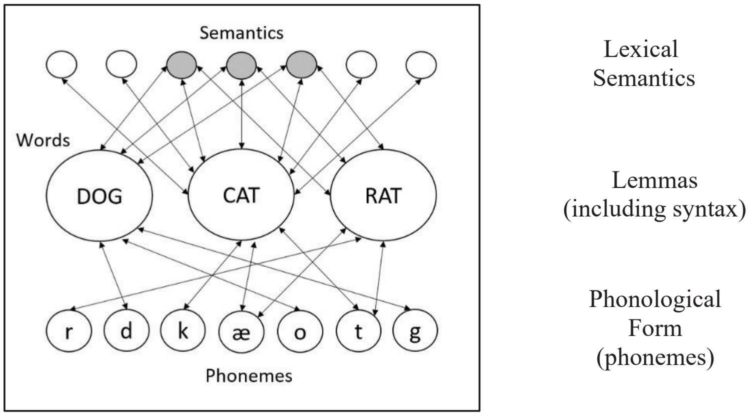
Word finding difficulties in monolingual speakers with a language disorder have been extensively researched within frameworks of well-known and established language production models (e.g., Levelt et al., 1999; Dell et al., 2007). These models agree on three major steps that are involved in spoken word production: Accessing (a) non-lexical concepts in the first step, followed by, (b) lexical semantic and syntactic information in the next step, and (c) phonological word form information as a last step before the information can be translated into articulatory movements. However, there is no consensus about the flow of information between the different levels. While some models propose an interactive activation flow between levels (e.g., Dell et al., 2007,), others assume a serial forward activation flow (e.g., Levelt et al., 1999). Below, we depict Dell's and Levelt's accounts in greater detail and hypothesis how this could extend to bilingual speakers.

The Interactive Activation Model (Dell et al., 2007)

The Interactive Activation Model (Dell et al., 2007) assumes three levels that are involved in monolingual spoken word production (see Figure 1): (a) semantic features (access of semantic information), (b) lexical-syntactic selection (lemma level = word node level), and (c) phonological form (activation of phonemes at the phoneme level). One of the model's key features is the bidirectional activation flow between the three postulated levels: selected word nodes (lemmas) activate related phonemes, that also provide feedback to further word nodes (lemmas) with shared phonemes to the target word. This bidirectional activation might influence lexical retrieval. Lemmas include syntactic information and are connected to the semantic nodes one level up and the phoneme nodes one level down, hence, the model proposes that syntactic information must be activated prior to activation of the form level.

Figure 1

Interactive Activation Model of Spoken Language Processing (Dell et al., 2007)

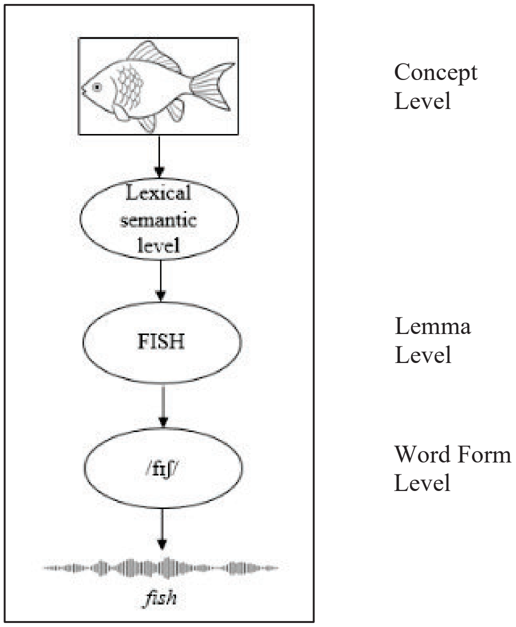


Two-Stage Model by Levelt et al. (1999)

Levelt et al.'s (1999) account consists of a serial forward activation flow during spoken word production (see Figure 2). Processing steps within this model involve a concept level (accessing concepts that are mostly language-unrelated), a lexical semantic level (access of semantic information), and a lexical level. The latter lexical level includes the Two-Step account: activation and selection of lemma level access, followed by phonological word form access. The lemma level stores syntactic word features such as word class, gender, tense, number, while the phonological word form level represents the phonological structure of the word. The lemma level, an interstage between the semantic and the phonological word form level, adds grammatical information to the already accessed semantic information and sends this combined information to the phonological word form level. In contrast to Dell's account, Levelt et al. (1999) propose a single activated word form, whereas Dell et al. assume a sequence of phonemes that are directly activated from the lemma/word node level. However, both models essentially assume the same layered architecture.

Figure 2

Word Processing in a Two-Stage Model (Levelt et al., 1999)



Application to the Bilingual Context

While both models were developed for the monolingual unimpaired context, it is reasonable to think about the extension of those theoretical frameworks to the context of impaired bilingual spoken word production.

While it is acknowledged that these monolingual models (e.g., Dell et al., 2007; Levelt et al., 1999) are in their current state not able to capture bilingual word processing, the findings of the three studies presented in this thesis will discuss theoretical assumptions that include hypothetical extensions of monolingual models to the bilingual context. However, this discussion will consider bilingual word processing accounts that can either be combined with current monolingual models or considered separately.

Below, two relevant bilingual accounts will be introduced as a basis for this thesis.

Word Finding Difficulties in Bilingual Word Processing Models

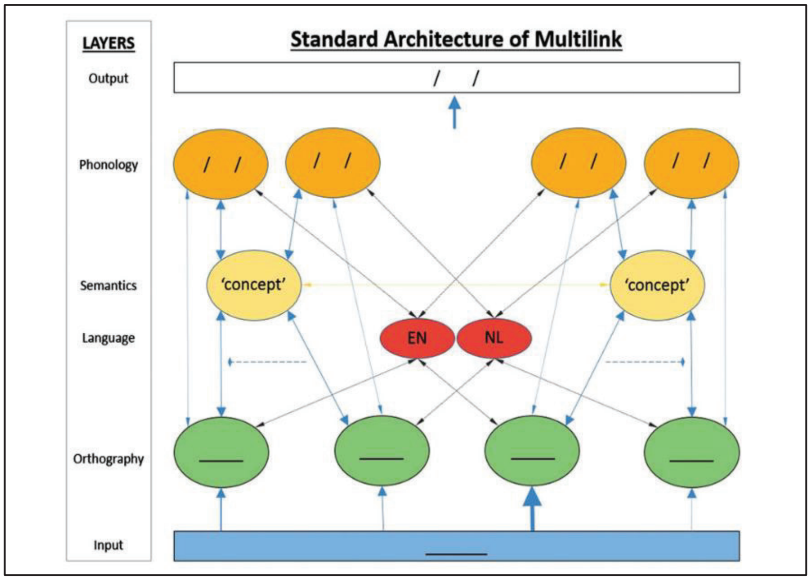
The MULTILINK Model by Dijkstra et al. (2019)

There are only a few comprehensive bilingual frameworks available that capture bilingual word comprehension, lexical-semantic *and* word production processes (e.g., Brysbaert and Duyck, 2010). Dijkstra et al., (2019) have developed a localist-connectionist model, the MULTILINK Model (see Figure 3) that addresses most of these components. MULTILINK is a computational model that can offer an explanation for bilingual word retrieval mechanisms. The model’s network architecture is layered including a concept, a semantic, a phonological and a (spoken) output level. The key representational structure is an interactive lexical network in which activation spread is in a bidirectional manner similar to Dell et al.’s account. However, it also includes the written modality (not only spoken), while Dell’s and Levelt’s account only consider the spoken modality. The layers of concern are the (written) input, orthography, language nodes and concepts nodes.

Upon receiving a written input word (see Figure 3 bottom level coloured in blue), multiple lexical-orthographic representations are activated, which in turn activate their corresponding semantic and phonological counterparts as well as language membership representations (e.g., English or Dutch, see Figure 3). The semantic representations in the model are holistic units and the semantic dispersion of activation between associated representations is currently not included in the model (similar to Levelt’s account). Phonological representations are the last step before the spoken output process (= articulation processes). The connections within the lexical network vary in their strength. When activated representations no longer receive input, their activation gradually decreases to their resting activation level. The MULTILINK model has a stronger focus on word recognition/ comprehension rather than production but can still offer direction when explaining word retrieval in the bilingual context.

Figure 3

MULTILINK: A Computational Model for Bilingual Word Retrieval in Comprehension and Production (Retrieved from Dijkstra et al., 2019)



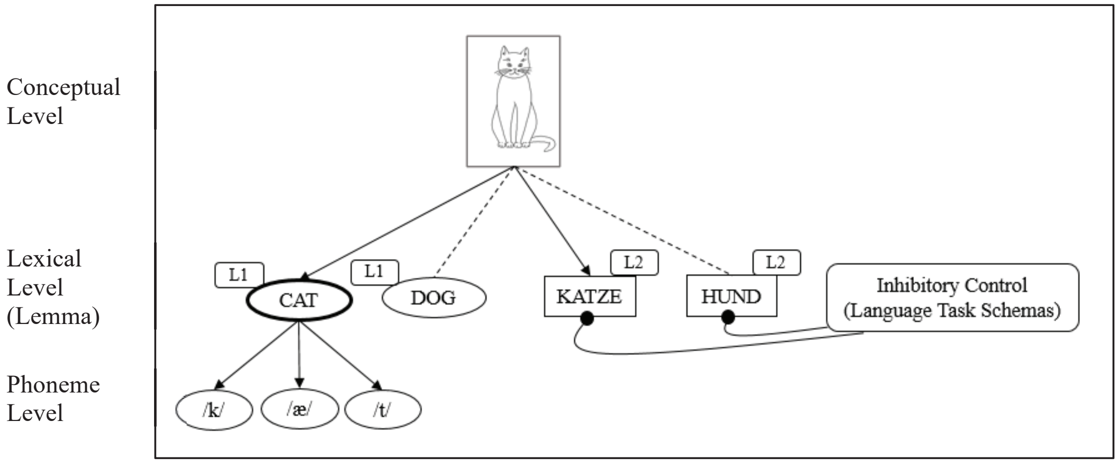
Note. This figure shows the standard lexical network architecture of MULTILINK with activation flow. The input is represented by a blue underscore, orthographic representations by a green underscore, and phonological representations by dark orange entries. The dashed line between the orthographic representations and the semantic representations signifies that their activation is summed after halving the input activation of the second node. The output, which varies depending on the task, is represented by the white layer, indicating a phonological output that can be word naming or translation in one of the available languages.

The Inhibitory Control Model by Green (1986, 1998)

Another relevant model which considers the unique aspect of bilingual speakers having two languages within their language network is the Inhibitory Control Model by Green (1986, 1998). As indicated by the name of the model, the model does not specify the different levels in the mental lexicon during lexical retrieval in a bilingual speaker. Instead, it focuses on the non-selective activation and associated inhibition processes that are hypothesised to occur during word production in bilingual speakers. *Non-selective activation* refers to a bilingual language system that involves two or more languages during production: not only is the target word activated but also the non-target language word. This parallel activation goes along with the presence of inhibition processes in bilingual speakers, which are necessary to suppress the non-target languages while speaking in the target language. According to the Inhibitory Control Model by (Green, 1986, 1998), the bilingual speech production system comprises multiple levels of control and lexical nodes containing language markers that assign them to a particular language. The model proposes that language production in bilinguals consists of an interplay of inhibition, control schemata, and a supervisory attentional system. The supervisory attentional system regulates tasks while additionally activating, maintaining, and updating the language task schema (see Figure 4). The selection of the correct word form is ensured by the language system tagging lexical word nodes (corresponding with Levelt's and Dell's lemmas) associated with the lexical concept. However, this is not sufficient to guarantee *correct* word selection. A key component of the model is the inhibition of word nodes without a language tag to inhibit the non-target language.

Figure 4

The Production of the Word 'Cat' in an English-German Bilingual Speaker in the Inhibitory Control Model (Green, 1986, 1998), Adapted Model From Schwieter & Ferreira, 2013



These presented bilingual models (Dijkstra et al., 2019, Green, 1986; 1998), which explain the existence of a language network holding more than one language with associated non-selective/parallel activations and inhibition processes, contribute to the complexity and specific language processing aspects in bilingual speakers, including those with aphasia. Recognising and considering these aspects are crucial for an understanding of the mechanisms of bilingual language production in word production.

However, these bilingual models are usually less specified when it comes to spoken word production in the bilingual mental lexicon, and it is difficult to pinpoint in these current versions where the influence of specific lexical variables sits during bilingual word form access. Further, any bilingual language profile will vary, and together with a language impairment, the bilingual language profile becomes a very heterogeneous profile that is hard to capture in its entirety in the currently available bilingual language models. The approach of this thesis is therefore to interpret findings in a combined account of existing detailed monolingual theories and broader bilingual theoretical accounts. The bilingual individual's language heterogeneity is also one key reason why this thesis has chosen a quantitative experimental case series research design. Averaged group results would have masked such heterogenous bilingual language variations that are so important to fine-tune bilingual word production theories.

While Grosjean's concern (1989), that a bilingual speaker cannot be considered to be the sum of two monolingual speakers is acknowledged, monolingual assumptions, diagnosis and treatment methods can still offer a basis to be expanded to bilingual clients (e.g., Cargnelutti, 2019; Khachatryan et al., 2016). However, this is always in combination with current bilingual theories in mind, even though the latter can only broader brushstroke frameworks. While we aim for standardised assessment and treatment protocols for bilingual aphasia, they are harder to achieve because of the many variables to consider as this thesis will point out. It is therefore not surprising that speech pathologists often feel overwhelmed when it comes to bilingual treatment decisions, in particular how to adapt their clinical practice to the unique characteristics of bilingual language processing to ensure the best outcomes for their clients (Rose et al., 2014).

Hence, research in spoken word production in bilingual speakers with aphasia is a starting point to increase the understanding of bilingual word production processes and inform and expand existing mono- and bilingual language theories.

Further Models on Bilingual Lexical Access. As mentioned above, we have opted for a comprehensive approach by using two monolingual theories of lexical access (Levelt et al., 1999; Dell et al., 2007) and two bilingual models (Dijkstra et al., 2019, Green, 1986; 1998) to interpret our findings. The incorporation of both, the monolingual and bilingual frameworks, is two-fold: The monolingual models offer valuable insight into the understanding of findings related to e.g., lexical variables, a feature that the bilingual models lack due to their less specified approach when it comes to spoken word production in the bilingual mental lexicon. On the contrary, the chosen bilingual models play a crucial role when it comes to the understanding of findings that are influenced by a language network encompassing more than one language and that is associated with non-selective/parallel activations and inhibition processes. However, it is essential to note, that alternative theories on bilingual lexical access exist. To ensure a comprehensive overview, seminal and important ideas will be presented briefly in the subsequent paragraph.

The model of bilingual lexical access by Costa et al. (2000) posits a shared semantic system. Irrespective of the target language, the semantic system activates both languages (parallel activation) of the bilingual speaker, and activated lexical nodes activate their phonological components. The subsequent steps involve language-specific lexical selection, wherein a selection mechanism operates exclusively on lexical nodes of the target language (no inhibitory processes required). In a study conducted five years later, Costa et al. (2005) introduce a refined model of bilingual lexical access, that again is defined by shared semantic representations across languages that activate lexical notes and related phonological components in both languages (parallel activation). Notably, in the 2005 model, the authors describe interactivity between the lexical and sublexical levels, both within and across the two languages.

Gollan et al.'s (2005) model of bilingual lexical access is characterized by their weaker links hypothesis. The authors suggest a shared semantic representation across available languages, that is connected to the separate word-level representations (lexical level) for each language. According to their hypothesis, the links between the semantic representations and the lexical representations are weaker in bilingual lexical access compared to monolingual speakers. The weaker links hypothesis has been identified as a key difference between monolingual and bilingual lexical access. An extension of the weaker links hypothesis was proposed in 2008 (Gollan et al., 2008), emphasizing the importance of frequency effects in bilingual lexical access. As proposed by the authors, bilingual models need to consider the analogy between bilingualism and frequency effects in bilingual lexical access.

The response conflict theory suggests a co-activation of word representations during word production. The greater the similarity between these activations and the target, the more conflict arises between the target and the co-activated representations. A high conflict makes it more difficult to suppress the co-activated representations; inhibition processes may no longer be sufficient for error-free target selection, resulting in an increased likelihood of errors in word production (Nozari & Pinet, 2020). These conflicts were also observed in bilingual speakers during lexical access (Nozari et al., 2019). In bilingual speakers, it can be assumed that co-activation of representations occurs both within and across languages during word production.

Preview of this Thesis

This thesis includes three experimental chapters followed by an overarching General Discussion and Conclusion section. The overall aim is to better understand word processing within and across languages in bilingual speakers with aphasia. Each chapter will take into account different influencing factors on bilingual word finding.

In Chapter 2 (paper 1) accuracy patterns, error patterns and error types within and across languages in bilingual speakers with aphasia are explored. The experimental task used is a spoken picture naming task with the aim to observe whether the same or different accuracy and error patterns occur within a bilingual individual with word finding problems. The research design comprises a quantitative experimental case series design, in which each individual undergoes in-depth language assessments and serves as their own control across languages. Eight bilingual participants with aphasia with different language combinations (Dutch-German, Polish-German, English-German, English-Italian, French-English) are included in this first study. Analyses include McNemar's Test, Fisher's Exact Test, and logistic regression analyses and consider factors such as the bilingual language profile, influencing linguistic variables (e.g., language-specific word length, frequency, visual complexity, name agreement, etc.), and the individual impairment of the participants.

In Chapter 3 (paper 2) the same task and research design is applied as in Paper 1, only that the investigation of influencing factors is expanded to the influence of similar sounding words (phonological neighbours) on spoken picture naming performance with a focus on accuracy. Logistic regression analyses capture the influence of within-language phonological neighbours and across-language phonological neighbours together with their respective neighbourhood word form frequencies on accuracy in and the same eight bilingual speakers with aphasia that were assessed for paper 1. In addition, ten monolingual speakers with aphasia are included to replicate the effects of previous studies on the influence of within-phonological neighbours on their spoken naming performance. This study is the first that investigates the effect of within and across phonological neighbourhood density *and* frequency on spoken picture naming performance.

In Chapter 4 (paper 3), the same eight participants from papers 1 and 2 were assessed when producing responses to pictures that were either a compound word or a simple word. Accuracy analysis within and across languages and analyses of language mixing errors across languages is carried out to gain insight into the representation of compounds in our mental lexicon considering non-selective language accounts that can explain the influence of the non-target language on the target language. Paper 3 is adding to the scarce evidence base around the representation of compound words in bilingual speakers with aphasia. To the best of our knowledge, there is only one study that captured compound processing in people with bilingual aphasia (Jarema et al., 2010). Paper 3 expands this evidence base by exploring novel aspects of language mixing errors in compound words in bilingual speakers with aphasia by analysing (logistic regression) the influence of phonological similarity across languages.

Chapter 5 provides the overarching General Discussion including an Overall Conclusion. A summary of each of the three studies is given and findings will be drawn together for an overall interpretation of existing language models (mono-and bilingual frameworks). It is emphasised how this thesis as a whole can contribute on a very small scale to a more in-depth understanding of bilingual word processing. Further, limitations of this research are flagged and potential future directions are given.

All three chapters contribute to a comprehensive picture and word material database that spans five languages/ language combinations. All pictures and words are controlled for influencing (lexical) variables. In addition, all three studies contribute to an extensive guide for bilingual word finding errors and defining different error types across languages, that can help to streamline the error classification process. It is hoped that the developed picture and word materials together with the error code guide can be published as open-access resources to serve researchers in the future when exploring unimpaired and impaired bilingual word retrieval processes in different languages.

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Chapter 2:

Accuracy and Error Patterns in Spoken Picture Naming Across Languages in Bilingual Speakers with Aphasia

(Study 1)

Introduction

We live in an increasingly multilingual world. Currently, 50% of the world's population is considered as being bilingual (Grosjean, 2021), and 21% of the Australian population speaks more than one language at home (Australian Bureau of Statistics, 2017). This increasingly bilingual population will eventually age and will be affected by age-related diseases, such as stroke, which may lead to language difficulties such as aphasia.

Based on this development, the question arises if the speech pathology profession is prepared for an increasing number of bilingual clients. According to Grosjean (1989), a bilingual speaker cannot be considered the "sum of two monolingual speakers". Hence, it seems inadequate to apply monolingual assumptions and monolingual diagnosis and treatment methods to bilingual clients (e.g., Cargnelutti, 2019; Khachatryan et al., 2016). However, existing language theories, language models, and diagnostic and treatment methods are mostly based on monolingual research (e.g., Levelt et al., 1999; Dell et al., 2007); and bilingual language theories remain underspecified and/or starting to emerge (e.g., Dijkstra et al., 2019; Kroll et al., 2010; Green, 1998). This project adds a piece to the puzzle of the mechanisms at work in bilingual word production. By capturing word finding error patterns across languages within a bilingual speaker with aphasia, we will be able to understand better what factors are at play when the error patterns look the same or show differences across languages. This new knowledge may be useful to better understand bilingual language profiles and will inform their specific assessment needs, which in turn will enhance clinical services for this population.

Word Production Difficulties in Monolingual Speakers with Aphasia

Difficulties in word finding are a main symptom of aphasia (e.g., Nickels & Howard, 2000). Therefore, it is a key area of concern to understand word production and its difficulties in bilingual speakers with aphasia and how it varies in comparison to monolingual speakers with aphasia. Word finding difficulties in monolingual speakers with a language disorder have been extensively researched within frameworks of well-known and established word production models for monolingual speakers (e.g., Dell et al., 2007; Levelt et al., 1999). These models overlap on three major processing steps in spoken word production: Accessing the (a) non-lexical concept, (b) lexical semantic information, and (c) lexical form information. While these models were initially developed for monolingual speakers, it is reasonable to assume that they can also be extended to impaired bilingual word production.

However, it is important to acknowledge that these monolingual models (e.g., Dell et al., 2007; Levelt et al., 1999) are incomplete with regard to bilingual word processing, as they cannot explain word retrieval in a mental lexicon that holds more than one language.

Word Production Difficulties in Bilingual Speakers with Aphasia

Error Types

Error types related to lexical retrieval difficulties in bilingual speakers with aphasia do not differ from the ones that have been observed in monolingual speakers with a language disorder (e.g., Fabbro, 2001). These different error types have been examined in detail over the last decades and can include semantic errors (e.g., target *cat*, response *dog*) or phonological errors (e.g., target *fish*, response *fush*) and many more (e.g., no responses, mixed errors; please refer to, e.g., Schwartz et al., 1994, for an overview of these different error types).

It is important to mention that these typical error types can also occur in the other language that is not targeted (non-target language errors) when a bilingual speaker names a picture. Again, these well-known error types can include semantic errors in the non-target language (e.g., target *cat*, response *Hund* [German for dog]), or phonological errors in the non-target language (e.g., target *desk*, response *Tusch* [German word Tisch [desk] with a phonological error]), and many more.

Due to the bilingual language profile of bilingual speakers, they also exhibit error types that are specifically related to their bilingualism. These error types include language mixing, language switching, and translation errors (Cargnelutti et al., 2019; Fabbro, 2001; Fabbro, 1999). Language mixing errors occur when an individual produces a word that includes parts of the target language and the non-target language (target *pear*, response *pearne* [response includes parts of word Birne, the German word for pear). Conversely, language switching involves the shift to another language between utterances and sentences (e.g., *I'm writing a letter to my mum. Sie hat morgen Geburtstag* [second sentence is in German]) (e.g., Albert & Obler, 1978; Fabbro, 1999; Paradis, 1977). Translation errors are defined as difficulties with translation from one language to the other, while research indicates a greater impairment when translating from the less impaired to the more impaired language (e.g., Adrover-Roig et al., 2011). These findings suggest that translation errors are more likely attributed to lexical access difficulties in the speaker's weaker/non-dominant language, an observation that has been found and suggested for the occurrence of language mixing errors as well (Cargnelutti et al., 2019).

Language Mixing Errors. Language mixing errors can be further classified (e.g., Cargnelutti et al., 2019; Perecman, 1984), such as: (a) use of the non-target language translation equivalent (e.g., target *cat*, response *Katze* [German equivalent to cat]), (b) use of the word root from one language and the suffix/prefix from the other language (e.g., target *witnesses*, response *witnessen*, the response is influenced by the word Zeugen [German word for witnesses]), (c) use of syllables from different languages in a single word, (e.g., target *potato*, response *kartato*, response includes the first syllable of Kartoffel [German for potato]), (d) use of words in the target language but with the intonation or phonological rules of the other language (e.g., target *thermometer*, while the intonation rules of *Thermometer* [German word for thermometer] are applied).

It is important to note that a response that is the correct word in the non-target language can also be considered a compensatory strategy rather than a language mixing error. This particular error might serve as a deliberate strategy to compensate for lexical access difficulties that an individual speaker experiences in one language but not in the other. Furthermore, this specific error might also occur when a bilingual speaker does not know any more or never knew the specific word in the target language, however, the knowledge of the target word is available in the non-target language. Moreover, this error can also be interpreted as a strategy that bilingual speakers with aphasia use to prompt themselves by providing the word in the non-target language and then translating it in a further step (e.g., Cargnelutti et al., 2019; Neumann et al., 2017). This language mixing error/strategy of producing the correct word in non-target language instead of the target word is a commonly observed error across the bilingual population with a language disorder (Roberts & Deslauriers, 1999). These explained strategies are also observed in healthy bilingual speakers; however, they are much faster and experience greater accuracy when applying these strategies compared to bilingual speakers with a language disorder, and the strategy might often be subtle and goes unnoticed (Khachatryan et al., 2016).

Language mixing errors that are specifically associated to bilingual speakers with aphasia are more likely among speakers that have languages with structural similarities available (e.g., Diéguez-Vide et al., 2012; Kong et al., 2014). While the presence of similar-sounding words and/or cognates (the latter overlap in sound and meaning) across languages in bilinguals speakers typically leads to faciliatory effects (e.g., Lalor & Kirsner, 2001; Roberts & Deslauriers, 1999), the opposite effect may occur for bilingual speakers with aphasia. In bilingual speakers with aphasia, structural similarities across languages/lexical forms can lead to interference effects, that in turn result in language mixing and language switching errors (e.g., Abutalebi et al., 2009; Kurland & Falcon, 2011). These findings have been supported by Siyambalapitiya et al. (2013) who found advantages for cognates and noncognates in word processing in bilingual speakers with aphasia (see further details on this study in next paragraph).

It has been suggested that underlying mechanisms leading to language mixing and language switching errors are not necessarily driven by a selective impairment of the bilingual language system, but might also be an impairment located within cognitive control mechanisms that manage the suppression or activation of the available languages spoken (e.g., Cargnelutti et al., 2019).

In sum, error types related to lexical retrieval difficulties in bilingual speakers with aphasia do not differ from the ones that have been observed in monolingual speakers with a language disorder. However, due to the existence of a bilingual language profile, these error types can also occur in the non-targeted language, while a bilingual wants to name a picture in the target language. Additionally, language mixing errors are commonly observed in bilingual speakers with a language disorder (Roberts & Deslauriers, 1999).

It is reasonable to assume that frequency/type of error patterns for phonological errors might differ across languages in a bilingual speaker since word forms often have different representations across languages. Semantic representations on the other hand might be shared across languages. Evidence supporting (partial) shared semantic representations in the mental lexicon have been found in healthy bilingual speakers (see Francis, 2005, for a review) and bilingual speakers with aphasia (e.g., Siyambalapitiya et al., 2013; Kiran and Lebel (2007). Siyambalapitiya et al. (2013) conducted an experimental single-case study with an Italian-English bilingual speaker with non-fluent aphasia and examined semantic, cognate, and non-cognate repetition priming within- and across-language via auditorily presented word pairs. Priming effects in both within-language conditions and in one across-language condition (English to Italian) were demonstrated. Across-language priming effects might be explained by shared semantic representation within the mental lexicon. Further evidence, that supported the existence of shared semantic representations in the mental lexicon in bilingual speakers with aphasia was provided by Kiran and Lebel (2007). They conducted a study with four Spanish-English participants that examined crosslinguistic semantic and translation priming during a lexical decision task. Participants showed cross-linguistic priming effects in both directions that interacted with their language proficiency and their language breakdown: The better their proficiency, the better priming effects were observed. Furthermore, the results of

Kiran and Lebel's study (2007) showed that aspects of the bilingual language profile might affect the language performance of bilingual speakers with aphasia. This was also shown in a later study by Kiran et al. (2014). The authors conducted three lexical retrieval tasks (two picture naming tasks, one category generation task) across 12 Spanish-English healthy speakers and ten Spanish-English speakers with aphasia. The bilingual speakers with aphasia presented with lexical deficits that were influenced by language proficiency for each language, participants produced often more words in the language with higher proficiency.

If semantic representations are indeed shared across the two languages of a bilingual speaker with aphasia, it is reasonable to expect a similar semantic error pattern across the languages of a bilingual speaker.

Lexical retrieval difficulties associated with the above error types (target language errors, non-target language errors, mixing errors) are often reported to be equally distributed among the available languages in bilingual speakers with aphasia, particularly in those speakers who reported equal and high proficiency in both available languages prior to the onset of aphasia (e.g., Kiran et al., 2014). For other bilingual speakers, lexical retrieval in one language is significantly more impaired than in the other. These differences in accuracy may depend on a number of factors, such as pre- and post-onset proficiency and language use (Goral, 2017). However, there are cases where balanced bilinguals (speakers with the same level of proficiency in both languages) experience differential aphasia, a pattern of recovery in bilingual aphasia that describes a much better recovery for one language than the other compared to premorbid language abilities (Ansaldo et al., 2010). Studies that have investigated lexical retrieval in balanced bilingual speakers and found differential accuracy patterns across languages argue for impaired cognitive control rather than a loss of linguistic representations (Van der Linden et al., 2018; Verreyt et al., 2013). These results support theories of bilinguals having one lexicon with word representations from both languages, rather than two separate systems for each language (Van Heuven et al., 1998).

Influencing Factors on Bilingual Word Production in Aphasia

Bilingual Language Profiles Including the Individual Language Breakdown

As mentioned previously, bilingual individuals with aphasia exhibit language mixing errors, an error type that is specifically associated with their bilingual status. However, the influence of the bilingual language profile on language performance extends beyond this error type. Various key aspects of an individual bilingual profile impact the language outcome. These key aspects include the age of acquisition for each language, proficiency of both languages, dominance, the context of language acquisition (e.g., full immersion versus classroom learning), and the linguistic similarities between languages (e.g., distant vs close).

(1) *Age of acquisition* captures the age a language has been learned. If language exposure happened before the age of 12, much of the literature refers to this as 'early' exposure and anything thereafter as late. However, this binary distinction is not useful by itself because an early acquired language can be less proficiently spoken than a language acquired later (a commonly used cut-off value that distinguishes between an early and late bilingual is the age of 12). The concept of language age of acquisition aligns with the categorization of being a simultaneous or sequential bilingual speaker. Simultaneous bilingual speakers learn two or more languages concurrently, while sequential bilingual speakers learn the L2 after they acquired the L1 (i.e., L2 acquisition occurs either early or late in life).

(2) *Language proficiency* reflects the level of performance across the linguistic domains such as mastering the specific sound and syntactic system of each language spoken. This is reflected in the ease of production and comprehension of each available language across modalities (speaking, listening, reading, and writing).

(3) *Language dominance*: The definition and concept of language dominance vary across research. While some studies ascertain language dominance by evaluating language proficiency (e.g., Genesee et al., 1995), others define it by language use and exposure (e.g., Argyri and Sorace, 2007) or the environmental languages (e.g., Polinksy, 2008). Hence, language dominance in bilingual individuals is a multifactorial concept and can be defined in various ways. In recent years, this topic has received increasing attention (Montrul, 2015; Hamann et al., 2019). In this thesis, language dominance is defined as a multifactorial construct that entails language proficiency, language use and exposure, and biographical factors such as the environmental language, age of acquisition, and language of residence. This definition is in line with previous research (e.g., Birdsong et al., 2012; Dunn & Fox Tree, 2009).

(4) *The context of exposure* outlines the circumstances, in which the L2 has been learned and used (e.g., full L2 immersion when living in the country of L2).

(5) *Linguistic similarities* can vary among the available languages, ranging from closely related to more distant languages (e.g., German-English vs. Mandarin-English). (e.g., Ansaldo et al., 2008; Kovelman et al., 2008; Akbari, 2014)

Among the mentioned factors above, language age of acquisition, language proficiency, and language dominance are significant factors on word processing in bilingual speakers with aphasia as a meta-analysis by (Kuzmina et al., 2019) highlights. This review included 65 studies (130 cases) and examined factors that influenced bilingual word production in aphasia. While the review revealed that participants across studies often showed better performance in their L1, the outcome was usually moderated by the age of acquisition of their L2: If L2 was acquired before the age of seven a similar performance was observed for the L1 and L2; when L2 was acquired after the age of seven participants exhibited better performance in their L1. Additionally, the authors pointed out, that language proficiency and language dominance had a moderating role in the results when the L2 was the more proficient and/or the dominant language. Further studies have especially highlighted the importance of language proficiency and language dominance on lexico-semantic access in bilingual speakers with aphasia. In a study conducted by Kiran and Tuchtenhagen (2005) 15 healthy English-Spanish bilingual speakers and one English-Spanish participant with aphasia performed two tasks, a naming-to-definition task, and a semantic priming task across both languages. Based on an error rate analysis, the authors proposed that language proficiency and language dominance are more reliable predictors for successful lexical access in bilingual word retrieval compared to language age of acquisition. Healthy bilingual speakers have shown similar patterns, for example, Kotz & Elston-Güttler (2004) conducted a study with 30 German-English bilingual speakers (German L1, English L2), who were either high- or low-proficient speakers in English. Participants read 640 targets in English and had to decide if it is either a real word or nonword. Language proficiency and the type of semantic information processed were important factors in determining how autonomous semantic processing could be in the L2.

Currently, evidence suggests that the stronger language (which is often the dominant and/or proficient language) interferes with the processing of the weaker language by suppressing the weaker language (e.g., Cargnelutti et al., 2019).

These findings underscore the importance of language proficiency and language dominance as positively influencing factors on lexical access/language performance in bilingual speakers with aphasia (Khachatryan et al., 2016; Cargnelutti et al., 2019). Cargnelutti et al. (2019) even suggested that available languages in bilingual speakers should be categorized according to their relative dominance rather than their chronological language age of acquisition.

Lexical Variables

Word retrieval in picture naming is typically a fast and efficient process. However, as stated above, people with aphasia experience difficulties during this process (e.g., Alario et al., 2004), which is influenced by the individual impairment and, in bilingual speakers, by their individual bilingual language profile. However, factors independent of the individual's profile can influence language performance e.g., lexical variables. Lexical variables or linguistic factors are associated with the features of the picture-naming word material, and have been thoroughly investigated over the last decades. They include (i) spoken word form frequency, (ii) syllable length, (iii) phoneme length, (iv) item age of acquisition, (v) familiarity, (vi) imageability, and (vii) visual complexity (e.g., Alario et al., 2004; Nickels & Howard, 1995). According to Alario et al. (2004) and Nickels and Howard (1995) they are defined as followed:

(1) *Spoken word form frequency:* Spoken word form frequency refers to the occurrence of use of an individual word/item and has been found to influence word retrieval in spoken picture naming (the higher the frequency, the higher accuracy/lower error rate).

(2) *Syllable length:* Syllable length is the number of syllables a spoken word is composed of (words with a higher number of syllables are predicted to take more time for encoding during word retrieval, and are also more error-prone).

(3) *Phoneme length:* Phoneme length is a second variable to assess the length of a target word. This linguistic variable quantifies the number of phonemes a spoken word contains (longer words need more phonological encoding time and are therefore more vulnerable to errors).

(4) *Item age of acquisition:* Item age of acquisition is a linguistic variable that refers to the typical age at which a word was acquired (earlier acquired words are produced more accurately).

(5) *Familiarity:* The linguistic variable represents the degree of familiarity that is associated with the concept of the presented item, which describes how frequently an object is seen, heard, or used in everyday life (highly familiar concepts are easier to name than concepts that an individual is less often exposed to).

(6) *Imageability:* Imageability indicates how easily an individual person can create a mental image of the presented target. It captures whether a presented item evokes a few or many different images for a specific object/word. This variable influences the

storage and processing of a word in the mental lexicon (a highly imageable item can be retrieved faster and is less error-prone).

(7) *Visual complexity:* This linguistic variable quantifies the amount of descriptive detail included in a presented image. Such details determine the ease or difficulty at the stage of object recognition during word retrieval (the simpler the object, the faster and easier the recognition).

These different lexical variables are, therefore, important to consider when investigating picture naming in people with aphasia since they can influence this process at various different stages during word retrieval. However, most evidence is derived from monolingual healthy speakers, while effects of linguistic variables might differ for bilingual speakers with aphasia. Moreover, the effects of spoken word form frequency, age of acquisition, and familiarity on naming accuracy might differ as observed for monolinguals speakers, since one of the available languages of the bilingual speakers might have been acquired later in life. Therefore, picture naming results of bilingual speakers, containing these variables, must be interpreted in combination with the bilingual profile of the participants.

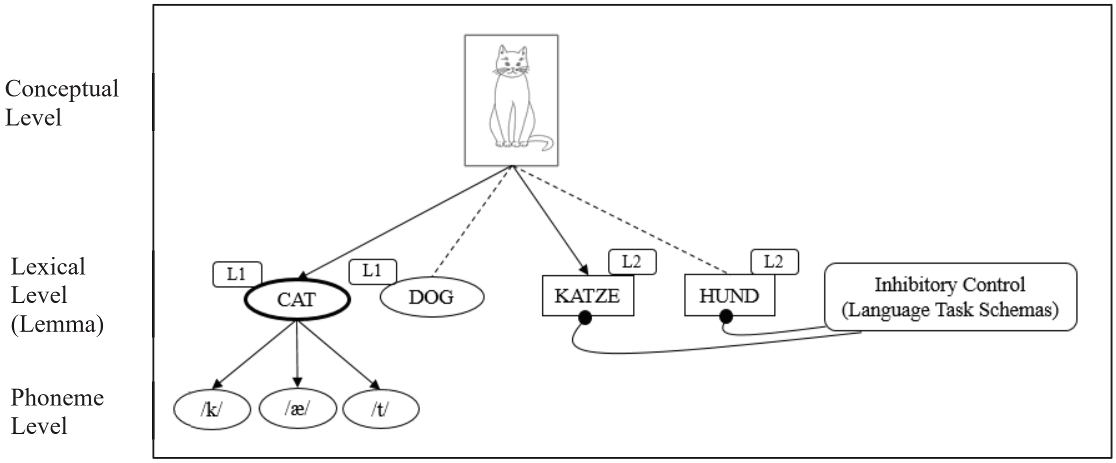
Non-Selective Activation and Inhibition Processes: The Inhibitory Control Model

In the context of bilingual speakers and factors that influence language performance, non-selective activation of languages and associated inhibition mechanisms need to be considered as well. Green (1998) suggested an inhibitory control mechanism that is at play when non-selective activation between two or more languages during bilingual word production occurs. Non-selective activation refers to a bilingual language system that involves two or more languages during production: Not only the target language/word is activated but also the non-target language/word. Non-selective activation of language in bilingual speakers has been found in healthy people (e.g., Moon & Jiang, 2012; Libben et al., 2017) but also in a bilingual population with language impairments (e.g., Gray & Kiran, 2013).

According to his Inhibitory Control Model (see Figure 1), multiple levels of control are part of the bilingual speech production system. Lexical nodes within the model contain language markers that assign them to a specific language. Green postulates that the language production of bilingual speakers involves a dynamic mechanism of inhibition, control schemata, and a supervisory attentional system. The supervisory attentional system has a regulation function for tasks within the language systems and additionally activates, maintains, and updates the language task schema (see Figure 1). Hereby, the lemma associated with the concept is tagged by selection processes within the language system to ensure that the correct word forms are selected. However, this procedure alone does not guarantee the correct word selection. A key component of the model is an inhibition process to deactivate/inhibit non-target language lemmas. Furthermore, according to the model, it will take longer for the dominant language to reactivate from inhibition compared to a weaker language since the dominant language in a bilingual speaker requires greater inhibition processes because of its underlying higher activation as the default state.

Figure 1

The Production of the Word 'Cat' in an English-German Bilingual Speaker in the Inhibitory Control Model (Green, 1986, 1998), Adapted from Schwieter & Ferreiera (2013)



Bilingual Empirical Evidence

Evidence supporting non-selective language activation has been found in healthy bilingual individuals (e.g., Moon & Jiang, 2012) but also in bilingual populations with language impairments (e.g., Gray & Kiran, 2013). Gray and Kiran (2013) conducted a study with 19 Spanish-English bilingual speakers. All underwent a number of background assessments in both languages to develop an account of bilingual language processing. The findings revealed significant correlations between the different language tasks (language comprehension and production tasks) across languages, which have been proposed in their developed framework of bilingual language processing.

In sum, as stated by Khachatryan et al. (2016), it can be tempting to assume that error types and rates correlate across languages and that language impairment is consistent across languages in an individual client; however, they also warn against such simplifications and emphasise that further research is needed that takes into account influencing factors, like, for example, the bilingual language profile. Existing studies have shown that the bilingual profile influences language performance, but the extent to which it affects accuracy and error types/patterns remains unknown (Kuzmina et al., 2019, Khachatryan et al., 2016). While some studies demonstrate better performance influenced by the language age of acquisition (Kuzmina et al., 2019), others highlight the importance of language dominance on accuracy as the L2 might become the dominant language over time and demonstrate greater resilience (protection) after, for example, a brain injury affecting language processes (e.g., Tiwari & Krishnan, 2015).

Study Aim

The aim of this study is to understand whether a*ccuracy* and *error* patterns across languages vary in relation to the heterogeneous bilingual language profiles, language impairments and influential lexical variables affecting spoken word production. Our broader aim is to enhance theories of bilingual language processing by interpreting our accuracy and error data in these frameworks and offer further explanations around bilingual word production mechanisms.

Research questions and predictions for accuracy

(1) Do accuracy patterns differ when bilingual speakers with aphasia name pictures across their languages taking into account their bilingual language profile and breakdown patterns?
We predicted a different accuracy pattern on picture naming between languages depending on the bilingual language profile (e.g., language age of acquisition, language dominance).

(2) What lexical variables influence accuracy patterns in spoken picture naming in bilingual speakers with aphasia?
While we predicted influences of lexical variables (such frequency, length, age of acquisition, etc.) on the accuracy pattern for bilingual speakers as for the monolingual cohort, we cannot confidentially predict the same direction based on the scarcity of bilingual studies in aphasia.

Research questions and predictions for error types

(1) What is the distribution of error categories (all errors in the target language versus all errors in the non-target language) across languages and what is the effect of the bilingual speaker’s profile (e.g., language dominance, languages acquired, language impairment) on these error categories?

We predicted an influence of the bilingual language profile such that there will be more non-target language errors in the weaker language than in the dominant/stronger language. This is because the dominant/stronger language interferes more with the processing of the weaker language than vice versa.

(2) Do error types distributions in a spoken picture naming task differ across languages in bilingual speakers with aphasia, and what is the effect of the bilingual language profile (e.g., language dominance, languages acquired, language impairment) on these error categories?

We predict semantic errors to be similarly distributed across languages, based on shared semantic representations across languages, while the distribution of other error types might be different (e.g., phonological errors since representations across languages are not shared). Furthermore, error type occurrence might be influenced by the bilingual language profile (e.g., language age of acquisition, language dominance).

Participants

Bilingual speakers with aphasia were recruited for a spoken picture naming task in their first and second language. Eight participants were included in this study using a snowball sampling method. Inclusion criteria were applied as followed: All speakers with aphasia (diagnosed by a speech-language pathologist) were post-acute or chronic and presented with spoken word finding difficulties as the main characteristic of their aphasia. Each participant's picture naming accuracy needed to be more than 10% and less than 90%. To screen the participants spoken naming abilities across languages, the Spoken Naming Subtest (Subtest 13) of the 'LEMO 2.0 Lexikon modellorientiert. Diagnostik für Aphasie, Dyslexie und Dysgraphie' (Stadie et al., 2013) was carried out. The Subtest consisted of 20 items, comprising ten high-frequent and ten low-frequent words, normed for the German language. The items were translated into the participants' respective languages to use the subtest as a screener for all bilingual speakers with aphasia. It is important to note that the classification of ten high-frequent and ten low-frequent words may not be accurate when translated into languages other than German. Exclusion criteria were as followed: Severe comprehension deficits (reported by a speech pathologist), apraxia of speech, dysarthria and other cognitive impairments (e.g., dementia). Mild cognitive impairments (e.g., attention, memory, etc.) were acceptable. All participants had self-reported normal or corrected-to-normal hearing and vision. Participants from Germany were recruited via the researcher's clinical network from different Speech Pathology Centres in the northwest of Germany. Participants from Australia were recruited from an outpatient Clinic attached to a university and a non-profit organisation supporting people with aphasia. Although eight bilingual speakers with aphasia participated in this study, 22 potential bilinguals were identified to participate. Fourteen potential participants did not meet the inclusion criteria because of their severe apraxia symptoms, cognitive impairments, and/or severe comprehension deficits. A further reason for non-participation was their unavailability/ inability to commit during data collection.

All participants received a project information sheet and provided written consent to participate in the study prior to testing (see General Appendix A and General Appendix B). Additionally, all bilinguals were asked to consent for accessing their medical background and demographic information as this data serves as a basis for interpreting the collected and analysed research data.

A self-developed personal data form (demographic questionnaire) was used to collect all participants' demographic and medical data and determine the bilingual language history (see General Appendix C). In addition, all participants were asked to complete the Language Experience and Proficiency Questionnaire (LEAP-Q, Marian et al., 2007). The LEAP-Q was used to determine language history and to obtain differences across their languages (language age-of-acquisition, language dominance). The LEAP-Q, initially designed for healthy bilingual speakers, features a non-aphasia-friendly structure, characterised by e.g., long and complex sentences or questions. Consequently, the completion of the questionnaire required a specifically tailored approach. Participants were assisted by the researcher to complete the questionnaire, with questions being read aloud and were given the opportunity to have the questions repeated or clarified as many times as needed. Furthermore, the participants received support in providing the correct answer by offering for example a visual aid in form of a numerical scale ranging from one to ten. Various background assessments spanning across receptive and expressive tasks were carried out in the participant's L1 and L2 to assess the language performance for both languages. Thirteen subtests of the Bilingual Aphasia Test (BAT, Paradis & Libben, 1987) were carried out in each of the participant's available languages to assess the participants' language impairments across modalities: Pointing, simple and semi-complex commands, complex commands, verbal auditory discrimination, semantic categories, synonyms, repetition and lexical decision of words and nonsense words, series, verbal fluency, naming, reading words, and reading comprehension for words. Since the BAT does not include a written naming test, written naming abilities were screened for each participant across 30 items for both languages. The 30 items consisted of item one to 30 of Subset 1a of the experimental naming task.

A detailed description of the participants' demographic and medical data, bilingual language profile data and background language assessment data can be found in Appendix X. A summary of these data is given below.

Ethics approval for this study was obtained by the ethics committee of Bielefeld University in Germany (EUB 2020-137-Am), the ethics committee of Curtin University Perth (HRE2017-0274) and the South Metropolitan Health Service Human Research Ethics Committee (RGS0000003763) (see General Appendix D).

Demographic and Medical Data of all Bilingual Speakers with Aphasia

Table 1 summarizes the demographic and medical data of the eight bilingual speakers with aphasia. The eight participants (four female) were aged between 55 years and 75 years (mean 66.1 years, SD 6.27). They were between 11 months and 28 years post-onset (mean 119.9 months [10 years], SD 109.5 [9.13 years])[2]. Seven out of the eight participants presented with a left hemisphere stroke: BwA1, BwA2, BwA3, BwA4, BwA5, BwA6, and BwA8. BwA7 presented with a right hemisphere stroke. Across the seven participants with a left hemisphere stroke, two participants had either additional stroke localisations in the right hemisphere (BwA8) or the right hemisphere and cerebellum (BwA2). See General Appendix E for detailed information on the localisations of the stroke(s) per participant. Based on the participants' self-reports and the medical records, all bilingual speakers with aphasia experienced aphasia post-onset.

Bilingual Language Profile Data (Including the Level of Breakdown) of all Bilingual Speakers with Aphasia

The eight participants presented with six different language profiles: Dutch-German (BwA1, BwA3), Polish-German (BwA2), English-German (BwA4), English-Italian (BwA5), English-French (BwA6) French-English (BwA7, BwA8). The participants' first language was either Dutch, Polish, English, Italian or French. The second language of the participants was German, French or English (see Table 1). Seven participants were late bilingual speakers, one participant was an early parallel bilingual speaker (BwA5). BwA5 grew up as an English-Italian bilingual speaker from birth. Immersion of L2 in the late bilinguals was between the age of 17 years and 35 years when living in the country and in an environment of the L2 (classroom language excluded).

Based on the bilingual profile assessment (self-report, LEAP-Q, background assessments) the L2 was the dominant language pre- and post-stroke for four participants (BwA1, BwA3, BwA7, and BwA8), the L1 was the dominant language pre- and post-stroke for three participants (BwA4, BwA5, BwA6). The language dominance was equally distributed among languages for BwA2. The dominant language was determined by the participants' language proficiency, language exposure and use, and biographical factors (language age of acquisition, environmental languages, language of residence). Language proficiency was determined by the language background assessments, spanning receptive and expressive tasks that were conducted with every participant (see below). Biographical factors were conducted by the LEAP-Q and the participants' self-reports. Language use and exposure

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[2] Three participants had experienced multiple strokes. To calculate the mean post-onset time, only the stroke that resulted in the language impairment (determined by medical data and the participants' self-reports) was considered (see Table 1).

were determined as per followed: A score (based on the participant's self-report and the results of the LEAP-Q [Marian et al., 2007]) was calculated for each of the participant’s languages to account for the language use and exposure ratio across the two available languages. This score could range from zero to eight (zero = no/minor language use and exposure, eight = high language use and exposure). The score per language was determined by considering eight categories: Interaction with family, interaction with friends, daily life activities (e.g., supermarket, medical appointments, restaurant), TV, radio/music etc., smartphone/social media/internet/computer, reading, writing. Each category was matched by either ‘using mostly my L1 in this category’ (one-point L1, zero points L2), ‘using mostly my L2 in this category’ (zero points L1, one-point L2) or ‘using both languages in this category’ (one-point L1, one-point L2). Thus, language use and exposure were indicated by a score between zero and eight. For detailed information for each participant see General Appendix E.

Background Language Assessment Data of all Bilingual Speakers with Aphasia

Background aphasia assessments spanning receptive and expressive tasks were conducted with every participant to determine the severity of the language impairment in both of the available languages. The pattern of language impairment was classified as anomic aphasia in six participants (BwA2, BwA3, BwA4, BwA6, BwA7, and BwA1) and as Broca’s aphasia in two participants (BwA1 and BwA5)[3].

Spoken naming accuracy was screened across languages in each participant with the Spoken Naming Subtest of the LEMO (Stadie et al., 2013) with the following result: Spoken picture naming accuracy ranged from 0% to 90% across participants. Selected parts of the BAT (Paradis & Libben, 1987) were conducted in each of the participant’s languages (pointing, simple and semi-complex commands, complex commands, verbal auditory discrimination, semantic categories, synonyms, repetition and lexical decision of words and nonsense words, series, verbal fluency, naming, reading words, and reading comprehension for words). According to the results of the BAT all participants presented with a language impairment across languages. Spoken picture naming within the BAT showed an accuracy of 6.25% to 100% across participants. Since BAT does not test for written naming, written naming abilities were screened in both of the available languages in every participant by the

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[3] Aphasia syndrome classifications are based on the following information: (i) Clinical observations during the project, (ii) the BAT and LEMO background assessment results, and (iii) speech pathology reports (if available).

first 30 items of subset 1a of the experimental picture naming task. To cater for potential priming and repetition effects, written naming accuracy was administered after the experimental task. For detailed information on all results of the Background language assessments per participant see General Appendix E.

The bilingual language recovery pattern post-onset was self-reported as parallel recovery pattern for all bilingual speakers with aphasia.

Table 1

Summary Data on the Background Information of all Bilingual Speakers with Aphasia

Demographic and medical data						Bilingual language profile data				Language background assessment data					
			Stroke								Naming results				
											BAT % correct		LEMO % correct		
ID	Age [y]	Sex	Post-Onset [y;m]	Lesion Hemisphere	Aetiol	L1	L2	Dominant language	L2 AoA	Aphasia types	L1	L2	L1	L2	Recovery pattern
BwA1	55	F	10;4	LH	Isch[g]	Dutch	German^	L2	23	Broca	65	90	30	55	parallel
BwA2	66	M	0;11	Cereb, LH, RH[a]	Isch[g]	Polish	German^	L1/L2	35	Anomic	95	60	85	60	parallel
BwA3	64	M	30/28[b]/14	LH	Isch[h]	Dutch	German^	L2	25	Anomic	80	60	75	50	parallel
BwA4	75	F	2;9	LH	Isch[h]	English^	German	L1	27	Anomic	100	80	80	65	parallel
BwA5	64	M	4/1;8/1;3[b]	LH	Isch[g]	English^[d]	Italian	L1: EN[e]	From birth	Broca	62.5	6.25	30	0	parallel[i]
BwA6	65	F	8	LH	Isch[g]	English^	French	L1	17	Anomic	94.74	89.47	75	65	parallel
BwA7	66	M	16	RH	Isch[g]	French	English^	L2	28	Anomic	95	95	80	80	parallel
BwA8	74	F	12;8[b]/9/0;3[c]	LH, RH	Isch[h]	French	English^	L2	28	Anomic	100	100	85	90	parallel

Note. y = Years, F = Female, M = Male, m = Months, LH = Left hemisphere, RH = Right hemisphere, Cereb = Cerebellum, Aetiol = Aetiology, isch = ischaemic stroke, ^ = dominant language, AoA = Age-of-acquisition.

[a] See further important information about lesions in General Appendix E.

[b] Stroke that resulted in aphasia.

[c] BwA8 suffered a mild stroke after recruitment. Neither the client nor her carers reported any change in her communication after the mild stroke. Testing did not commence until three months after this stroke.

[d] Parallel language acquisition.

[e] English and Italian are the BwA5's first languages, and English is the BwA5's dominant language pre-stroke and post-stroke.

[f] Aphasia syndrome classifications are based on the following information: (i) Clinical observations during the project, (ii) the BAT and LEMO background assessment results, and (iii) speech pathology reports (if available).

[g] Based on medical records.

[h] Based on the participant's self-report.

[i] Based on the participant's background assessments, including comprehension tasks.

Experimental Task

Research Design

This study used a case-series design. Participants were bilingual speakers with aphasia. Aphasia is a heterogeneous disorder since this language impairment can originate from many different potential sources causing language breakdown. When considering bilingual participants, even greater heterogeneity can occur since participants will also vary in, for example, their language history (e.g., age of acquisition for each language or language dominance). Hence, a single-case approach that treats each client as a separate case and takes into account inter-individual differences across the population is most appropriate for this context and is an accepted research methodology in bilingual speakers with aphasia (e.g., Howard et al., 2015; Schwartz & Dell, 2010). The experimental task was spoken picture naming, which examined the accuracy and error types for each language spoken by taking into account the participants' bilingual language profile and the targets' lexical variables.

Method

Materials

Pictures were taken from MultiPic (Duñabeitia et al., 2018), a database providing 750 normed noun pictures available for seven languages (Dutch-Belgium, Dutch-Netherlands, English-British, French, German, Italian, Spanish). Item lists were designed per language combination for the bilingual speakers with aphasia. All pictures with less than 80% name agreement (degree of agreement on a name of an image [Alario et al., 2004]) were excluded. Hence, bilingual item lists for the experimental task only consisted of items that had a name agreement of 80% or more in both languages of a speaker. As name agreement for Polish was not available using the MultiPic database, the item list of all German items with 80% name agreement or more were named by the bilingual Polish-German participant in both languages. It is acknowledged that some included items might not fulfill the 80% name agreement for Polish. All German items were translated by a native speaker into Polish to define the target Polish response.[4]

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[4] After data collection and data analysis Duñabeitia et al. (2022) published Polish name agreement data for 500 of the 750 normed noun pictures of their MultiPic study (Duñabeitia et al., 2018). Based on the 2022 study, not all included 422 items of the Polish-German item list had a name agreement of 80% for Polish. Of all 422 items, Duñabeitia et al. (2022) translated 13 pictures differently to the native speaker in this study. Since data collection and analysis were completed, we continued our work with our translation. The name agreement data

Item lists included 331 to 422 items per list depending on the item pool of the respective language combination. Every item list was divided into two item sets with three subsets each (Item set 1: Subset 1a, Subset 1b, Subset 1c; Item set 2: Subset 2a, Subset 2b, Subset 2c). All subsets were consistent of 55 to 71 items. Three subsets per item set allowed all participants having a break between different subsets. The order of items in each subset was quasi-randomised. After randomisation, all item lists were checked and controlled for subsequent items that were either semantically related, had the same onset or, in the case of noun compounds, included the same word form. Items to which one or more of these factors applied to were distributed more evenly to avoid priming or interference effects. Lists were controlled for both languages. Table 2 summarises the final item lists with the number of items for the different language combinations. For a detailed list of all included items per language and language combination see Appendix A.

Table 2

Number of Included Items per Language Combination

Language-combination	Item lists (n)	Item sets	Subsets (n)
Dutch-German	347 each language	Set 1: Dutch	1a (n=58), 1b (n=58), 1c (n=58)
		Set 2: Dutch	2a (n=58), 2b (n=58), 2c (n=57)
		Set 1: German	1a (n=58), 1b (n=58), 1c (n=58)
		Set 2: German	2a (n=58), 2b (n=58), 2c (n=57)
Polish-German[a]	422[a] each language	Set 1: Polish	1a (n=71), 1b (n=71), 1c (n=70)
		Set 2: Polish	2a (n=70), 2b (n=70), 2c (n=70)
		Set 1: German	1a (n=71), 1b (n=71), 1c (n=70)
		Set 2: German	2a (n=70), 2b (n=70), 2c (n=70)
English-German	331 each language	Set 1: English	1a (n=55), 1b (n=55), 1c (n=55)
		Set 2: English	2a (n=56), 2b (n=55), 2c (n=55)
		Set 1: German	1a (n=55), 1b (n=55), 1c (n=55)
		Set 2: German	2a (n=56), 2b (n=55), 2c (n=55)
English-Italian	356 each language	Set 1: English	1a (n=60), 1b (n=59), 1c (n=60)
		Set 2: English	2a (n=59), 2b (n=59), 2c (n=59)

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of the 13 items translated differently are therefore not included in the final Polish item list of this study. For more details see Appendix A.

		Set 1: Italian	1a (n=60), 1b (n=59), 1c (n=60)
		Set 2: Italian	2a (n=59), 2b (n=59), 2c (n=59)
English-French	365 each language	Set 1: English	1a (n=61), 1b (n=61), 1c (n=60)
		Set 2: English	2a (n=61), 2b (n=61), 2c (n=61)
		Set 1: French	1a (n=61), 1b (n=61), 1c (n=60)
		Set 2: French	2a (n=61), 2b (n=61), 2c (n=61)

[a] German item list for both languages, name agreement data for Polish was not available with the start of the project using the MultiPic database (Duñabeitia et al., 2018).

For all items, we retrieved a set of lexical variables defined by Alario et al., (2004), that have been found to influence picture naming (spoken word form frequency, syllable length, phoneme length, age of acquisition, familiarity, imageability, visual complexity)[5]. *Spoken word form frequency* is defined as a measure of occurrence of use of an individual item and influences word retrieval and the rate of phonological encoding in spoken picture naming. *Syllable length* is defined as the number of syllables a is word composed of. The lexical variable *phoneme length* describes the number of phonemes an item consists of and *age of acquisition* is a variable that describes when a word is acquired in the general population. Both lexical variables have an influence on word retrieval and the rate of phonological encoding in spoken picture naming. *Familiarity* refers to the familiarity of the concept presented. The more familiar a concept is the faster the naming time is. *Imageability* indicates how easily a person can form an associated mental image to a given word; it influences storage and processing of words in the mental lexicon and the speed of picture naming. *Visual complexity* quantifies the amount of detail in a given image. Values for all lexical variables obtained from different sources per language (see Table 3). For a detailed information on lexical variables per item see Appendix A.

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[5] It is acknowledged that the measures of spoken word form frequency, age of acquisition, and familiarity are not as accurate for bilingual speakers as for monolingual speakers.

Table 3

References of Lexical Variables per Language

Lexical variables	Sources lexical variables per language					
	Dutch	German	Polish	English	Italian	French
Spoken word form frequency	Keuleers et al., 2010	Brysbaert et al., 2011	Mandera et al., 2015	van Heuven et al., 2014	Crepaldi et al., 2015	Desrochers & Thompson, 2009
Syllable length	Nederlands woordenboek, n.d.	Martin-Luther-Universität Halle-Wittenberg, n.d.	Wikisłownik, 2023	Wilson, 1988	Olivetti, n.d.	Lexique - Boris New & Christophe Pallier, n.d.
Phoneme length	Nederlands woordenboek, n.d.	Martin-Luther-Universität Halle-Wittenberg, n.d.	Wikisłownik, 2023	WordReference.com, n.d.	Olivetti, n.d.	Le Dictionnaire, n.d.
Age of acquisition	Brysbaert et al., 2014	Birchenough et al., 2017	Imbir, 2016	Johnston et al., 2010	Montefinese et al., 2019	Alario & Ferrand, 1999
Familiarity	Shao & Stiegert, 2016	Schröder et al., 2012	Duñabeitia et al., 2022 [a]	Johnston et al., 2010	Montefinese et al., 2014	Alario & Ferrand, 1999
Imageability	Shao & Stiegert, 2016	Võ et al., 2009	Imbir, 2016	Scott et al., 2019	Montefinese et al., 2014	Desrochers & Thompson, 2009
Visual complexity	Duñabeitia et al., 2018	Duñabeitia et al., 2018	Duñabeitia et al., 2018[b]	Duñabeitia et al., 2018	Duñabeitia et al., 2018	Duñabeitia et al., 2018

Note. Number of phonemes was collected by the International Phonetic Alphabet (IPA).

[a] = The native speaker in this study translated 13 out of the 422 items differently to Duñabeitia et al. (2022). We continued our work with our translation since data collection and analysis were already completed. The familiarity values for these 13 items are, therefore, not included in the final Polish item list. For more details see Appendix A.

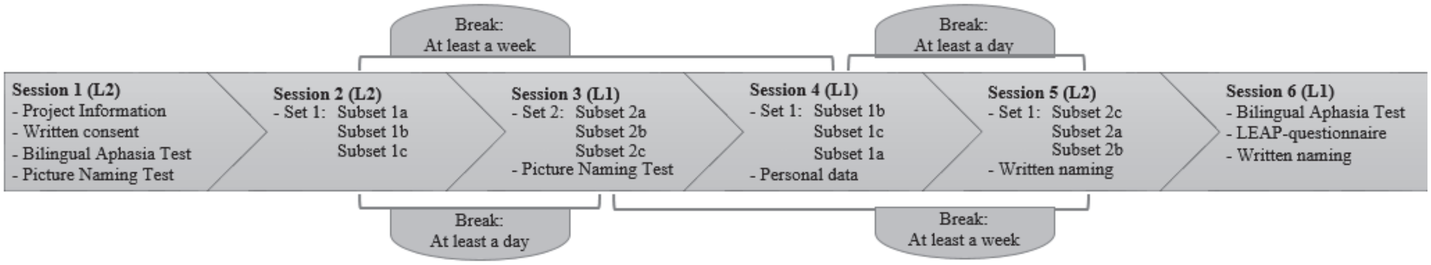
[b] = Visual complexity norms were not available for Polish. Visual complexity values of the German items were taken. This approach was acceptable since the visual complexity values showed a high cross-linguistic correlation ($r > 0.90$) and can therefore be applied to Polish (Duñabeitia et al., 2022).

Procedure

Each bilingual participant was tested at least six times with each session lasting around 60 to 90 minutes. Sessions were scheduled over a period of at least three weeks ensuring that at least one day break was incorporated between naming sessions in the same language (but different items). Naming sessions with the same item set but different languages were scheduled with a break of at least a week to avoid priming effects. Figure 2 provides an overview of the study procedure.

Figure 2

Procedure Bilingual Speakers with Aphasia When Starting the Study in L2



Note. The figure is an example of a study procedure starting in a participant's L2. If the study started in a participant's L1, the following session were accordingly adjusted.
L1 = First language, L2 = Second language.

The Bilingual Aphasia Test and Picture Naming Test was administered in the participants' second language in session one. The picture-naming task in both languages was undertaken across four sessions. Separate testing sessions for the two different languages per participant were scheduled to maintain 'language mode' for a language and minimise the need for switching between languages. Session two (Item set 1) and session five (Item set 2) consisted of the experimental picture naming task in the participant's second language, while session three (Item set 1) and session four (Item set 2) consisted of the experimental picture naming task in the individual's first language (either English, Dutch, Polish, or French, depending on the individual participant). Subsets of Item set 1 and Item set 2 were presented in an alternate order in session four and session five to minimise order effects. Additionally, the experimental picture naming task was followed by a picture naming test in the first language (session three), the collection of demographic and medical data (session four) and the written naming task[6] for the second language (session five). The last session consisted of the Bilingual Aphasia Test[7] in the participant's first language. Additionally, the written naming task (administered in the participant's first language) and the LEAP-Q (to capture the participants bilingual language profile) were conducted in the last session. Due to onset of fatigue and/or language impairment and/or level of task tolerance, four bilingual speakers

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[6] To control for potential priming or repetition effects, written naming was always administered after the experimental task with a break of at least a day/eight days from the administration of the experimental task (see Figure 2).

[7] For BwA2 and BwA5, an informal language broker training was provided to a family member, who delivered the Bilingual Aphasia Test to the participant, (with the researcher present) since the examiner did not speak Polish nor Italian. The examiners were proficient in all other assessed languages (Dutch, German, English, French).

with aphasia (BwA2, BwA4, BwA5, BwA7) received a modified procedure: Session six was split into two sessions for BwA2, BwA4, and BwA7. The picture naming task for Italian was spread over three and not two sessions for BwA5 (session 2: Subset 2a and Subset 2b, session 3: Subset 2c and Subset 1a, session 6: Subset 1c and Subset 1b).

During the picture naming task, items were presented on a laptop using the software DMDX (Forster & Forster, 2003). Instructions for the picture-naming task were given verbally by the researcher, and additionally presented on the screen. Bilingual participants were provided with instructions on the screen in the target language. All participants were asked to name the picture with one single word, as quickly and as accurately as possible in the target language. Each subset started with five practice items[8] to name. Each trial started with a fixation cross in the centre of the screen for 250ms. Target pictures then appeared in the centre of the screen and audio recording started upon appearance of the picture. The examiner used the keyboard to stop the audio recording and to move to the next picture. Pictures were removed from the screen as soon as the participant named the picture or gave a sign to proceed to the next picture. The division of an item set into three subsets allowed for a break of five to ten minutes between the subsets. Naming of one subset took approximately ten to 20 minutes for completion.

Data Analysis

DMDX created a WAV-audio file for every spoken response to each item. These audio files were used to transcribe and code all responses as correct or incorrect. Incorrect responses were assigned a further error code to describe the error type (see General Appendix F and further explanation below). A transcription and error coding guideline was developed. All examiners being involved in transcription and error coding received a transcription and error coding training, followed by a second training session after the transcription and coding of the first item set. Transcription and error coding was realised by either a native or a highly proficient speaker of the given language. Upcoming difficulties with the transcription and/or error coding were discussed with a second examiner. Unresolved issues with either a transcription or error coding were further presented to a third or fourth person until agreement was reached.

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[8] Items were taken from MultiPic and were not included in the item list of the experimental task since they had a name agreement of 79% or less.

The first complete given attempt within ten seconds after the onset of the item was coded as correct or incorrect[9]. A first complete attempt was defined as followed: A minimal consonant-vowel response or vowel-consonant response (schwa was not considered a vowel) that was not self-interrupted and had a downward/upward intonation or had level intonation but was followed by a noticeable pause (one second). Attempts that were a minimal vowel-consonant response or consonant-vowel responses (schwa was not considered a vowel) that were self-interrupted or directly followed by a further utterance were defined as fragment and not coded as an attempt. Participants were allowed dialect and accent patterns, filler words (e.g., *uhm*) and automatism (e.g., *oh god*) without penalisation. If a determiner was given before the target, the determiner was not coded. The following response variations were allowed without penalisation: Addition of prepositional phrase (e.g., target *can*, response *can of peas*), addition of modifier (e.g., target *bone*, response *dog's bone*), addition of type of X whereas X is the target (target *banana*, response *type of banana*), negation of the target (e.g., target *banana*, response *not a banana*). A response with a modifier component that resulted in a compound word was coded as acceptable alternative.

Incorrect responses were assigned with a further error code to define the error type in the target or non-target language. (e.g., semantic error in the target language: Target *dog*, response *cat*; semantic error in the non-target language: Target *dog*, response *Katze* [non-target language [German] word for *cat*]). The following error types were coded to define incorrect responses in the target or non-target language:

- Phonological error (e.g., target language: Target *horse*, response *lorse*; non-target language: Target *horse*, response *Pfefd* [substitution in the non-target language [German] target *Pferd*).
- Phonologically unrelated non-word (e.g., target language: Target *bed*, response *ucsenchail*; non-target language: Target *bed*, response *ülänak* [German non-word]).
- Semantic error (e.g., target language: Target *dog*, repones *cat*; non-target language: Target *dog*, response *Katze* [non-target language [German] word for *cat*]).
- Semantically unrelated error (e.g., target language: Target *airplane*, response *kitchen*; non-target language: Target *airplane*, response *Küche* [German equivalent to *kitchen*]).

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[9] All secondary responses were also transcribed and coded for further analyses. However, the secondary response transcription and coding is not part of the current analysis.

- Semantically unrelated non-word (e.g., target language: Target *chair,* response *eeggarden*; non-target language: Target *chair,* response *Eiergarten* [German equivalent to *eeggarden,* which is not common in the standard German language]).
- Semantic-then-phonological error (e.g., target language: Target *apple*, response *banuna*; non-target language: target *apple*, response *Bänane* [phonological error of *Banane,* the German equivalent to *banana]*).
- Mixed error (e.g., target language: Target *strawberries*, response *cherries*; non-target language: target *rice*, response *Fleisch* [German word for meat]).
- Morphological error (e.g., target language: target *book*, response *books*; non-target language: target *book*, response *Bücher* [German equivalent to *books*]).
- Unspecified error (e.g., target language: Target *fireman*, response *fire*: non-target language: Target *fireman*, response *Feuer* [German equivalent to *fire*).
- Multiword circumlocution (e.g., target language: target *spoon*, response *to eat a soup*). non-target language: target *spoon*, response *um eine Suppe zu essen* [German equivalent to *to eat a soup*]).
- Single-word circumlocution (e.g., target language: target *sandwich*, response *eating*), non-target language: target *sandwich*, response *essen* [German equivalent to *eating*]),
- Visual error (e.g., target language: target *bow*, response *harp*). non-target language: target *bow*, response *Harfe* [German equivalent to *harp*]).
- Acceptable alternative (e.g., target language: target *sink*, response *basin*) non-target language: target *fruit*, response *Obst* [German equivalent is *Fruechte*, *Obst* is an acceptable alternative/synonym])
- Use-of-language error (e.g., target language: target *dog*, response *doggy*). non-target language: target *dog*, response *Huendchen* [German equivalent to *doggy]*).
- Other error (e.g., target language: target *beanie*, response *starts with a B*), non-target language: target *beanie*, response *beginnt mit einem B* [German equivalent to *starts with a B*),

For a definition of the error types with further examples for the target and non-target language see General Appendix F. Additionally to the existing error types that could appear in either the target or non-target language (described above), four further error types were added:

- No response
- Correct in non-target language (e.g., target *chair*, response *Stuhl* [German equivalent to *chair*]).

- Language mixing error (e.g., target language: target *pear*, response *pearne* [language mixing of the target *pear* and the German equivalent *Birne*],
- Back-translation error (e.g., target language: non-target language: (e.g., target *medusa* [French for *jellyfish*], response *poisson de gellée* [literal back-translation into French of the English translation equivalent *jellyfish*].

For a definition with further examples of these four error types see General Appendix F[10]. For response examples per error type for each bilingual speaker with aphasia see general Appendix G.

McNemar's Test and Fisher's Exact Test. The transcription and coding of all responses was followed by accuracy distribution analysis across languages for each participant by running a McNemar's Test. In a next step, error types were analysed across target language, non-target language, and language mixing, always in both languages for each participant. After that, we analysed the incorrect responses based on developed guide for error types (see General Appendix F). Most common reported error types, including phonological errors, semantic errors, no responses and correct in non-target language responses (e.g., Roberts & Deslauriers, 1999) where furthermore extracted within each language and the distribution was compared across languages for each participant. We used Fisher's Exact Test to analyse the distribution of theses error types across languages in each participant.

Binomial Logistic Regression Analysis. Logistic regression analyses were carried out and preceded by correlational analysis using the analysis software jamovi (The jamovi project, n.d.). Analyses were performed for each bilingual participant for each of their languages to examine the influence of linguistic factors (frequency, number of phonemes, number of syllables, age of acquisition, familiarity, imageability, visual complexity) on accuracy of their naming responses. These analyses were carried out to examine how these factors influence accuracy in general, and to capture how they vary across the participant factors (in our context: language dominance, and age-of-acquisition).

Multicollinearity. Before conducting the binomial logistic regression analysis, we examined the extent of multicollinearity (cut-off: r > .7) (Field, 2013) between the

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[10] After coding an incorrect response with an error type, the coding guideline allowed for a second error code – when applicable – to specify the error type (e.g., target *bone,* response *bune*, coded as a phonological error with a second code specifying the phonological error as phonologically related non-word) or to specify an incorrect response holding two error types (e.g., target *book*, response *bools*, the response was coded as a morphological error with a phonological error [second code]). However, this second error code is not part of the analysis of this study.

psycholinguistic variables (frequency, number of phonemes, number of syllables, age of acquisition, familiarity, imageability, and visual complexity). Pearson's r correlation matrix indicated a high level of multicollinearity between the word length variables, number of phonemes and number of syllables for all languages ($r > .781$). Additionally, familiarity and frequency were highly correlated for French ($r = .831$). We decided to exclude the predictors number of syllables and frequency from the analyses to minimize potentially problematic levels of multicollinearity[11]. All remaining intercorrelations between variables were $r <$ (-).641 or less. In addition, multicollinearity was monitored using the variance inflation factor (VIF). Depending on the author, a VIF above 2.5 (Allison, 2012) or 5 (Hutcheson, 1999) can be a sign of problematic multicollinearity. Across all analyses, the VIFs of the included psycholinguistic variables (number of phonemes, age of acquisition, familiarity, imageability, visual complexity) had a value of 2.44 or less. The outcome of the correlation matrixes and VIF results are in Appendix B to Appendix I.

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[11] Both phonemes and syllables can be considered measures of word length, and familiarity and frequency are measures of frequency (Nickels & Howard, 1995).

Results

Data on Accuracy and Error Types of all Bilingual Speakers with Aphasia

Accuracy: All Bilingual Speakers with Aphasia

Across Language Accuracy. Table 4 summarises the naming data from all bilingual speakers with aphasia. Seven participants (BwA1, BwA2, BwA3, BwA4, BwA5[12], BwA6, BwA8) displayed a significant difference in their naming accuracy across languages. Six of these seven participants (BwA1, BwA2[13], BwA3, BwA4, BwA5, BwA6, BwA8) showed significantly higher naming accuracy in their dominant language, regardless of whether the dominant language was their first or second language. BwA7 was the only participant (for whom statistics were possible) not to show a significant difference in naming accuracy across his languages, French and English.

Factors Affecting L1 Accuracy. Table 5 summarises the results of the binomial logistic regression model examining predictors of L1 naming accuracy for all participants. Of all the variables entered into the regression model, three variables significantly predicted picture naming accuracy in the participants' L1: Word length (number of phonemes) (BwA2: p = .010), imageability (BwA5: p = .029, BwA7: p = .028) and age of acquisition (BwA6: p = .021, BwA8: p < .001). Higher accuracy was found for shorter words, for words that were acquired early in life, and for words that had a high imageability.

Factors Affecting L2 Accuracy. Of all the variables entered into the regression model, two variables significantly predicted picture naming accuracy in the participants' L2: age of acquisition (BwA1: p = .030, BwA6: p < .001) and imageability (BwA4: p = .016, BwA7: p = .044). Higher accuracy was found for shorter words and for words that had a high imageability.

Error types: All Bilingual Speakers with Aphasia

Each participant's incorrect overt responses were classified by error category: Target language errors, non-target language errors (all) and language mixing errors. Analysis for the non-target language errors resulted in significantly more non-target language naming errors in the non-dominant language in five participants (BwA1, BwA3, BwA4, BwA5, BwA6); see

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[12] BwA5 experienced severe naming difficulties in Italian with naming accuracy of 0% (0/356). To obtain an estimated p-value (McNemar's Test) of naming accuracy across languages, one single Italian error-response was transferred to correct.

[13] BwA2 showed significantly higher naming accuracy in his first language, Polish. It needs to be mentioned that the dominance of the participant's languages was equally distributed/balanced across the participant's L1 (Polish) and L2 (German).

Table 4. This was regardless of whether the non-dominant language was the participant's first language or second language. BwA2 showed significantly more non-target language errors in his L1 Polish, while it is important to mention, that the dominance of the participant's languages was equally distributed/balanced across the participant's L1 (Polish) and L2 (German). BwA7 and BwA8 both displayed no evidence for a difference in the proportions of the non-target language errors category versus other error categories across their languages.

All incorrect responses were further classified by error type. Appendix B to Appendix I present all errors specified by error type per participant. Table 4 features the results of the most common error types produced by bilingual speakers with aphasia (phonological errors in target language, semantic errors in target language, no responses in target language, and correct in non-target language responses) across all bilingual participants in this study. The analysis (Fisher's Exact test, two-tailed: Error type/all other errors [L1] vs error type/all other errors [L2]) of phonological errors, semantic errors, no responses, and correct in non-target language responses across languages within each participant, showed significant differences across languages in proportions of at least one error type for seven participants (see Table 4 for p-values, BwA1: Phonological errors and correct in non-target language responses, BwA2: Phonological and semantic errors, BwA3: Phonological errors and correct in non-target language responses, BwA4: Phonological and semantic errors and correct in non-target language responses, BwA5: Semantic errors and correct in non-target language responses, BwA6: No responses, BwA8: No responses). BwA7 was the only participant showing no evidence of a difference in cross-language error rates for all error types. Important to note, five participants (BwA1, BwA3, BwA6, BwA7, BwA8) showed no evidence for a difference in the distribution of semantic errors across languages.

Table 4

Summary Naming Data with Cross-Linguistic Comparisons for all Bilingual Speakers with Aphasia

							Error types														
				Accuracy			All non-target language errors			Phonological			Semantic			No response			Correct non-target language		
ID	Language profile		N items	N items correct	% correct	L1vs L2[d] p(2tailed)	N total errors	% errors	L1vs L2[e] p(2tailed)	N total errors	% errors	L1vs L2[e] p(2tailed)	N total errors	% errors	L1vs L2[e] p(2tailed)	N total errors	% errors	L1vs L2[e] p(2tailed)	N total errors	% errors	L1vs L2[e] p(2tailed)
BwA1	L1	DUT	347	142	40.92	<.001*	81	39.51	<.001*	6	2.93	.026*	36	17.56	.211	43	20.98	.169	46	22.44	.006*
	L2	GER[a]	347	203	58.50		18	12.50		13	9.03		34	23.61		21	14.58		15	10.42	
BwA2	L1	POL[a]	422	285	67.54	<.001*	16	11.68	.047*	5	3.65	.012*	57	41.61	<.001*	14	10.22	.101	11	8.03	.272
	L2	GER[a]	422	168	39.81		14	5.51		30	11.81		59	23.23		43	16.93		12	4.72	
BwA3	L1	DUT	347	186	53.60	.041*	31	19.25	<.001*	4	2.48	<.001*	29	18.01	1	21	13.04	.313	24	14.91	<.001*
	L2	GER[a]	347	209	60.23		4	2.90		33	23.91		24	17.39		12	8.70		2	1.45	
BwA4	L1	ENG[a]	331	265	80.06	<.001*	3	4.55	.003*	2	3.03	.018*	21	31.82	.008*	14	21.21	.212	2	3.03	.018*
	L2	GER	331	195	58.91		30	22.06		21	15.44		20	14.71		18	13.24		21	15.44	
BwA5	L1[b]	ENG[a]	356	72	20.22	<.001*[c]	0	0	<.001*	5	1.76	.130	33	11.62	<.001*	123	43.31	.407	0	0	<.001*
	L1[b]	ITA	356	0	0		186	52.25		1	0.28		0	0		167	46.91		65	18.26	
BwA6	L1	ENG[a]	365	314	86.03	<.001*	4	7.84	.008*	2	3.92	.161	7	13.73	.727	4	7.84	.052*	4	7.84	.086
	L2	FRE	365	189	51.78		47	26.70		21	11.93		30	17.05		37	21.023		34	19.32	
BwA7	L1	FRE	365	254	69.59	.409	7	6.31	.396	3	2.70	1	25	22.52	1	35	31.53	.305	4	3.60	1
	L2	ENG[a]	365	262	71.78		3	2.91		2	1.94		23	22.33		25	24.27		3	2.91	
BwA8	L1	FRE	365	240	65.75	<.001*	12	9.60	.133	19	15.20	.748	13	10.40	.119	46	36.80	.002*	9	7.20	.329
	L2	ENG[a]	365	293	80.27		2	2.78		13	18.06		14	19.44		11	15.28		2	2.78	

Note. DUT = Dutch, GER = German, POL = Polish, ENG = English, ITA = Italian, FRE = French.

[a] Dominant language.

[b] Early parallel bilingual speaker, both languages (English and Italian) are L1.

[c] BwA5 experienced severe naming difficulties in Italian with naming accuracy of 0% (0/356). One single Italian error response was transferred to correct to obtain an estimated p-value (McNemar's Test) of naming accuracy across languages.

[d] McNemar's Test, two-tailed.

[e] Fisher's Exact Test, two-tailed; the comparison was always the following: Error type/all other errors (L1) vs error type/all other errors (L2).

Table 5

Summary Data of the Logistic Regression Analysis of all Bilingual Speakers with Aphasia

							Significance of Model Coefficients (p value) Predictors (Psycholinguistic variables)				
Participant and language profile			Language dominance	Model test	R^2_{CS}	R^2_N	Phonemes	Age of acquisition	Familiarity	Imageability	Visual complexity
BwA1	L1	DUT	L2	$\chi^2(5)=7.94$, p=.160	.058	.077	.688	.059	.735	.600	.813
	L2	GER[a]		$\chi^2(5)=15.1$, p=.010*	.220	.317	.786	.030*	.662	.930	.177
BwA2	L1	POL[a]	L1/L2	$\chi^2(5)=19.9$, p=.001*	.073	.104	.010*	.999	.055	.144	.496
	L2	GER[a]		$\chi^2(5)=3.79$, p=.580	.050	.067	.356	.985	.171	.843	.917
BwA3	L1	DUT	L2	$\chi^2(5)=6.78$, p=.238	.049	.068	.546	.260	.362	.985	.977
	L2	GER[a]		$\chi^2(5)=2.40$, p=.792	.039	.056	.798	.754	.464	.348	.508
BwA4	L1	ENG[a]	L1	$\chi^2(5)=1.16$, p=.949	.006	.011	.575	.671	.989	.766	.887
	L2	GER		$\chi^2(5)=8.00$, p=.156	.131	.178	.464	.850	.992	.016*	.580
BwA5	L1	ENG[a]	ENG	$\chi^2(5)=15.4$, p=.009*	.073	.107	.242	.153	.947	.029*	.874
	L1	ITA						n/a[b]			
BwA6	L1	ENG[a]	L1	$\chi^2(5)=6.34$, p=.274	.030	.066	.372	.021*	.454	.956	.493
	L2	FRE		$\chi^2(5)=37.3$, p<.001*	.231	.317	.760	<.001*	.403	.616	.229
BwA7	L1	FRE	L2	$\chi^2(5)=15.7$, p=.008*	.105	.173	.563	.089	.356	.028*	.214
	L2	ENG[a]		$\chi^2(5)=6.45$, p=.265	.031	.053	.714	.974	.476	.044*	.419
BwA8	L1	FRE	L2	$\chi^2(5)=28.1$, p<.001*	.179	.257	.837	<.001*	.077	.496	.495
	L2	ENG[a]		$\chi^2(5)=13.8$, p=.017*	.065	.108	.164	.070	.910	.669	.580

Note. DUT = Dutch, GER = German, POL = Polish, ENG = English, ITA = Italian, FRE = French, R^2_{CS} = Cox and Snell's R^2, R^2_N = Nagelkerke's.

[a] Dominant language.

[b] BwA5 experienced severe naming difficulties in Italian with naming accuracy of 0% (0/356). Therefore, a logistic regression analysis was not possible to run for the participant's non-dominant L1.

Data on Accuracy and Error Types of Individual Participants: BwA1

Accuracy: BwA1

Across Language Accuracy: BwA1. BwA1 showed significantly higher naming accuracy for German (58.50%), her dominant L2, than Dutch (40.92%; McNemar's Test Exact, two-tailed: p < .001).

Factors Affecting L1 Accuracy: BwA1. The binomial logistic regression model examining predictors of accuracy in L1 was not statistically significant, $\chi^2(df = 5) = 7.94$, p = .160, Cox and Snell's $R^2 = .058$, Nagelkerke's $R^2 = .077$. The overall percentage of accuracy in classification was 61.9% (cut-off < 50%). No variable significantly predicted BwA1's picture naming in Dutch, her non-dominant L1. Full details of the analysis can be found in Appendix B.

Factors Affecting L2 Accuracy: BwA1. The model was statistically significant, $\chi^2(df = 5) = 15.1$, p = .010, Cox and Snell's $R^2 = .220$, Nagelkerke's $R^2 = .317$, with 80.3% of responses classified correctly. Only Age of acquisition (p = .030, OR = 0.238, 95%-CI[0.065, 0.867]) significantly predicted L2 accuracy, while the other psycholinguistic variables showed no significant effect (see Appendix B).

Error Types: BwA1

Table 6 lists the distribution of error rates across target language, non-target language, and language mixing for BwA1 in Dutch (L1) and German (L2). BwA1 showed significantly more non-target language errors when naming pictures in Dutch (relative to naming in German), the participant's non-dominant L1 (Fisher's Exact Test, two-tailed: p < .001).

Table 6

Distribution of Errors Across Error Categories (Target Language Errors, Non-Target Language Errors, and Language Mixing Errors) for BwA1 in Dutch (L1) and German (L2)

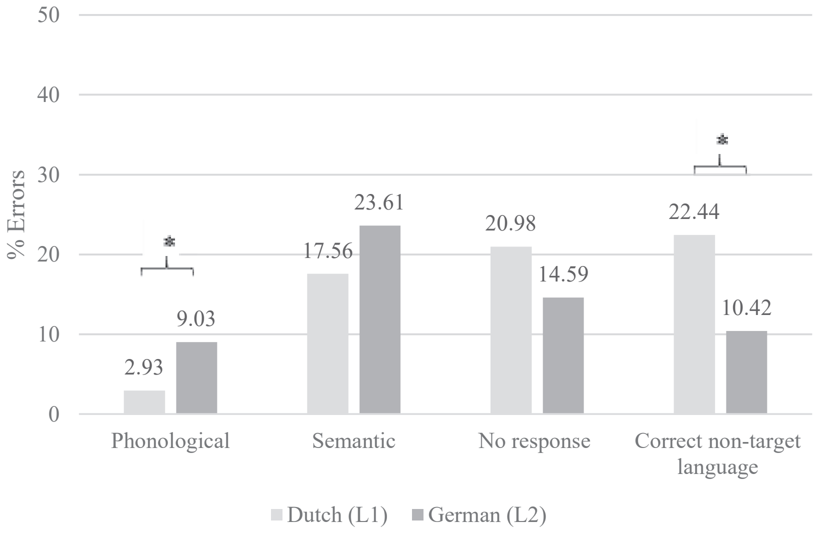
Errors across error categories	Dutch (L1)	German (L2)
Number of errors (n)	205	144
Errors: Target language		
Number of errors in target language (n)	116	118
% of target language errors	56.59	81.94
Errors: Non-target language		
Number of errors in non-target language (n)	81	18
% of non-target language errors	39.51	12.50
Errors: Language mixing		

Number of language mixing errors (n)	8	8
% of language mixing errors	3.90	5.56

Appendix B presents in detail all error types that arose during both Dutch and German picture naming. Figure 3 visualises the most common error types produced by bilingual participants with aphasia (phonological errors, semantic errors, no responses, correct in non-target language errors for BwA1. The analysis for the distribution of error types revealed differences across languages: BwA1 showed a significantly different error rate for phonological errors and correct in non-target language responses across languages (Fisher's Exact Test, two-tailed: Phonological errors, p = .026; correct in non-target language responses, p = .006). Semantic errors and no responses were not significantly different across languages for BwA1 (Fisher's Exact Test, two-tailed: semantic errors, p = .211; no responses, p = .169).

Figure 3

Distribution of Error Types (Phonological Errors, Semantic Errors, No Responses, Correct in Non-Target Language Responses) for Dutch (L1) and German (L2) for BwA1



Note. Fisher's Exact Test, two-tailed: Phonological errors, p = .026*; semantic errors, p = .211; no responses, p = .169; correct in non-target language responses, p = .006*.

Data on Accuracy and Error Types of Individual Participants: BwA2

Accuracy: BwA2

Across Language Accuracy: BwA2. The participant showed significantly higher naming accuracy for Polish (67.54%) than German (39.81%; McNemar's Test Exact, two-tailed: p < .001). The dominance of the participant's languages was equally distributed/balanced across the participant's L1 (Polish) and L2 (German).

Factors Affecting L1 Accuracy: BwA2. The binomial logistic regression model examining predictors of accuracy in L1 was statistically significant, $\chi^2(df = 5) = 19.9$, p = .001, Cox and Snell's $R^2 = .073$, Nagelkerke's $R^2 = .104$. The overall percentage of accuracy in classification was 71.0% (cut-off < 50%). The predictor word length (number of phonemes) (p = .010, OR = 0.855, 95%-CI[0.758, 0.963]) significantly predicted L1 accuracy, while the other psycholinguistic variables showed no significant effect (see Appendix C).

Factors Affecting L2 Accuracy: BwA2. The model was not statistically significant, $\chi^2(df = 5) = 3.79$, p = .580, Cox and Snell's $R^2 = .050$, Nagelkerke's $R^2 = .067$, with 55.4% of responses classified correctly. No variable significantly predicted BwA2's picture naming in German, his L2. Full details of the analysis can be found in Appendix C.

Error Types: BwA2

Table 7 provides the distribution of rates across target language errors, non-target language errors, and language mixing errors for Polish (L1) and German (L2). Analyse across the error categories described significantly more non-target language errors in Polish (relatively to German), BwA2's L1 (Fisher's Exact Test, two-tailed: p = .047).

Table 7

Distribution of Errors Across Error Categories (Target Language Errors, Non-Target Language Errors, and Language Mixing Errors) for BwA2 in Polish (L1) and German (L2)

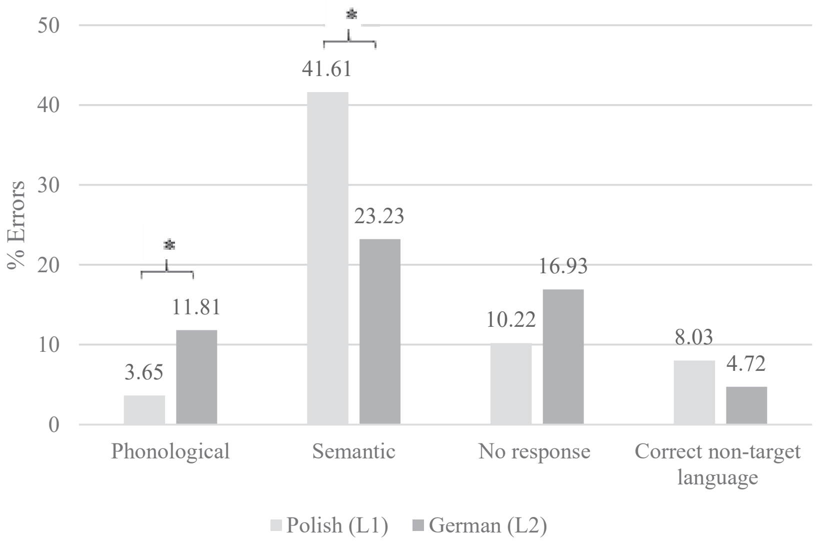
Errors across error categories	Polish (L1)	German (L2)
Number of errors (n)	137	254
Errors: Target language		
Number of errors in target language (n)	121	240
% of target language errors	88.32	94.49
Errors: Non-target language		
Number of errors in non-target language (n)	16	14
% of non-target language errors	11.68	5.51

Errors: Language mixing		
Number of language mixing errors (n)	0	0
% of language mixing errors	0	0

Appendix C lists the various error types that appeared during both Polish and German picture naming in BwA2. Figure 4 features the most common error types produced by bilingual participants with aphasia (phonological errors, semantic errors, no responses, correct in non-target language errors for BwA2. The distribution of phonological errors and semantic errors was significantly different across BwA2's languages (Fisher's Exact Test, two-tailed: Phonological errors, p = .012; semantic errors, p < .001). On the other hand, no responses and correct in non-target language responses were not significantly different across languages for BwA2 (Fisher's Exact Test, two-tailed: No responses, p = .101, correct in non-target language responses, p = .272).

Figure 4

Distribution of Error Types (Phonological Errors, Semantic Errors, No Responses, Correct in Non-Target Language Responses) for Polish (L1) and German (L2) for BwA2



Note. Fisher's Exact Test, two-tailed: Phonological errors, p = .012*; semantic errors, p < .001*; no responses, p = .101; correct in non-target language responses, p = .272.

Data on Accuracy and Error Types of Individual Participants: BwA3

Accuracy: BwA3

Across Language Accuracy: BwA3. The participant showed significantly higher naming accuracy for German (60.23%), BwA3's dominant L2, than Dutch (53.60%; McNemar's Test Exact, two-tailed: p = .041).

Factors Affecting L1 Accuracy: BwA3. The binomial logistic regression model examining predictors of accuracy in L1 was not statistically significant, $\chi^2(df = 5) = 6.78$, p = .238, Cox and Snell's $R^2 = .049$, Nagelkerke's $R^2 = .068$. The overall percentage of accuracy in classification was 63.4% (cut-off < 50%). No variable significantly predicted BwA3's picture naming in Dutch, his non-dominant L1. Full details of the analysis can be found in Appendix D.

Factors Affecting L2 Accuracy: BwA3. The model was not statistically significant, $\chi^2(df = 5) = 2.40$, p = .792, Cox and Snell's $R^2 = .039$, Nagelkerke's $R^2 = .056$, with 72.1% of responses classified correctly. No variable significantly predicted BwA3's picture naming in German, his dominant L2.

Error Types: BwA3

Table 8 provides BwA3's distribution of error rates across the target language, the non-target language, and language mixing errors for Dutch (L1) and German (L2). The participant presented significantly more non-target language errors when naming pictures in his non-dominant L1 Dutch (relatively to naming in German) (Fisher's Exact Test, two-tailed: p < .001).

Table 8

Distribution of Errors Across Error Categories (Target Language Errors, Non-Target Language Errors, and Language Mixing Errors) for BwA3 in Dutch (L1) and German (L2)

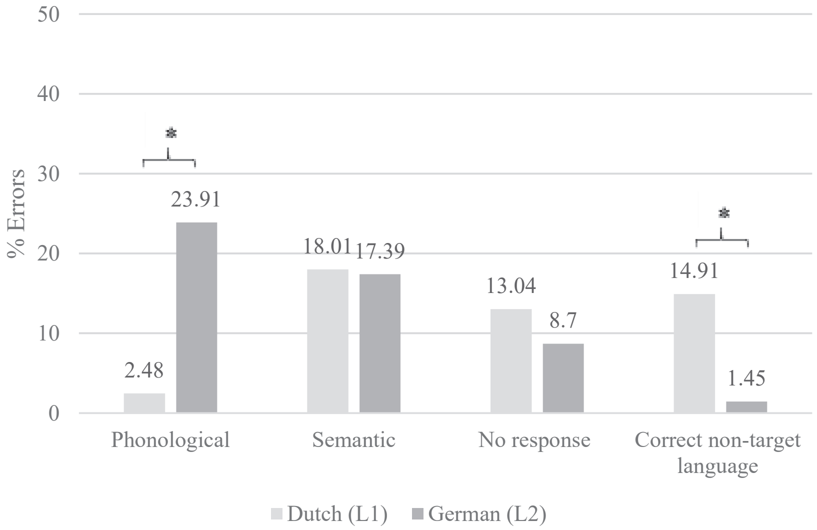
Errors across error categories	Dutch (L1)	German (L2)
Number of errors (n)	161	138
Errors: Target language		
Number of errors in target language (n)	120	126
% of target language errors	74.53	91.30
Errors: Non-target language		
Number of errors in non-target language (n)	31	4
% of non-target language errors	19.25	2.90
Errors: Language mixing		

Number of language mixing errors (n)	10	8
% of language mixing errors	6.21	5.80

Appendix D highlights all error types that occurred in both Dutch and German picture naming. Figures 5 shows the most common error types that are produced by bilingual individuals with aphasia (including phonological errors, semantic errors, no responses as well as correct in non-target language errors for BwA3. The analysis revealed a significant difference for the rate of phonological errors and correct in non-target language responses across languages (Fisher's Exact Test, two-tailed: Phonological errors, p < .001; correct in non-target language responses, p < .001). In contrast, the rate of semantic errors and no responses were not significantly different across languages for BwA3 (Fisher's Exact Test, two-tailed: Semantic errors, p = 1, no responses, p = .313).

Figure 5

Distribution of Error Types (Phonological Errors, Semantic Errors, No Responses, Correct in Non-Target Language Responses) for Dutch (L1) and German (L2) for BwA3



Note. Fisher's Exact Test, two-tailed: Phonological errors, p < .001*; semantic errors, p = 1; no responses, p = .313; correct in non-target language responses, p < .001*.

Data on Accuracy and Error Types of Individual Participants: BwA4

Accuracy: BwA4

Across Language Accuracy: BwA4. The participant showed significantly higher naming accuracy for English (80.06%), her dominant L1, than German (58.91%; McNemar's Test Exact, two-tailed: p < .001).

Factors Affecting L1 Accuracy: BwA4. The binomial logistic regression model examining predictors of accuracy in L1 was not statistically significant, χ^2(df = 5) = 1.16, p = .949, Cox and Snell's R^2 = .006, Nagelkerke's R^2 = .011. The overall percentage of accuracy in classification was 86.7% (cut-off < 50%). No variable significantly predicted BwA4's picture naming in English, her dominant L1. Full details of the analysis can be found in Appendix E.

Factors Affecting L2 Accuracy: BwA4. The model was not statistically significant, χ^2(df = 5) = 8.00, p = .156, Cox and Snell's R^2 = .131, Nagelkerke's R^2 = .178, with 66.7% of responses classified correctly. Only imageability (p = .016, OR = 14.128, 95%-CI[1.625, 122.829]) significantly predicted L2 accuracy, while the other psycholinguistic variables showed no significant effect (see Appendix E).

Error Types: BwA4

Table 9 details the distribution of error rates across the target language, the non-target language, and language mixing errors for BwA4 in English (L1) and German (L2). BwA4 showed significantly more non-target language errors when naming pictures in German (relatively to naming in English), the participant's non-dominant L2 (Fisher's Exact Test, two-tailed: p = .003).

Table 9

Distribution of Errors Across Error Categories (Target Language Errors, Non-Target Language Errors, and Language Mixing Errors) for BwA4 in English (L1) and German (L2)

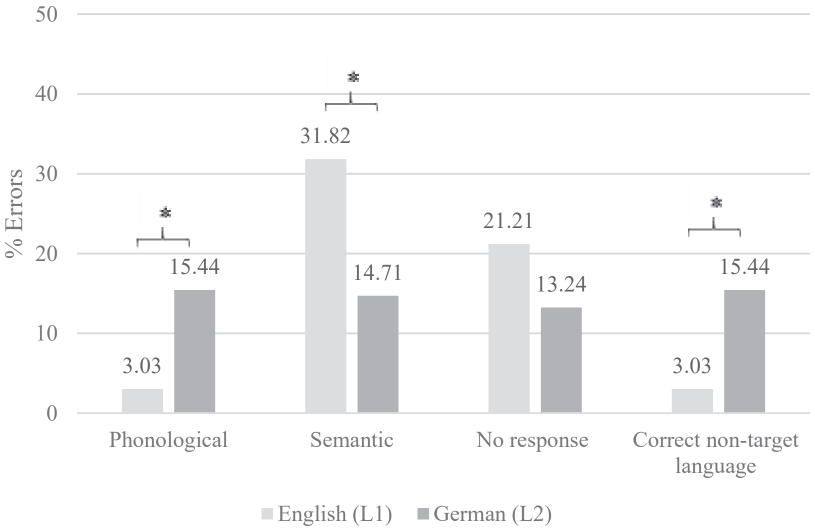
Errors across error categories	English (L1)	German (L2)
Number of errors (n)	66	136
Errors: Target language		
Number of errors in target language (n)	63	104
% of target language errors	95.45	76.47
Errors: Non-target language		
Number of errors in non-target language (n)	3	30
% of non-target language errors	4.55	22.06

Errors: Language mixing		
Number of language mixing errors (n)	0	2
% of language mixing errors	0	1.47

Appendix E presents in detail all error types that arose during both English and German picture naming. Figure 6 visualises the most common error types produced by bilingual participants with aphasia (phonological errors, semantic errors, no responses, correct in non-target language errors) for BwA4. The analysis for the distribution of error types devoted differences across languages: BwA4 showed a significant different rate for phonological errors, semantic errors and correct in non-target language responses (Fisher's Exact Test, two-tailed: Phonological errors, p = .018; semantic errors, p = .008; correct in non-target language responses, p = .018). The rate of no responses was not significantly different across languages for BwA4 (Fisher's Exact Test, two-tailed: No responses, p = .212).

Figure 6

Distribution of Error Types (Phonological Errors, Semantic Errors, No Responses, Correct in Non-Target Language Responses) for English (L1) and German (L2) for BwA4



Note. Fisher's Exact Test, two-tailed: Phonological errors, p = .018*; semantic errors, p = .008*; no responses, p = .212; correct in non-target language responses, p = .018*.

Data on Accuracy and Error Types of Individual Participants: BwA5

Accuracy: BwA5

Across Language Accuracy: BwA5. BwA5 showed significantly higher naming accuracy for English (20.22%), his dominant L1, than Italian (L1) (0%; McNemar's Test Exact, two-tailed: p < .001[14]).

Factors Affecting L1 (English) Accuracy: BwA5. The binomial logistic regression model examining predictors of accuracy in English (L1) was statistically significant, χ^2(df = 5) = 15.4, p = .009, Cox and Snell's R^2 = .073, Nagelkerke's R^2 = .107. The overall percentage of accuracy in classification was 72.3% (cut-off < 50%). The predictor imageability (p = .029, OR = 7.024, 95%-CI[1.218, 40.52]) significantly predicted English (L1) picture naming accuracy, while the other psycholinguistic variables showed no significant effect (see Appendix F).

Factors Affecting L1 (Italian) Accuracy: BwA5. BwA5 experienced severe naming difficulties in Italian with naming accuracy of 0% (0/356). Therefore, a logistic regression analysis was not possible to run for the participant's non-dominant L1.

Error Types: BwA5

Table 10 provides the distribution of error rates across target language, non-target language, and language mixing for English (L1) and Italian (L1). Analysis across the error categories described significantly more non-target language errors in Italian (relatively to English), BwA5's non-dominant L1 (Fisher's Exact Test, two-tailed: p < .001).

Table 10

Distribution of Errors Across Error Categories (Target Language Errors, Non-Target Language Errors, and Language Mixing Errors) for BwA5 in English (L1) and Italian (L1)

Errors across error categories	English (L1)	Italian (L1)
Number of errors (n)	284	356
Errors: Target language		
Number of errors in target language (n)	284	170
% of target language errors	100	47.75
Errors: Non-target language		
Number of errors in non-target language (n)	0	186

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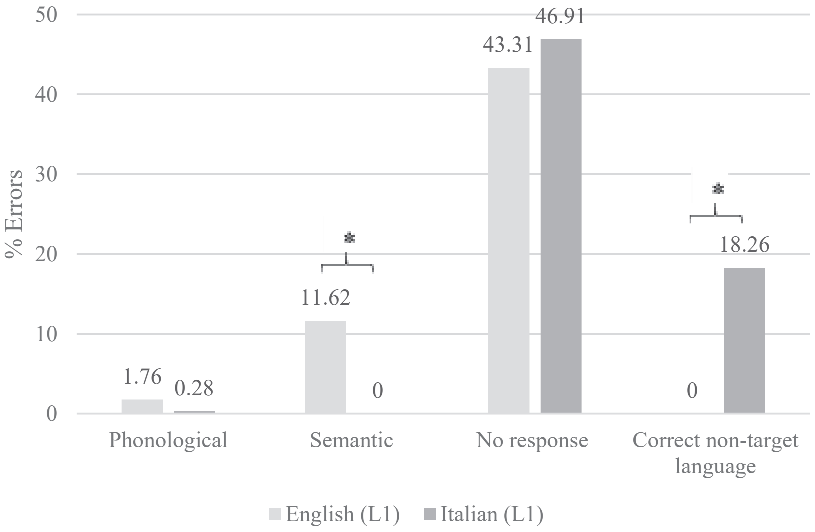
[14] BwA5 experienced severe naming difficulties in Italian with naming accuracy of 0% (0/356). To obtain an estimated p-value (McNemar's Test) of naming accuracy across languages, one single Italian error-response was transferred to correct.

% of non-target language errors	0	52.25
Errors: Language mixing		
Number of language mixing errors (n)	0	0
% of language mixing errors	0	0

Appendix F specifies the various error types that appeared during both English and Italian picture naming in BwA5. Figure 7 presents the most common error types produced by bilingual participants with aphasia (phonological errors, semantic errors, no responses, correct in non-target language errors) for BwA5. The distribution of error types was significantly different across languages for semantic errors and correct in non-target language responses (Fisher's Exact Test, two-tailed: Semantic errors, p < .001, correct in non-target language responses, p < .001). On the other hand, the rate of phonological errors and no responses was not significantly different across languages for BwA5 (Fisher's Exact Test, two-tailed: Phonological errors, p = .130; no responses, p = .407).

Figure 7

Distribution of Error Types (Phonological Errors, Semantic Errors, No Responses, Correct in Non-Target Language Responses) for English (L1) and Italian (L1) for BwA5



Note. Fisher's Exact Test, two-tailed: Phonological errors, p = .130; semantic errors, p < .001*; no responses, p = .407; correct in non-target language responses, p < .001*.

Data on Accuracy and Error Types of Individual Participants: BwA6

Accuracy: BwA6

Across Language Accuracy: BwA6. BwA6 showed significantly higher naming accuracy for English (86.03%), her dominant L1, than French (51.78%; McNemar's Test Exact, two-tailed: p < .001).

Factors Affecting L1 Accuracy: BwA6. The binomial logistic regression model examining predictors of accuracy in L1 was not statistically significant, χ^2(df = 5) = 6.34, p = .274, Cox and Snell's R^2 = .030, Nagelkerke's R^2 = .066. The overall percentage of accuracy in classification was 90.8% (cut-off < 50%). Only age of acquisition (p = .021, OR = 0.363, 95%-CI[0.154, 0.856]) significantly predicted L1 accuracy, while the other psycholinguistic variables showed no significant effect (see Appendix G).

Factors Affecting L2 Accuracy: BwA6. The model was statistically significant, χ^2(df = 5) = 37.3, p < .001, Cox and Snell's R^2 = .231, Nagelkerke's R^2 = .317, with 76.8% of responses classified correctly. Only age of acquisition (p < .001, OR = 0.173, 95%-CI[0.0611, 0.489]) significantly predicted L2 accuracy, BwA6's non-dominant language, while the other psycholinguistic variables showed no significant effect (see Appendix G).

Error Types: BwA6

Table 11 lists BwA6's distribution of error rates across the target language, the non-target language, and language mixing errors for English (L1) and French (L2). The participant presented significantly more non-target language errors when naming pictures in her non-dominant L2 French (relatively to English) (Fisher's Exact Test, two-tailed: p = .008).

Table 11

Distribution of Errors Across Error Categories (Target Language Errors, Non-Target Language Errors, and Language Mixing Errors) for BwA6 in English (L1) and French (L2)

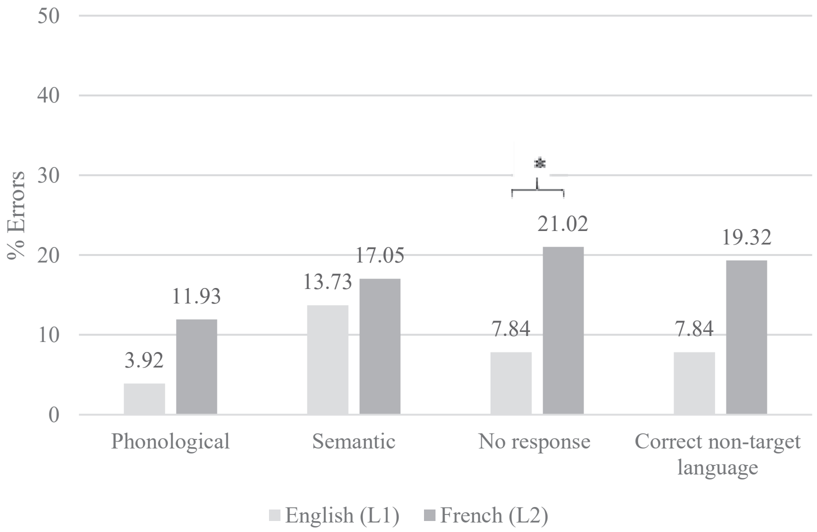
Errors across error categories	English (L1)	French (L2)
Number of errors (n)	51	176
Errors: Target language		
Number of errors in target language (n)	47	128
% of target language errors	92.16	72.73
Errors: Non-target language		
Number of errors in non-target language (n)	4	47
% of non-target language errors	7.84	26.70

Errors: Language mixing		
Number of language mixing errors (n)	0	1
% of language mixing errors	0	0.57

Appendix G highlights all error types that occurred in both English and French picture naming in BwA6. Figures 8 provides the most common error types produced by bilingual individuals with aphasia, (including phonological errors, semantic errors, no responses as well as correct in non-target language errors) for BwA6. The analysis revealed a significant difference for the rate of no responses across languages (Fisher's Exact Test, two-tailed: No responses, p = .052). In contrast, the rate of phonological errors, semantic errors and correct in non-target language responses was not significantly different across languages for BwA6 (Fisher's Exact Test, two-tailed: Phonological errors, p = .161; semantic errors, p = .727; correct in non-target language responses, p = .086).

Figure 8

Distribution of Error Types (Phonological Errors, Semantic Errors, No Responses, Correct in Non-Target Language Responses) for English (L1) and French (L2) for BwA6



Note. Fisher's Exact Test, two-tailed: Phonological errors, p = .161; semantic errors, p = .727; no responses, p = .052*; correct in non-target language responses, p = .086.

Data on Accuracy and Error Types of Individual Participants: BwA7

Accuracy: BwA7

Across Language Accuracy: BwA7. BwA7 was the only participant not to show a significant difference in naming accuracy across his languages, L1 French (69.59%) and L2 English (71.78%; McNemar's Test Exact, two-tailed: p = .409).

Factors Affecting L1 Accuracy: BwA7. The binomial logistic regression model examining predictors of accuracy in L1 was statistically significant, χ^2(df = 5) = 15.7, p = .008, Cox and Snell's R^2 = .105, Nagelkerke's R^2 = .173. The overall percentage of accuracy in classification was 82.4% (cut-off < 50%). Imageability (p = .028, OR = 3.5848, 95%-CI[1.145, 11.23]) significantly predicted L1 accuracy, while the other psycholinguistic variables showed no significant effect (see Appendix H).

Factors Affecting L2 Accuracy: BwA7. The model was not statistically significant, χ^2(df = 5) = 6.45, p = .265, Cox and Snell's R^2 = .031, Nagelkerke's R^2 = .053, with 85.0% of responses classified correctly. Imageability (p = .044, OR = 3.66477, 95%-CI[1.036, 12.96]) significantly predicted L2 accuracy, while the other psycholinguistic variables showed no significant effect (see Appendix H).

Error Types: BwA7

Table 12 lists the distribution of error rates across the target language, the non-target language, and language mixing errors for BwA7 in French (L1) and English (L2). The rate of non-target language errors was not significantly different across the participant's two languages (Fisher's Exact Test, two-tailed: p = .396).

Table 12

Distribution of Errors Across Error Categories (Target Language Errors, Non-Target Language Errors, and Language Mixing Errors) for BwA7 in French (L1) and English (L2)

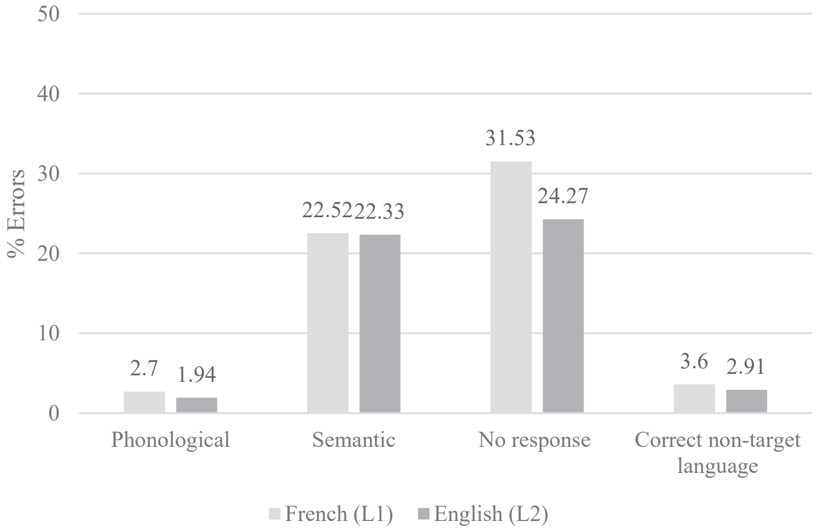
Errors across error categories	French (L1)	English (L2)
Number of errors (n)	111	103
Errors: Target language		
Number of errors in target language (n)	102	98
% of target language errors	91.89	95.15
Errors: Non-target language		
Number of errors in non-target language (n)	7	3
% of non-target language errors	6.31	2.91
Errors: Language mixing		

Number of language mixing errors (n)	2	2
% of language mixing errors	1.80	1.94

Appendix H presents all error types that arose during both French and English picture naming in detail. Figure 9 visualises the most common error types produced by bilingual participants with aphasia (phonological errors, semantic errors, no responses, correct in non-target language errors) for BwA7. The rate of all error types was not significantly different across the languages for BwA7 (Fisher's Exact Test, two-tailed: Phonological errors, p = 1; semantic errors, p = 1; no responses, p = .305; correct in non-target language responses, p = 1).

Figure 9

Distribution of Error Types (Phonological Errors, Semantic Errors, No Responses, Correct in Non-Target Language Responses) for French (L1) and English (L2) for BwA7



Note. Fisher's Exact Test, two-tailed: Phonological errors, p = 1; semantic errors, p = 1; no responses, p = .305; correct in non-target language responses, p = 1.

Data on Accuracy and Error Types of Individual Participants: BwA8

Accuracy: BwA8

Across Language Accuracy: BwA8. Significantly higher naming accuracy was determined for English (80.27%), the participant's dominant L2, than French (65.75%; McNemar's Test Exact, two-tailed: $p < .001$).

Factors Affecting L1 Accuracy: BwA8. The binomial logistic regression model examining predictors of accuracy in L1 was statistically significant, $\chi^2(df = 5) = 28.1$, $p < .001$, Cox and Snell's $R^2 = .179$, Nagelkerke's $R^2 = .257$. The overall percentage of accuracy in classification was 74.6% (cut-off < 50%). The predictor age of acquisition ($p < .001$, OR = 0.122, 95%-CI[0.0414, 0.361]) significantly predicted L1 accuracy, while the other psycholinguistic variables showed no significant effect (see Appendix I).

Factors Affecting L2 Accuracy: BwA8. The model was statistically significant, $\chi^2(df = 5) = 13.8$, $p = .017$, Cox and Snell's $R^2 = .065$, Nagelkerke's $R^2 = .108$, with 83.6% of responses classified correctly. No variable significantly predicted BwA8's picture naming in English, her dominant L2. Full details of the analysis can be found in Appendix I.

Error Types: BwA8

Table 13 below provides the distribution of errors for both of the participant's languages across the different error categories: Target language, non-target language, and language mixing. The distribution of non-target language errors was not significantly different across BwA8's two languages (Fisher's Exact Test, two-tailed: $p = .133$).

Table 13

Distribution of Errors Across Error Categories (Target Language Errors, Non-Target Language Errors, and Language Mixing Errors) for BwA8 in French (L1) and English (L2)

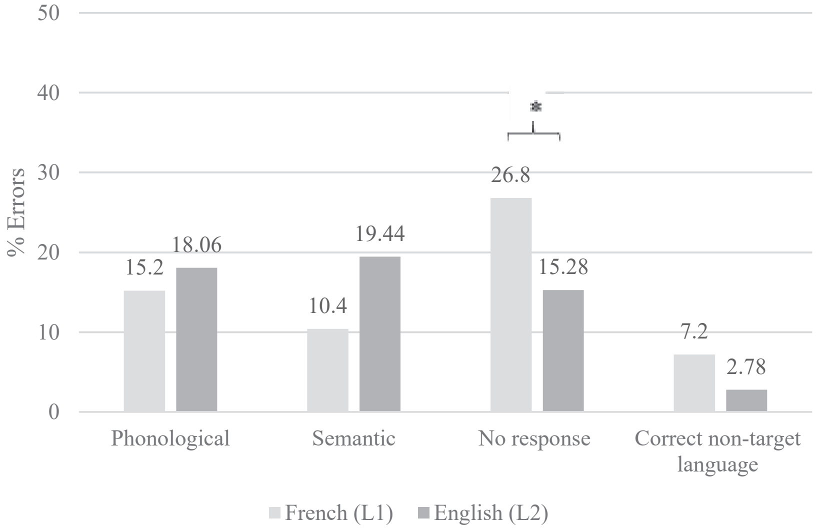
Errors across error categories	French (L1)	English (L2)
Number of errors (n)	125	72
Errors: Target language		
Number of errors in target language (n)	109	70
% of target language errors	87.20	97.22
Errors: Non-target language		
Number of errors in non-target language (n)	12	2
% of non-target language errors	9.60	2.78
Errors: Language mixing		
Number of language mixing errors (n)	4	0

% of language mixing errors	3.2	0

Appendix I lists details about the various error types that emerged in the picture naming process in both French (L1) and English (L2). Figure 10 features the most produced error types by bilingual participants with aphasia (phonological errors, semantic errors, no responses, correct in non-target language errors encountered) for BwA8. The distribution analysis of these error types identified a significantly different error rate for no responses across languages for BwA8 (Fisher's Exact Test, two-tailed: No responses, p = .002). In contrast, the rates for phonological errors, semantic errors, and correct in non-target language responses were not significantly different across BwA8's languages (Fisher's Exact Test, two-tailed: Phonological errors, p = .748, semantic errors, p = .119; correct in non-target language responses, p = .329).

Figure 10

Distribution of Error Types (Phonological Errors, Semantic Errors, No Responses, Correct in Non-Target Language Responses) for French (L1) and English (L2) for BwA8



Note. Fisher's Exact Test, two-tailed: Phonological errors, p = .748; semantic errors, p = .119; no responses, p = .002*; correct in non-target language responses, p = .329.

Discussion

This study investigated spoken picture naming in eight bilingual speakers with aphasia, examining accuracy and error patterns, and error types within and across languages for each participant.

Language dominance emerged as a key factor for accuracy patterns, error patterns, and error types. Across six participants, higher accuracy was found in the dominant language, regardless of whether the dominant language was the L1 or L2. Moreover, within error pattern and error type analyses, language dominance emerged as an important factor, alongside further aspects that are assumed to be associated with a bilingual language profile, such as non-selective activation and related inhibition processes. These findings illustrate the significance of considering specific aspects associated with bilingualism when investigating word processing in bilingual speakers with aphasia.

Furthermore, analysis revealed a different distribution of error types across languages for seven participants which was for example indicated by different most common error types occurring across the available languages; supporting research highlighting the importance of developing a comprehensive understanding of the language impairment and related symptoms in each single case. The findings on sematic errors across the participants showed similar semantic error distributions across languages, which might suggest that semantic representations are the same/similar within a bilingual language system.

Language Dominance as a Driver for Accuracy Patterns and the Influence of Linguistic Variables

Language Dominance

While seven participants (BwA1, BwA2[15], BwA3, BwA4, BwA5, BwA6, BwA8) showed significantly higher accuracy for their dominant language, one participant posed an exception to this 'rule': BwA7 did not show a significant difference in naming accuracy across his languages, French and English. These results highlight the influence of language dominance in determining accuracy within a bilingual speaker. The results suggest that language dominance holds a greater influence on accuracy than language age of acquisition since the influence of language dominance across participants was regardless of whether it was the participants L1 or L2. The different accuracy patterns presented by the one

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[15] Note: The dominance of BwA2's available languages (L1: Polish, L2: German) is equally distributed.

participant in our study can be attributed to the individual functional impairment and bilingual language profile. BwA7 exhibited a balanced level of accuracy across his languages. The participant's self-report and the project's dominance assessment depicted BwA7 as a nearly balanced bilingual speaker, with only a slightly stronger performance for English. This was further supported by the background assessment performance, revealing a similar language impairment across the available languages. Thus, BwA7 differs from the other participants by being a nearly balanced bilingual speaker (whereas all other participants had a cleared dominant/non-dominant language), which resulted in the same accuracy pattern across languages.

These findings align with previous research indicating the importance of the bilingual language profile on the language performance of bilingual speakers with aphasia (e.g., Kiran & Lebel, 2004; Kiran et al., 2014). Goral (2017) has shown, that accuracy differences may depend on various factors, including pre- and post-onset proficiency and language use. More specifically, previous research highlighted the significance of language dominance as a more reliable factor for lexical access in bilingual speakers with a language disorder compared to the variable age of acquisition of each available language within a speaker (e.g., Kiran & Tuchtenhagen, 2005; Kotz & Elston-Güttler, 2004; Khachatryan et al., 2016; Cargnelutti et al., 2019).

Linguistic Factors

The effect of lexical variables on accuracy within languages was also examined. Three variables (word length [BwA2], item age of acquisition [BwA1, BwA6, BwA8], imageability [BwA4, BwA5, BwA7]) had a faciliatory effect on accuracy, in the direction as predicted from previous monolingual findings. In particular, higher accuracy was found for shorter words, for words that were acquired early in life, and for words that had a high imageability. Visual complexity and familiarity had no significant influence on picture naming accuracy.

Visual complexity quantifies the amount of descriptive detail included in a picture and determines the ease or difficulty at the stage of object recognition during word retrieval (the simpler the object, the faster and easier the recognition). Our findings might suggest that images obtained from MultiPic (Duñabeitia et al., 2018) were well depicted and not influencing picture naming (important to note, MultiPic provided visual complexity values for each item in each language). Familiarity was the second linguistic variable that did not exert any influence on accuracy among the bilingual participants (familiarity values were collected for each item in each language). This aligns with the assumption that familiarity has less of an influence on accuracy in bilingual speakers with aphasia in comparison to monolingual speakers. The degree of familiarity that is associated with the concept of the presented item is accurate for monolingual speakers but less for bilinguals because bilinguals experience more differences in how frequently a linguistic label (related to e.g., an object) is seen, heard, or used in everyday life based on their bilingual status.

The lexical variable word length (number of phonemes) was found to have a significant influence solely in BwA2 in Polish. The explanation for significantly higher accuracy in shorter words might lie in the characteristics of the Polish language itself. Polish is considered a phonologically complex language as it includes complex phonotactics, which means that there are specific rules for combining sounds in words; the phonotactics of Polish allows complex combinations of consonants in syllable beginnings and endings (e.g., skrzypce [scissors]). Hence, BwA2 complex phonotactics inherent to Polish may be specifically affected in his aphasia, thereby leading to the observed effects of higher accuracy in less complex words. Three participants (language combinations: English-German, English-Italian, French-English) showed an imageability effect: Highly imageable items enhanced their naming accuracy. Further, the linguistic variable item age of acquisition demonstrated a facilitatory effect in three participants. Item age of acquisition is a linguistic variable that refers to the language-specific average age at which a word was acquired (earlier acquired words are produced more accurately, e.g., Nickels & Howard, 1995). However, age of acquisition does not exhibit the same effect on accuracy in bilingual speakers as for monolingual speakers, since usually early acquired words might have been learned late in life in a late bilingual speaker.

To summarise, when linguistic variables had an influence on accuracy in bilinguals with aphasia, the direction of the influence was observed as predicted from research in monolinguals: Higher accuracy was found for shorter words, for words that were acquired early in life, and for words that had a high imageability. The absence of the influence of visual complexity and familiarity, might be related to the testing material and to the bilingual language profile for familiarity, since bilingual speakers experience more differences in how frequently an object is seen, heard, or used in everyday life.

Distribution of Error Types

Among participants included in this study, seven participants (BwA1, BwA2, BwA3, BwA4, BwA5, BwA6, BwA8) showed a different error pattern of error types across languages and only one participant (BwA7) displayed a consistent error pattern of error types (no responses > semantic errors > correct in non-target language responses > phonological errors) across languages (equally distributed). These findings highlight the importance of developing a comprehensive understanding of the language impairment and related symptoms in each language (Grosjean, 1989; Khachatryan et al., 2016), as bilingual speakers' language performance may vary across languages (Khachatryan et al., 2016).

The bilingual language profile (and language impairment) of BwA7 can explain his pattern of equally distributed error types across both languages. As previously mentioned, BwA7 presented with a mild and similar level of impairment across languages and was a nearly balanced bilingual speaker within his daily life. Given this, it is reasonable to assume that balanced bilingual speakers (with mild and similar language impairment across languages) might exhibit consistent error patterns across their available languages.

Returning to the seven participants (BwA1, BwA2, BwA3, BwA4, BwA5, BwA6, BwA8) with a different distribution of error types across available languages. This can be observed by the most common error type within each language. Five (BwA1, BwA3, BwA4, BwA6, BwA8) out of the seven participants exhibited a different most common error type across their available languages, supporting the assertion of Khachatryan et al. (2016) that bilingual speakers' language performance may vary across languages. The two participants with a shared most common error type across their languages were BwA2 and BwA5. BwA2 experienced semantic errors as the most common error types across both of his languages, which indicates a distinct semantic impairment, which will be discussed in this section further below. In BwA5, no responses emerged as the most common error type across both of his languages English and Italian. BwA5 experienced a more severe language impairment than the other participants, explaining the no responses as the most common error type. Moreover, the different distribution of errors across available languages is evident in terms of phonological errors; no clear and consistent pattern occurs across participants. While some participants (BwA1, BwA2, BwA3, BwA4) displayed significantly more phonological errors in their L2, the other four participants experienced no difference in phonological errors across their available languages.

Although seven participants showed a different error pattern across their languages, it is important to note that five participants (BwA1, BwA3, BwA6, BwA7, BwA8) showed the same distribution of semantic errors across languages. When comparing semantic errors across languages among the individual participants, there is often a consistent occurrence of semantic errors in the same items across languages. This pattern, the same distribution of semantic errors across languages and the occurrence of semantic errors in the same items, may hint to the assumption that bilingual people with aphasia have (partly) shared semantic representations across languages. This would be in accordance with previous research that suggests the existence of shared semantic representations in the bilingual language system of bilingual speakers with aphasia (Siyambalapitiya et al., 2013; Kiran and Lebel, 2007; see an overview for research on shares semantic representations in bilingual healthy speakers in Francis, 2005).

BwA2, BwA4, and BwA5 were the three participants showing different error patterns for semantic errors across languages, which will be discussed per participant below. BwA2 showed significantly more semantic errors in Polish. A closer examination of the participants naming performance in the other language German might provide an explanation for this presented pattern. Interestingly, the majority of responses were also incorrect when BwA2 named the equivalent items in German (the items that had elicited semantic errors in Polish). Moreover, the errors assigned to equivalent items were often ‘related’ to a semantic error; the participant produced, for example, semantic errors including phonological errors, single-word circumlocutions, or multiword circumlocutions. Consequently, it is plausible to consider that BwA2 exhibited a similar pattern of semantic errors across languages, however, in the case of German, the number of ‘standard’ semantic errors was relatively lower compared to Polish, resulting in a statistically different error pattern for semantic errors across languages. This assumption gets also supported by the result that semantic errors in this participant are the most common errors across his available languages.

BwA4 showed significantly more semantic errors in English, her dominant L1. This is surprising and might be explained by the error pattern observed in the participant’s other language, German. Some of the items (that were named with a semantic error in English) were named with an error in the non-target language, which indicates lexical access difficulties, that might be based on semantic difficulties.

For BwA5, the underlying functional impairment offers an explanation for the different patterns of semantic errors. BwA5 presented with a severe naming impairment in Italian with a naming accuracy of 0%. Given the severe impairment in his language Italian, it is not feasible to draw conclusions or make assumptions about shared or unshared semantic representations in his bilingual language network.

Language Dominance, Non-Selective Activation, and Inhibition Processes as Drivers for Error Patterns and Error Types

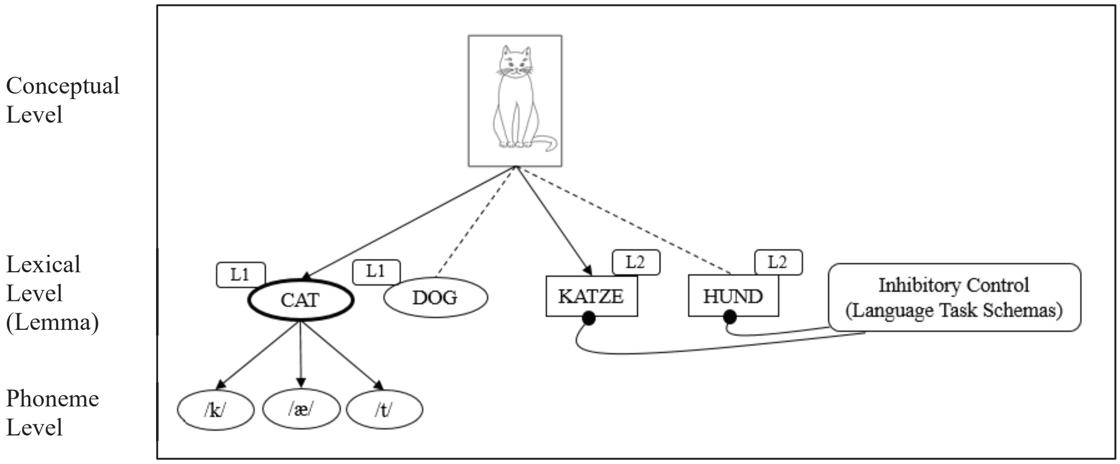
Error Pattern Across Error Categories: Non-Target Language Errors

The important role of language dominance in word processing was also supported by the occurrence of non-target language errors (e.g., semantic errors and phonological errors in the non-target language; examples: Target *desk*, response *Stuhl* [German word for chair], target *desk*, response *Pisch* [German word for desk (Tisch) with a phonological error]). Five participants (BwA1, BwA3, BwA4, BwA5, BwA6) revealed significantly more non-target language errors in the non-dominant language regardless of whether the non-dominant language was L1 or L2, while two participants (BwA7 and BwA8) showed an equal distribution of non-target language errors across their languages. BwA2 showed significantly more non-target language errors in his L1 Polish, while it is important to mention, that the dominance of the participant's languages was equally distributed across the L1 and L2.

These findings provide evidence for the impact of language dominance not only on accuracy but also on error patterns. Moreover, the results support previous findings demonstrating that interference between the available languages predominantly originate from the dominant language and thereby influences the non-dominant language (e.g., Cargnelutti et al., 2019). This interference is consistent with reported non-selective activation in the bilingual language network, which refers to the parallel activation of both languages/both lexical forms during word processing; a phenomenon that has also been reported for healthy bilingual individuals (e.g., Moon & Jiang, 2011) and bilingual speakers with aphasia (e.g., Gray & Kiran, 2013). Non-selective activation is accompanied by consistent inhibition processes, as proposed by Green (1986, 1998), to suppress the non-target language (see Figure 11, inhibition processes occur via the language task schemas according to the Inhibitory Control Model of Green [1986, 1998]). However, in the context of a stroke, inhibition processes might be (partly) impaired, leading to non-target language responses. Furthermore, research proposes greater inhibition processes for the dominant language compared to the non-dominant language (Green, 1986; 1998), which provides an explanation for the error pattern of this study: The occurrence of significantly more non-target language errors in the non-dominant language in five participants, attributed to impaired inhibition processes that specifically manifest in the dominant/strong language, given its higher demand for inhibition. It is important to note, that words produced in the non-target language can be correct or incorrect since lexical retrieval is impaired in both, the dominant and non-dominant language.

Figure 11

The Production of the Word 'Cat' in an English-German Bilingual Speaker in the Inhibitory Control Model (Green, 1986, 1998), Adapted from Schwieter & Ferreiera (2013)



As previously mentioned BwA7 and BwA8 presented a different pattern compared to the other six participants: An equal distribution of non-target language errors across their languages. This different pattern can be attributed to their individual functional impairment and bilingual language profile. Both participants displayed a mild and similar level of language impairment across their languages, evidenced by the overall background assessments score and the spoken naming results. Moreover, as mentioned earlier, BwA7 was identified as a nearly balanced bilingual speaker. Consequently, we infer from our findings that when the level of language impairment (and the language use and exposure) is similar across languages, there tends to be less interference between the available languages, resulting in a relatively equal distribution of non-target language errors across languages in bilingual speakers with aphasia.

BwA2 exhibited more non-target language errors in his L1 Polish compared to his L2 German. This pattern of more non-target language errors in the participant's L1 may be attributed to the bilingual language profile of BwA2: Generally, the percentage of language use in German is slightly higher than the language use in Polish. Additionally, communication around the participant's stroke and aphasia is conducted in German. Furthermore, it is important to note that although the participation in the research project takes place in both of the participant's languages, BwA2 is aware that the researcher's first language is German. These aspects may account for the pattern of more non-target language errors in Polish, as German tends to be the prominent language in the context of his stroke and his participation in the research project.

Error Type: Correct in Non-Target Language Responses

The importance of language dominance in word processing and word production within bilingual speakers with aphasia is also reflected by the following: Four participants (BwA1, BwA3, BwA4, BwA5) showed significantly more correct non-target language responses (e.g., target *cat*, response *Katze* [German for cat]) in their non-dominant language. The other four participants showed the same, but non-significant pattern: A higher percentage of correct non-target language responses in their non-dominant language[16].

This specific error type is commonly observed in picture naming in bilingual people with aphasia (Roberts & Deslauriers, 1999). It is often described as a strategy (a) to compensate for lexical access difficulties that individual speakers experience in one language but not in the other, (b) when a bilingual speaker does not know/has never known the specific word in the target language, however, the knowledge of the word is available in the non-target language, (c) that bilingual speakers with aphasia use to cue themselves by providing the word in the non-target language and in the next step translating it (e.g., Cargnelutti et al., 2019, Neumann et al., 2017).

The observation of this error type/strategy occurring significantly more often in the non-dominant language aligns with the understanding that the non-dominant is often considered as the ‘weaker’ language. Consequently, it is reasonable to assume, that non-target language translation equivalents are more often observed in the non-dominant language, as words of the dominant language are more accessible due to the ‘strong’ language status. As this error type/strategy is part of the ‘errors in the non-target language’-category it also serves as evidence for non-selective activation of lexical forms (parallel activation of the target and non-target lexical form) (e.g., Gray & Kiran, 2013; Moon & Jiang, 2011;) and related impaired inhibition processes (e.g., Green, 1986, 1998) in bilingual speakers with aphasia (see further explanation above). This error - considered in the model of Green (1986, 1998) - occurring more often in the non-dominant language, can therefore be attributed to impaired inhibition processes, which are influenced by the fact that the dominant language necessitates a greater extent of inhibition (Green, 1986, 1998).

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[16] Note: BwA2 showed more correct in non-target language error in his L1 Polish compared to his L2 German. However, German tends to be his prominent language in the context of his stroke and his participation in the research project. Therefore, the statement above remains true for BwA2.

Conclusion

The current study has provided insights into the complexity of a bilingual language system. Word processing in a bilingual speaker with aphasia is influenced by the bilingual language profile, specifically language dominance. Language dominance was found to have an impact on accuracy patterns as well as error patterns and error types for most participants. Furthermore, the analysis of error patterns and error types provide evidence to support the processing principles of non-selective activation of available languages and related inhibition processes that control the target language output in bilingual speakers affecting word production.

Moreover, this project has shown that error types are differently distributed across languages. Error patterns across a bilingual speaker's languages are not the same, supporting the importance of developing a comprehensive understanding of the language impairment and related symptoms in each language (Grosjean, 1989; Khachatryan et al., 2016), as bilingual speakers' language performance may vary across languages (Khachatryan et al., 2016). Furthermore, the findings on semantic errors across languages might suggest that semantic representations are the same/similar or overlapping within a bilingual language system.

The present study supports the notion, that bilingual speakers are not the sum of two monolingual speakers in one person (Grosjean, 1989), due to an interplay between available languages that does not exist in a monolingual language system. However, it must be acknowledged that existing diagnostic and treatment methods in speech pathology are mostly based on monolingual research. Theses diagnostic and treatment methods are therefore not constructed for an adequate clinical service for bilingual speakers with aphasia, since important aspects like the influence of the bilingual language profile are not considered in these materials. However, as shown by this study it is important to, for example, consider the dominant language to deliver appropriate and effective clinical services.

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Appendices

Appendix A

Item List of all Included Language Combinations

Due to size of Appendix A (87 pages) item lists for all included language combinations of all bilingual speakers with aphasia are to find on the Open Science Framework Platform under the following link: https://osf.io/23zpc/

Appendix B

Results of BwA1

Correlation Matrix Outcome and Logistic Regression Outcome for BwA1 in Dutch (L1)

Table B1

Correlation Matrix BwA1 Dutch (L1)

	Phonemes	Age of acquisition	Familiarity	Imageability	Visual complexity
Phonemes	—				
Age of acquisition	0.518	—			
Familiarity	-0.254	-0.466	—		
Imageability	-0.091	-0.218	0.164	—	
Visual complexity	0.123	0.060	-0.355	-0.115	—

Table B2

Binomial Logistic Regression BwA1 Dutch (L1) – Model Fit Measures, Predictive Measures

Model Fit Measures									Predictive measures – Accuracy[a]
						Overall Model Test			
Model	Deviance	AIC	BIC	R^2_{CS}	R^2_N	χ^2	df	p	
1	178	190	207	0.0575	0.0767	7.94	5	0.160	0.619

[a] The cut-off value is set to 0.5.

Table B3

Binomial Logistic Regression BwA1 Dutch (L1) – Model Coefficients, Collinearity Statistics, Omnibus Likelihood Radio Tests

	Model Coefficients - Accuracy							Collinearity Statistics		Omnibus Likelihood Ratio Tests		
						95% CI						
Predictor	Estimate	SE	Z	p	OR	Lower	Upper	VIF	T	χ^2	df	p
Intercept	1.6224	3.142	0.516	0.606	5.065	0.0107	2393.95					
Phonemes	-0.0516	0.129	-0.401	0.688	0.950	0.7380	1.22	1.34	0.747	0.1618	1	0.688
Age of acquisition	-0.3666	0.194	-1.892	0.059	0.693	0.4740	1.01	1.64	0.610	3.7249	1	0.054
Familiarity	-0.0972	0.287	-0.338	0.735	0.907	0.5168	1.59	1.45	0.688	0.1146	1	0.735
Imageability	0.1892	0.361	0.525	0.600	1.208	0.5960	2.45	1.05	0.953	0.2767	1	0.599
Visual complexity	-0.0685	0.289	-0.237	0.813	0.934	0.5295	1.65	1.17	0.856	0.0561	1	0.813

Note. Estimates represent the log odds of "accuracy = 1" vs. "accuracy = 0". CI=Confidence Interval, OR=Odds ratio, T=Tolerance.

Correlation Matrix Outcome and Logistic Regression Outcome for BwA1 in German (L2)

Table B4

Correlation Matrix BwA1 German (L2)

	Phonemes	Age of acquisition	Familiarity	Imageability	Visual complexity
Phonemes	—				
Age of acquisition	0.494	—			
Familiarity	-0.201	-0.334	—		
Imageability	0.110	-0.273	0.185	—	
Visual complexity	0.128	0.069	-0.374	0.033	—

Table B5

Binomial Logistic Regression BwA1 German (L2) – Model Fit Measures, Predictive Measures

Model Fit Measures									Predictive measures – Accuracy[a]
						Overall Model Test			
Model	Deviance	AIC	BIC	R^2_{CS}	R^2_N	χ^2	df	p	
1	57.1	69.1	81.7	0.220	0.317	15.1	5	0.010	0.803

^The cut-off value is set to 0.5.

Table B6

Binomial Logistic Regression BwA1 German (L2) – Model Coefficients, Collinearity Statistics, Omnibus Likelihood Radio Tests

Model Coefficients - Accuracy								Collinearity Statistics		Omnibus Likelihood Ratio Tests		
						95% CI						
Predictor	Estimate	SE	Z	p	OR	Lower	Upper	VIF	T	χ^2	df	p
Intercept	5.8884	7.283	0.8085	0.419	360.828	2.28e-4	5.71e+8					
Phonemes	-0.0743	0.274	-0.2711	0.786	0.928	0.5426	1.589	1.55	0.645	0.07335	1	0.787
Age of acquisition	-1.4368	0.660	-2.1757	0.030	0.238	0.0651	0.867	1.47	0.679	6.01461	1	0.014
Familiarity	0.2535	0.580	0.4374	0.662	1.288	0.4138	4.012	1.23	0.812	0.19190	1	0.661
Imageability	0.0859	0.974	0.0882	0.930	1.090	0.1615	7.354	1.33	0.754	0.00776	1	0.930
Visual complexity	-0.9046	0.670	-1.3507	0.177	0.405	0.1089	1.504	1.28	0.782	1.93189	1	0.165

Note. Estimates represent the log odds of "accuracy = 1" vs. "accuracy = 0". CI=Confidence Interval, OR=Odds ratio, T=Tolerance.

Error Rates per Error Type in Dutch (L1) and German (L2) for BwA1

Table B7

Distribution of Errors per Error Type in Dutch (L1) and German (L2) for BwA1

	Dutch (L1)				German (L2)			
	Target language		Non-target language		Target language		Non-target language	
Error type	Number of errors	% all errors	Number of errors	% all errors	Number of errors	% all errors	Number of errors	% all errors
Phonological error	6	2.93	6	2.93	13	9.03	0	0
Phonologically unrelated non-word	2	0.98	0	0	1	0.69	0	0
Semantic error	36	17.56	17	8.30	34	23.61	3	2.08
Semantically unrelated error	1	0.49	0	0	1	0.69	0	0
Semantically unrelated non-word	1	0.49	0	0	0	0	0	0
Semantic-than-phonological error	2	0.98	0	0	2	1.39	0	0
Mixed error	1	0.49	0	0	0	0	0	0
Morphological error	4	1.95	4	1.95	8	5.56	0	0
Unspecified error	2	0.98	2	0.98	5	3.47	0	0
Multiword circumlocution	4	1.95	1	0.49	10	6.94	0	0
Single word circumlocution	2	0.98	2	0.98	2	1.39	0	0
Perseveration	0	0	0	0	0	0	0	0
Visual error	3	1.46	1	0.49	2	1.39	0	0

Acceptable semantic alternative	2	0.98	0	0	8	5.56	0	0
Use-of-language error	2	0.98	0	0	0	0	0	0
Other error	5	2.44	2	0.98	11	7.64	0	0
No response	43	20.98	--	--	21	14.59	--	--
Correct in non-target language	--	--	46	22.44	--	--	15	10.42

Table B8

Distribution of Language Mixing Errors in Dutch (L1) and German (L2) for BwA1

	Dutch (L1)		German (L2)	
Language mixing errors	Number of errors	% all errors	Number of errors	% all errors
Language mixing error I	7	3.41	7	4.86
Language mixing error II: Back-translation error	1	0.49	1	0.69

Appendix C

Results of BwA2

Correlation Matrix Outcome and Logistic Regression Outcome for BwA2 in Polish (L1)

Table C1

Correlation Matrix BwA2 Polish (L1)

	Phonemes	Age of acquisition	Familiarity	Imageability	Visual complexity
Phonemes	—				
Age of acquisition	0.250	—			
Familiarity	-0.118	-0.414	—		
Imageability	-0.098	-0.401	0.203	—	
Visual complexity	0.050	0.103	-0.175	0.002	—

Table C2

Binomial Logistic Regression BwA2 Polish (L1) – Model Fit Measures, Predictive Measures

Model Fit Measures									Predictive measures – Accuracy[a]
						Overall Model Test			
Model	Deviance	AIC	BIC	R^2_{CS}	R^2_N	χ^2	df	p	
1	301	313	334	0.0732	0.104	19.9	5	0.001	0.710

[a] The cut-off value is set to 0.5.

Table C3

Binomial Logistic Regression BwA2 Polish (L1) – Model Coefficients, Collinearity Statistics, Omnibus Likelihood Radio Tests

	Model Coefficients - Accuracy							Collinearity Statistics		Omnibus Likelihood Ratio Tests		
						95% CI						
Predictor	Estimate	SE	Z	p	OR	Lower	Upper	VIF	T	χ^2	df	p
Intercept	-10.1754	5.1936	-1.95924	0.050	3.81e-5	1.45e-9	1.004					
Phonemes	-0.1572	0.0612	-2.56899	0.010	0.855	0.758	0.963	1.05	0.953	6.977	1	0.008
Age of acquisition	1.65e-4	0.1555	0.00106	0.999	1.000	0.737	1.356	1.34	0.748	1.13e-6	1	0.999
Familiarity	0.0775	0.0403	1.92160	0.055	1.081	0.998	1.169	1.27	0.789	4.005	1	0.045
Imageability	0.5959	0.3772	1.57989	0.114	1.815	0.866	3.801	1.13	0.887	2.644	1	0.104
Visual complexity	0.1681	0.2468	0.68119	0.496	1.183	0.729	1.919	1.07	0.937	0.467	1	0.495

Note. Estimates represent the log odds of "accuracy = 1" vs. "accuracy = 0". CI=Confidence Interval, OR=Odds ratio, T=Tolerance.

Correlation Matrix Outcome and Logistic Regression Outcome for BwA2 in German (L2)

Table C4

Correlation Matrix BwA2 German (L2)

	Phonemes	Age of acquisition	Familiarity	Imageability	Visual complexity
Phonemes	—				
Age of acquisition	0.452	—			
Familiarity	-0.175	-0.340	—		
Imageability	0.114	-0.292	0.149	—	
Visual complexity	0.154	0.091	-0.303	0.040	—

Table C5

Binomial Logistic Regression BwA2 German (L2) – Model Fit Measures, Predictive Measures

Model Fit Measures									Predictive measures – Accuracy[a]
						Overall Model Test			
Model	Deviance	AIC	BIC	R^2_{CS}	R^2_N	χ^2	df	p	
1	96.8	109	123	0.0500	0.0672	3.79	5	0.580	0.554

[a] The cut-off value is set to 0.5.

Table C6

Binomial Logistic Regression BwA2 German (L2) – Model Coefficients, Collinearity Statistics, Omnibus Likelihood Radio Tests

Model Coefficients - Accuracy								Collinearity Statistics		Omnibus Likelihood Ratio Tests		
						95% CI						
Predictor	Estimate	SE	Z	p	OR	Lower	Upper	VIF	T	χ^2	df	p
Intercept	-3.5715	5.035	-0.7093	0.478	0.0281	1.45e-6	543.31					
Phonemes	0.1784	0.193	0.9234	0.356	1.1953	0.818	1.75	1.27	0.790	0.87364	1	0.350
Age of acquisition	0.0214	0.409	0.0524	0.958	1.0217	0.458	2.28	1.36	0.737	0.00274	1	0.958
Familiarity	0.6087	0.445	1.3690	0.171	1.8381	0.769	4.39	1.40	0.714	1.92831	1	0.165
Imageability	0.1340	0.675	0.1985	0.843	1.1434	0.304	4.29	1.18	0.850	0.03941	1	0.843
Visual complexity	-0.0519	0.476	-0.1089	0.913	0.9495	0.373	2.41	1.28	0.784	0.01185	1	0.913

Note. Estimates represent the log odds of "accuracy = 1" vs. "accuracy = 0". CI=Confidence Interval, OR=Odds ratio, T=Tolerance.

Error Rates per Error Type in Polish (L1) and German (L2) for BwA2

Table C7

Distribution of Errors per Error Type in Polish (L1) and German (L2) for BwA2

	Polish (L1)				German (L2)			
	Target language		Non-target language		Target language		Non-target language	
Error type	Number of errors	% all errors	Number of errors	% all errors	Number of errors	% all errors	Number of errors	% all errors
Phonological error	5	3.65	2	1.46	30	11.81	1	0.39
Phonologically unrelated non-word	0	0	0	0	8	3.15	0	0
Semantic error	57	41.61	1	0.73	59	23.23	0	0
Semantically unrelated error	0	0	0	0	3	1.18	0	0
Semantically unrelated non-word	0	0	0	0	0	0	0	0
Semantic-than-phonological error	1	0.73	0	0	7	2.76	0	0
Mixed error	0	0	0	0	0	0	0	0
Morphological error	2	1.46	0	0	13	5.12	0	0
Unspecified error	8	5.84	2	1.46	18	7.09	0	0
Multiword circumlocution	0	0	0	0	16	6.30	0	0
Single word circumlocution	1	0.73	0	0	9	3.54	0	0
Perseveration	0	0	0	0	0	0	0	0
Visual error	10	7.30	0	0	14	5.51	0	0

Acceptable semantic alternative	19	13.87	0	0	10	3.94	1	0.39
Use-of-language error	2	1.46	0	0	0	0	0	0
Other error	2	1.46	0	0	10	3.94	0	0
No response	14	10.22	--	--	43	16.93	--	--
Correct in non-target language	--	--	11	8.03	--	--	12	4.72

Table C8

Distribution of Language Mixing Errors in Polish (L1) and German (L2) for BwA2

	Polish (L1)		German (L2)	
Language mixing errors	Number of errors	% all errors	Number of errors	% all errors
Language mixing error I	0	0	0	0
Language mixing error II: Back-translation error	0	0	0	0

Appendix D

Results of BwA3

Correlation Matrix Outcome and Logistic Regression Outcome for BwA3 in Dutch (L1)

Table D1

Correlation Matrix BwA3 Dutch (L1)

	Phonemes	Age of acquisition	Familiarity	Imageability	Visual complexity
Phonemes	—				
Age of acquisition	0.518	—			
Familiarity	-0.254	-0.466	—		
Imageability	-0.091	-0.218	0.164	—	
Visual complexity	0.123	0.060	-0.355	-0.115	—

Table D2

Binomial Logistic Regression BwA3 Dutch (L1) – Model Fit Measures, Predictive Measures

Model Fit Measures									Predictive measures – Accuracy[a]
						Overall Model Test			
Model	Deviance	AIC	BIC	R^2_{CS}	R^2_N	χ^2	df	p	
1	166	178	195	0.0493	0.0682	6.78	5	0.238	0.634

[a] The cut-off value is set to 0.5.

Table D3

Binomial Logistic Regression BwA3 Dutch (L1) – Model Coefficients, Collinearity Statistics, Omnibus Likelihood Radio Tests

	Model Coefficients - Accuracy							Collinearity Statistics		Omnibus Likelihood Ratio Tests		
						95% CI						
Predictor	Estimate	SE	Z	p	OR	Lower	Upper	VIF	T	χ^2	df	p
Intercept	1.31906	3.279	0.4023	0.687	3.740	0.00606	2309.94					
Phonemes	-0.07927	0.131	-0.6043	0.546	0.924	0.71438	1.19	1.35	0.741	0.364	1	0.546
Age of acquisition	-0.21699	0.193	-1.1256	0.260	0.805	0.55167	1.17	1.61	0.621	1.277	1	0.259
Familiarity	0.27895	0.306	0.9121	0.362	1.322	0.72581	2.41	1.40	0.714	0.845	1	0.358
Imageability	0.00728	0.378	0.0193	0.985	1.007	0.48004	2.11	1.07	0.937	3.71e-4	1	0.985
Visual complexity	-0.00903	0.312	-0.0290	0.977	0.991	0.53796	1.83	1.18	0.845	8.40e-4	1	0.977

Note. Estimates represent the log odds of "accuracy = 1" vs. "accuracy = 0". CI=Confidence Interval, OR=Odds ratio, T=Tolerance.

Correlation Matrix Outcome and Logistic Regression Outcome for BwA3 in German (L2)

Table D4

Correlation Matrix BwA3 German (L2)

	Phonemes	Age of acquisition	Familiarity	Imageability	Visual complexity
Phonemes	—				
Age of acquisition	0.494	—			
Familiarity	-0.201	-0.334	—		
Imageability	0.110	-0.273	0.185	—	
Visual complexity	0.128	0.069	-0.374	0.033	—

Table D5

Binomial Logistic Regression BwA3 German (L2) – Model Fit Measures, Predictive Measures

Model Fit Measures									Predictive measures – Accuracy[a]
						Overall Model Test			
Model	Deviance	AIC	BIC	R^2_{CS}	R^2_N	χ^2	df	p	
1	67.8	79.8	92.5	0.0385	0.0564	2.40	5	0.792	0.721

[a] The cut-off value is set to 0.5.

Table D6

Binomial Logistic Regression BwA3 German (L2) – Model Coefficients, Collinearity Statistics, Omnibus Likelihood Radio Tests

	Model Coefficients - Accuracy							Collinearity Statistics		Omnibus Likelihood Ratio Tests		
						95% CI						
Predictor	Estimate	SE	Z	p	OR	Lower	Upper	VIF	T	χ^2	df	p
Intercept	-6.9679	6.991	-0.997	0.319	9.42e-4	1.06e-9	840.22					
Phonemes	0.0652	0.254	0.256	0.798	1.067	0.648	1.76	1.39	0.722	0.0661	1	0.797
Age of acquisition	-0.1537	0.490	-0.313	0.754	0.858	0.328	2.24	1.45	0.691	0.0996	1	0.752
Familiarity	0.3971	0.542	0.732	0.464	1.487	0.514	4.30	1.53	0.653	0.5452	1	0.460
Imageability	0.8967	0.956	0.938	0.348	2.452	0.377	15.96	1.24	0.809	0.8878	1	0.346
Visual complexity	0.4032	0.609	0.663	0.508	1.497	0.454	4.93	1.43	0.697	0.4473	1	0.504

Note. Estimates represent the log odds of "accuracy = 1" vs. "accuracy = 0". CI=Confidence Interval, OR=Odds ratio, T=Tolerance.

Error Rates per Error Type in Dutch (L1) and German (L2) for BwA3

Table D7

Distribution of errors per error type in Dutch (L1) and German (L2) for BwA3

	Dutch (L1)				German (L2)			
	Target language		Non-target language		Target language		Non-target language	
Error type	Number of errors	% all errors	Number of errors	% all errors	Number of errors	% all errors	Number of errors	% all errors
Phonological error	4	2.48	1	0.62	33	23.91	0	0
Phonologically unrelated non-word	1	0.62	0	0	1	0.72	0	0
Semantic error	29	18.01	6	3.23	24	17.39	2	1.45
Semantically unrelated error	0	0	0	0	1	0.72	0	0
Semantically unrelated non-word	0	0	0	0	0	0	0	0
Semantic-than-phonological error	1	0.62	0	0	1	0.72	0	0
Mixed error	0	0	0	0	0	0	0	0
Morphological error	2	1.24	0	0	4	2.90	0	0
Unspecified error	4	2.48	0	0	5	3.62	0	0
Multiword circumlocution	7	4.35	0	0	6	4.35	0	0
Single word circumlocution	5	3.11	0	0	0	0	0	0
Perseveration	0	0	0	0	0	0	0	0
Visual error	10	6.21	0	0	11	7.97	0	0

Acceptable semantic alternative	27	16.77	0	0	23	16.67	0	0
Use-of-language error	3	1.86	0	0	0	0	0	0
Other error	6	3.73	0	0	5	3.62	0	0
No response	21	13.04	--	--	12	8.70	--	--
Correct in non-target language	--	--	24	14.91	--	--	2	1.45

Table D8

Distribution of Language Mixing Errors in Dutch (L1) and German (L2) for BwA3

	Dutch (L1)		German (L2)	
Language mixing errors	Number of errors	% all errors	Number of errors	% all errors
Language mixing error I	7	4.35	8	5.80
Language mixing error II: Back-translation error	3	1.86	0	0

Appendix E

Results of BwA4

Correlation Matrix Outcome and Logistic Regression Outcome for BwA4 in English (L1)

Table E1

Correlation Matrix BwA4 English (L1)

	Phonemes	Age of acquisition	Familiarity	Imageability	Visual complexity
Phonemes	—				
Age of acquisition	0.441	—			
Familiarity	-0.246	-0.602	—		
Imageability	0.083	-0.104	0.051	—	
Visual complexity	0.094	0.107	-0.378	-0.026	—

Table E2

Binomial Logistic Regression BwA4 English (L1) – Model Fit Measures, Predictive Measures

Model Fit Measures									Predictive measures – Accuracy[a]
						Overall Model Test			
Model	Deviance	AIC	BIC	R^2_{CS}	R^2_N	χ^2	df	p	
1	152	164	184	0.00588	0.0108	1.16	5	0.949	0.867

[a] The cut-off value is set to 0.5.

Table E3

Binomial Logistic Regression BwA4 English (L1) – Model Coefficients, Collinearity Statistics, Omnibus Likelihood Radio Tests

	Model Coefficients - Accuracy							Collinearity Statistics		Omnibus Likelihood Ratio Tests		
						95% CI						
Predictor	Estimate	SE	Z	p	OR	Lower	Upper	VIF	T	χ^2	df	p
Intercept	0.92412	6.124	0.1509	0.880	2.520	1.54e-5	411555.70					
Phonemes	-0.07500	0.134	-0.5612	0.575	0.928	0.714	1.21	1.29	0.778	0.3105	1	0.577
Age of acquisition	-0.17299	0.407	-0.4247	0.671	0.841	0.379	1.87	2.00	0.500	0.1777	1	0.673
Familiarity	0.00341	0.254	0.0134	0.989	1.003	0.610	1.65	1.97	0.509	1.81e-4	1	0.989
Imageability	0.24879	0.836	0.2974	0.766	1.282	0.249	6.61	1.03	0.970	0.0857	1	0.770
Visual complexity	0.06289	0.441	0.1426	0.887	1.065	0.449	2.53	1.24	0.808	0.0203	1	0.887

Note. Estimates represent the log odds of "accuracy = 1" vs. "accuracy = 0". CI=Confidence Interval, OR=Odds ratio, T=Tolerance.

Correlation Matrix Outcome and Logistic Regression Outcome for BwA4 in German (L2)

Table E4

Correlation Matrix BwA4 German (L2)

	Phonemes	Age of acquisition	Familiarity	Imageability	Visual complexity
Phonemes	—				
Age of acquisition	0.477	—			
Familiarity	-0.119	-0.255	—		
Imageability	0.070	-0.315	0.180	—	
Visual complexity	0.125	0.106	-0.321	-0.002	—

Table E5

Binomial Logistic Regression BwA4 German (L2) – Model Fit Measures, Predictive Measures

Model Fit Measures									Predictive measures – Accuracy[a]
						Overall Model Test			
Model	Deviance	AIC	BIC	R^2_{CS}	R^2_N	χ^2	df	p	
1	68.0	80.0	92.3	0.131	0.178	8.00	5	0.156	0.667

[a] The cut-off value is set to 0.5.

Table E6

Binomial Logistic Regression BwA4 German (L2) – Model Coefficients, Collinearity Statistics, Omnibus Likelihood Radio Tests

	Model Coefficients - Accuracy							Collinearity Statistics		Omnibus Likelihood Ratio Tests		
						95% CI						
Predictor	Estimate	SE	Z	p	OR	Lower	Upper	VIF	T	χ^2	df	p
Intercept	-15.65154	7.598	-2.0599	0.039	1.59e-7	5.43e-14	0.468					
Phonemes	-0.17817	0.243	-0.7319	0.464	0.837	0.519	1.348	1.24	0.803	0.5381	1	0.463
Age of acquisition	0.08688	0.458	0.1897	0.850	1.091	0.445	2.676	1.32	0.757	0.0359	1	0.850
Familiarity	-0.00548	0.526	-0.0104	0.992	0.995	0.355	2.790	1.44	0.695	1.09e-4	1	0.992
Imageability	2.64813	1.103	2.3999	0.016	14.128	1.625	122.829	1.19	0.844	7.5110	1	0.006
Visual complexity	0.32959	0.595	0.5541	0.580	1.390	0.433	4.461	1.38	0.724	0.3107	1	0.577

Note. Estimates represent the log odds of "accuracy = 1" vs. "accuracy = 0". CI=Confidence Interval, OR=Odds ratio, T=Tolerance.

Error Rates per Error Type in English (L1) and German (L2) for BwA4

Table E7

Distribution of Errors per Error Type in English (L1) and German (L2) for BwA4

	English (L1)				German (L2)			
	Target language		Non-target language		Target language		Non-target language	
Error type	Number of errors	% all errors	Number of errors	% all errors	Number of errors	% all errors	Number of errors	% all errors
Phonological error	2	3.03	0	0	21	15.44	2	1.47
Phonologically unrelated non-word	0	0	0	0	3	2.21	0	0
Semantic error	21	31.82	1	1.51	20	14.71	2	1.47
Semantically unrelated error	1	1.52	0	0	0	0	1	0.74
Semantically unrelated non-word	0	0	0	0	0	0	0	0
Semantic-than-phonological error	0	0	0	0	3	2.21	1	0.74
Mixed error	0	0	0	0	0	0	0	0
Morphological error	3	4.55	0	0	11	8.09	1	0.74
Unspecified error	1	1.52	0	0	5	3.68	0	0
Multiword circumlocution	0	0	0	0	1	0.74	0	0
Single word circumlocution	0	0	0	0	0	0	0	0
Perseveration	0	0	0	0	0	0	0	0
Visual error	8	12.12	0	0	7	5.15	0	0

Acceptable semantic alternative	5	7.58	0	0	10	7.35	0	0
Use-of-language error	4	6.06	0	0	0	0	2	1.47
Other error	4	6.06	0	0	5	3.68	0	0
No response	14	21.21	--	--	18	13.24	--	--
Correct in non-target language	--	--	2	3.03	--	--	21	15.44

Table E8

Distribution of Language Mixing Errors in English (L1) and German (L2) for BwA4

	English (L1)		German (L2)	
Language mixing errors	Number of errors	% all errors	Number of errors	% all errors
Language mixing error I	0	0	0	0
Language mixing error II: Back-translation error	0	0	2	1.47

Appendix F

Results of BwA5

Correlation Matrix Outcome and Logistic Regression Outcome for BwA5 in English (L1)

Table F1

Correlation Matrix BwA5 English (L1)

	Phonemes	Age of acquisition	Familiarity	Imageability	Visual complexity
Phonemes	—				
Age of acquisition	0.446	—			
Familiarity	-0.225	-0.596	—		
Imageability	0.139	-0.145	0.102	—	
Visual complexity	0.112	0.153	-0.390	-0.036	—

Table F2

Binomial Logistic Regression BwA5 English (L1) – Model Fit Measures, Predictive Measures

Model Fit Measures									Predictive measures – Accuracy[a]
						Overall Model Test			
Model	Deviance	AIC	BIC	R^2_{CS}	R^2_N	χ^2	df	p	
1	219	231	251	0.0733	0.107	15.4	5	0.009	0.723

[a] The cut-off value is set to 0.5.

Table F3

Binomial Logistic Regression BwA5 English (L1) – Model Coefficients, Collinearity Statistics, Omnibus Likelihood Radio Tests

	Model Coefficients - Accuracy							Collinearity Statistics		Omnibus Likelihood Ratio Tests		
						95% CI						
Predictor	Estimate	SE	Z	p	OR	Lower	Upper	VIF	T	χ^2	df	p
Intercept	-11.9636	6.383	-1.8742	0.061	6.37e-6	2.35e-11	1.73	1.33	0.753			
Phonemes	-0.1354	0.116	-1.1701	0.242	0.873	0.696	1.10	2.12	0.472	1.40742	1	0.235
Age of acquisition	-0.5095	0.356	-1.4297	0.153	0.601	0.299	1.21	2.17	0.461	2.14199	1	0.143
Familiarity	-0.0140	0.209	-0.0669	0.947	0.986	0.654	1.49	1.12	0.891	0.00447	1	0.947
Imageability	1.9494	0.894	2.1804	0.029	7.024	1.218	40.52	1.31	0.761	5.63080	1	0.018
Visual complexity	0.0563	0.356	0.1584	0.874	1.058	0.527	2.12	1.33	0.753	0.02512	1	0.874

Note. Estimates represent the log odds of "accuracy = 1" vs. "accuracy = 0". CI=Confidence Interval, OR=Odds ratio, T=Tolerance.

Correlation Matrix Outcome and Logistic Regression Outcome for BwA5 in Italian (L1)

Table F4

Correlation Matrix BwA5 Italian (L1)

	Phonemes	Age of acquisition	Familiarity	Imageability	Visual complexity
Phonemes	—				
Age of acquisition	0.202	—			
Familiarity	-0.002	-0.443	—		
Imageability	0.076	-0.353	0.646	—	
Visual complexity	0.101	0.142	-0.216	-0.141	—

Error Rates per Error Type in English (L1) and Italian (L1) for BwA5

Table F5

Distribution of Errors per Error Type in English (L1) and Italian (L1) for BwA5

	English (L1)				Italian (L1)			
	Target language		Non-target language		Target language		Non-target language	
Error type	Number of errors	% all errors	Number of errors	% all errors	Number of errors	% all errors	Number of errors	% all errors
Phonological error	5	1.76	0	0	1	0.28	1	0.28
Phonologically unrelated non-word	0	0	0	0	0	0	0	0
Semantic error	33	11.62	0	0	0	0	29	8.15
Semantically unrelated error	6	2.11	0	0	2	0.56	3	0.84
Semantically unrelated non-word	0	0	0	0	0	0	0	0
Semantic-than-phonological error	0	0	0	0	0	0	0	0
Mixed error	0	0	0	0	0	0	0	0
Morphological error	5	1.76	0	0	0	0	6	1.69
Unspecified error	3	1.06	0	0	0	0	5	1.40
Multiword circumlocution	13	4.58	0	0	0	0	7	1.97
Single word circumlocution	5	1.76	0	0	0	0	0	0
Perseveration	0	0	0	0	0	0	0	0
Visual error	0	0	0	0	0	0	0	0

Acceptable semantic alternative	3	1.06	0	0	0	0	2	0.56
Use-of-language error	2	0.70	0	0	0	0	2	0.56
Other error	86	30.28	0	0	0	0	66	18.54
No response	123	43.31	--	--	167	46.91	--	--
Correct in non-target language	--	--	0	0	--	--	65	18.26

Table F6

Distribution of Language Mixing Errors in English (L1) and Italian (L1) for BwA5

	English (L1)		Italian (L1)	
Language mixing errors	Number of errors	% all errors	Number of errors	% all errors
Language mixing error I	0	0	0	0
Language mixing error II: Back-translation error	0	0	0	0

Appendix G

Results of BwA6

Correlation Matrix Outcome and Logistic Regression Outcome for BwA6 in English (L1)

Table G1

Correlation Matrix BwA6 English (L1)

	Phonemes	Age of acquisition	Familiarity	Imageability	Visual complexity
Phonemes	—				
Age of acquisition	0.487	—			
Familiarity	-0.280	-0.583	—		
Imageability	0.073	-0.091	0.070	—	
Visual complexity	0.143	0.109	-0.364	0.026	—

Table G2

Binomial Logistic Regression BwA6 English (L1) – Model Fit Measures, Predictive Measures

Model Fit Measures									Predictive measures – Accuracy[a]
						Overall Model Test			
Model	Deviance	AIC	BIC	R^2_{CS}	R^2_N	χ^2	df	p	
1	121	133	153	0.0302	0.0658	6.34	5	0.274	0.908

[a] The cut-off value is set to 0.5.

Table G3

Binomial Logistic Regression BwA6 English (L1) – Model Coefficients, Collinearity Statistics, Omnibus Likelihood Radio Tests

	Model Coefficients - Accuracy							Collinearity Statistics		Omnibus Likelihood Ratio Tests		
						95% CI						
Predictor	Estimate	SE	Z	p	OR	Lower	Upper	VIF	T	χ^2	df	p
Intercept	4.2632	6.825	0.6246	0.532	71.039	1.10e-4	4.58e+7					
Phonemes	0.1498	0.168	0.8935	0.372	1.162	0.836	1.613	1.38	0.724	0.83444	1	0.361
Age of acquisition	-1.0134	0.438	-2.3144	0.021	0.363	0.154	0.856	1.75	0.570	5.16185	1	0.023
Familiarity	-0.2047	0.273	-0.7485	0.454	0.815	0.477	1.393	1.64	0.611	0.56723	1	0.451
Imageability	0.0549	0.996	0.0551	0.956	1.056	0.150	7.438	1.08	0.925	0.00301	1	0.956
Visual complexity	0.3575	0.522	0.6850	0.493	1.430	0.514	3.976	1.20	0.831	0.46771	1	0.494

Note. Estimates represent the log odds of "accuracy = 1" vs. "accuracy = 0". CI=Confidence Interval, OR=Odds ratio, T=Tolerance.

Correlation Matrix Outcome and Logistic Regression Outcome for BwA6 in French (L2)

Table G4

Correlation Matrix BwA6 French (L2)

	Phonemes	Age of acquisition	Familiarity	Imageability	Visual complexity
Phonemes	—				
Age of acquisition	0.452	—			
Familiarity	-0.246	-0.641	—		
Imageability	0.004	-0.404	0.203	—	
Visual complexity	0.128	0.207	-0.438	-0.068	—

Table G5

Binomial Logistic Regression BwA6 French (L2) – Model Fit Measures, Predictive Measures

Model Fit Measures									Predictive measures – Accuracy[a]
						Overall Model Test			
Model	Deviance	AIC	BIC	R^2_{CS}	R^2_N	χ^2	df	p	
1	148	160	178	0.231	0.317	37.3	5	< .001	0.768

[a] The cut-off value is set to 0.5.

Table G6

Binomial Logistic Regression BwA6 French (L2) – Model Coefficients, Collinearity Statistics, Omnibus Likelihood Radio Tests

Model Coefficients - Accuracy								Collinearity Statistics		Omnibus Likelihood Ratio Tests		
						95% CI						
Predictor	Estimate	SE	Z	p	OR	Lower	Upper	VIF	T	χ^2	df	p
Intercept	0.8900	4.316	0.206	0.837	2.435	5.17e-4	11480.842					
Phonemes	0.0438	0.143	0.306	0.760	1.045	0.7892	1.383	1.24	0.804	0.0937	1	0.759
Age of acquisition	-1.7560	0.531	-3.310	< .001	0.173	0.0611	0.489	2.01	0.499	12.0987	1	< .001
Familiarity	0.1953	0.234	0.836	0.403	1.216	0.7690	1.922	1.82	0.550	0.7066	1	0.401
Imageability	0.2721	0.543	0.501	0.616	1.313	0.4528	3.805	1.19	0.842	0.2618	1	0.609
Visual complexity	0.5254	0.437	1.203	0.229	1.691	0.7182	3.982	1.30	0.769	1.4695	1	0.225

Note. Estimates represent the log odds of "accuracy = 1" vs. "accuracy = 0". CI=Confidence Interval, OR=Odds ratio, T=Tolerance.

Error Rates Per Error Type in English (L1) and French (L2) for BwA6

Table G7

Distribution of Errors per Error Type in English (L1) and French (L2) for BwA6

	English (L1)				French (L2)			
	Target language		Non-target language		Target language		Non-target language	
Error type	Number of errors	% all errors	Number of errors	% all errors	Number of errors	% all errors	Number of errors	% all errors
Phonological error	2	3.92	0	0	21	11.93	1	0.57
Phonologically unrelated non-word	0	0	0	0	6	3.41	0	0
Semantic error	7	13.73	0	0	30	17.05	3	1.70
Semantically unrelated error	0	0	0	0	6	3.41	0	0
Semantically unrelated non-word	0	0	0	0	0	0	0	0
Semantic-than-phonological error	0	0	0	0	3	1.70	0	0
Mixed error	0	0	0	0	0	0	0	0
Morphological error	4	7.84	0	0	5	2.84	1	0.57
Unspecified error	7	13.73	0	0	3	1.70	3	1.70
Multiword circumlocution	0	0	0	0	4	2.27	0	0
Single word circumlocution	2	3.92	0	0	1	0.57	0	0
Perseveration	0	0	0	0	0	0	0	0
Visual error	3	5.88	0	0	3	1.70	0	0

Acceptable semantic alternative	9	17.65	0	0	5	2.84	0	0
Use-of-language error	4	7.84	0	0	2	1.14	1	0.57
Other error	5	9.80	0	0	2	1.14	4	2.27
No response	4	7.84	--	--	37	21.02	--	--
Correct in non-target language	--	--	4	7.84	--	--	34	19.32

Table G8

Distribution of Language Mixing Errors in English (L1) and French (L2) for BwA6

	English (L1)		French (L2)	
Language mixing errors	Number of errors	% all errors	Number of errors	% all errors
Language mixing error I	0	0	0	0
Language mixing error II: Back-translation error	0	0	1	0.57

Appendix H

Results of BwA7

Correlation Matrix Outcome and Logistic Regression Outcome for BwA7 in French (L1)

Table H1

Correlation Matrix BwA7 French (L1)

	Phonemes	Age of acquisition	Familiarity	Imageability	Visual complexity
Phonemes	—				
Age of acquisition	0.452	—			
Familiarity	-0.246	-0.641	—		
Imageability	0.004	-0.404	0.203	—	
Visual complexity	0.128	0.207	-0.438	-0.068	—

Table H2

Binomial Logistic Regression BwA7 French (L1) – Model Fit Measures, Predictive Measures

Model Fit Measures									Predictive measures – Accuracy[a]
						Overall Model Test			
Model	Deviance	AIC	BIC	R^2_{CS}	R^2_N	χ^2	df	p	
1	116	128	146	0.105	0.173	15.7	5	0.008	0.824

[a] The cut-off value is set to 0.5.

Table H3

Binomial Logistic Regression BwA7 French (L1) – Model Coefficients, Collinearity Statistics, Omnibus Likelihood Radio Tests

	Model Coefficients - Accuracy							Collinearity Statistics		Omnibus Likelihood Ratio Tests		
						95% CI						
Predictor	Estimate	SE	Z	p	OR	Lower	Upper	VIF	T	χ^2	df	p
Intercept	-2.8540	4.653	-0.613	0.540	0.0576	6.31e-6	525.75					
Phonemes	0.0976	0.169	0.578	0.563	1.1025	0.792	1.53	1.37	0.730	0.337	1	0.562
Age of acquisition	-0.9859	0.580	-1.701	0.089	0.3731	0.120	1.16	2.43	0.412	2.917	1	0.088
Familiarity	-0.2498	0.271	-0.922	0.356	0.7790	0.458	1.32	2.01	0.498	0.848	1	0.357
Imageability	1.2767	0.583	2.192	0.028	3.5848	1.145	11.23	1.22	0.820	5.598	1	0.018
Visual complexity	-0.6444	0.519	-1.242	0.214	0.5250	0.190	1.45	1.22	0.821	1.586	1	0.208

Note. Estimates represent the log odds of "accuracy = 1" vs. "accuracy = 0". CI=Confidence Interval, OR=Odds ratio, T=Tolerance.

Correlation Matrix Outcome and Logistic Regression Outcome for BwA7 in English (L2)

Table H4

Correlation Matrix BwA7 English (L2)

	Phonemes	Age of acquisition	Familiarity	Imageability	Visual complexity
Phonemes	—				
Age of acquisition	0.487	—			
Familiarity	-0.280	-0.583	—		
Imageability	0.073	-0.091	0.070	—	
Visual complexity	0.143	0.109	-0.364	0.026	—

Table H5

Binomial Logistic Regression BwA7 English (L2) – Model Fit Measures, Predictive Measures

Model Fit Measures									Predictive measures – Accuracy[a]
						Overall Model Test			
Model	Deviance	AIC	BIC	R^2_{CS}	R^2_N	χ^2	df	p	
1	172	184	204	0.0307	0.0531	6.45	5	0.265	0.850

[a] The cut-off value is set to 0.5.

Table H6

Binomial Logistic Regression BwA7 English (L2) – Model Coefficients, Collinearity Statistics, Omnibus Likelihood Radio Tests

Model Coefficients - Accuracy								Collinearity Statistics		Omnibus Likelihood Ratio Tests		
						95% CI						
Predictor	Estimate	SE	Z	p	OR	Lower	Upper	VIF	T	χ^2	df	p
Intercept	-6.5782	4.581	-1.4361	0.151	0.00139	1.75e-7	11.02					
Phonemes	-0.0463	0.126	-0.3664	0.714	0.95476	0.745	1.22	1.32	0.759	0.13331	1	0.715
Age of acquisition	0.0124	0.385	0.0321	0.974	1.01245	0.476	2.15	1.90	0.526	0.00103	1	0.974
Familiarity	0.1642	0.230	0.7124	0.476	1.17844	0.750	1.85	1.82	0.550	0.50930	1	0.475
Imageability	1.2988	0.644	2.0153	0.044	3.66477	1.036	12.96	1.06	0.947	3.80414	1	0.051
Visual complexity	-0.3292	0.408	-0.8073	0.419	0.71948	0.324	1.60	1.24	0.806	0.65843	1	0.417

Note. Estimates represent the log odds of "accuracy = 1" vs. "accuracy = 0". CI=Confidence Interval, OR=Odds ratio, T=Tolerance.

Error Rates per Error Type in French (L1) and English (L2) for BwA7

Table H7

Distribution of Errors per Error Type in French (L1) and English (L2) for BwA7

	French (L1)				English (L2)			
	Target language		Non-target language		Target language		Non-target language	
Error type	Number of errors	% all errors	Number of errors	% all errors	Number of errors	% all errors	Number of errors	% all errors
Phonological error	3	2.70	0	0	2	1.94	0	0
Phonologically unrelated non-word	0	0	0	0	0	0	0	0
Semantic error	25	22.52	0	0	23	22.33	0	0
Semantically unrelated error	1	0.90	0	0	0	0	0	0
Semantically unrelated non-word	0	0	0	0	0	0	0	0
Semantic-than-phonological error	0	0	0	0	0	0	0	0
Mixed error	0	0	0	0	0	0	0	0
Morphological error	0	0	0	0	4	3.88	0	0
Unspecified error	1	0.90	0	0	5	4.85	0	0
Multiword circumlocution	0	0	0	0	1	0.97	0	0
Single word circumlocution	0	0	0	0	0	0	0	0
Perseveration	0	0	0	0	0	0	0	0
Visual error	12	10.81	0	0	12	11.65	0	0

Acceptable semantic alternative	10	9.01	3	2.70	11	10.68	0	0
Use-of-language error	2	1.80	0	0	3	2.91	0	0
Other error	13	11.71	0	0	12	11.65	0	0
No response	35	31.53	--	--	25	24.27	--	--
Correct in non-target language	--	--	4	3.60	--	--	3	2.91

Table H8

Distribution of Language Mixing Errors in French (L1) and English (L2) for BwA7

	French (L1)		English (L2)	
Language mixing errors	Number of errors	% all errors	Number of errors	% all errors
Language mixing error I	1	0.90	2	1.94
Language mixing error II: Back-translation error	1	0.90	0	0

Appendix I

Results BwA8

Correlation Matrix Outcome and Logistic Regression Outcome for BwA8 in French (L1)

Table I1

Correlation Matrix BwA8 French (L1)

	Phonemes	Age of acquisition	Familiarity	Imageability	Visual complexity
Phonemes	—				
Age of acquisition	0.452	—			
Familiarity	-0.246	-0.641	—		
Imageability	0.004	-0.404	0.203	—	
Visual complexity	0.128	0.207	-0.438	-0.068	—

Table I2

Binomial Logistic Regression BwA8 French (L1) – Model Fit Measures, Predictive Measures

Model Fit Measures									Predictive measures – Accuracy[a]
						Overall Model Test			
Model	Deviance	AIC	BIC	R^2_{CS}	R^2_N	χ^2	df	p	
1	143	155	172	0.179	0.257	28.1	5	< .001	0.746

[a] The cut-off value is set to 0.5.

Table I3

Binomial Logistic Regression BwA8 French (L1) – Model Coefficients, Collinearity Statistics, Omnibus Likelihood Radio Tests

	Model Coefficients - Accuracy							Collinearity Statistics		Omnibus Likelihood Ratio Tests		
						95% CI						
Predictor	Estimate	SE	Z	p	OR	Lower	Upper	VIF	T	χ^2	df	p
Intercept	3.8701	4.128	0.938	0.348	47.945	0.0147	156344.183					
Phonemes	0.0292	0.142	0.206	0.837	1.030	0.7795	1.360	1.25	0.798	0.0424	1	0.837
Age of acquisition	-2.1014	0.553	-3.803	< .001	0.122	0.0414	0.361	2.44	0.409	16.6177	1	< .001
Familiarity	-0.4272	0.241	-1.769	0.077	0.652	0.4064	1.047	2.15	0.464	3.2068	1	0.073
Imageability	0.3465	0.509	0.681	0.496	1.414	0.5220	3.831	1.18	0.851	0.4748	1	0.491
Visual complexity	0.3043	0.446	0.682	0.495	1.356	0.5655	3.250	1.24	0.806	0.4660	1	0.495

Note. Estimates represent the log odds of "accuracy = 1" vs. "accuracy = 0". CI=Confidence Interval, OR=Odds ratio, T=Tolerance.

Correlation Matrix Outcome and Logistic Regression Outcome for BwA8 in English (L2)

Table I4

Correlation Matrix BwA8 English (L2)

	Phonemes	Age of acquisition	Familiarity	Imageability	Visual complexity
Phonemes	—				
Age of acquisition	0.487	—			
Familiarity	-0.280	-0.583	—		
Imageability	0.073	-0.091	0.070	—	
Visual complexity	0.143	0.109	-0.364	0.026	—

Table I5

Binomial Logistic Regression BwA8 English (L2) – Model Fit Measures, Predictive Measures

Model Fit Measures									Predictive measures – Accuracy[a]
						Overall Model Test			
Model	Deviance	AIC	BIC	R^2_{CS}	R^2_N	χ^2	df	p	
1	174	186	206	0.0647	0.108	13.8	5	0.017	0.836

[a] The cut-off value is set to 0.5.

Table I6

Binomial Logistic Regression BwA8 English (L2) – Model Coefficients, Collinearity Statistics, Omnibus Likelihood Radio Tests

	Model Coefficients - Accuracy							Collinearity Statistics		Omnibus Likelihood Ratio Tests		
						95% CI						
Predictor	Estimate	SE	Z	p	OR	Lower	Upper	VIF	T	χ^2	df	p
Intercept	7.5279	5.962	1.263	0.207	1859.198	0.0156	2.21e+8					
Phonemes	-0.1701	0.122	-1.391	0.164	0.844	0.6638	1.07	1.35	0.742	1.9175	1	0.166
Age of acquisition	-0.6542	0.361	-1.810	0.070	0.520	0.2560	1.06	1.76	0.568	3.2287	1	0.072
Familiarity	-0.0253	0.223	-0.113	0.910	0.975	0.6301	1.51	1.71	0.585	0.0129	1	0.910
Imageability	-0.3589	0.839	-0.428	0.669	0.698	0.1349	3.62	1.06	0.944	0.1921	1	0.661
Visual complexity	-0.2352	0.425	-0.554	0.580	0.790	0.3436	1.82	1.25	0.798	0.3091	1	0.578

Note. Estimates represent the log odds of "accuracy = 1" vs. "accuracy = 0". CI=Confidence Interval, OR=Odds ratio, T=Tolerance.

Error Rates per Error Type in French (L1) and English (L2) for BwA8

Table I7

Distribution of Errors per Error Type in French (L1) and English (L2) for BwA8

	French (L1)				English (L2)			
	Target language		Non-target language		Target language		Non-target language	
Error type	Number of errors	% all errors	Number of errors	% all errors	Number of errors	% all errors	Number of errors	% all errors
Phonological error	19	15.20	0	0	13	18.06	0	0
Phonologically unrelated non-word	0	0	1	0.80	0	0	0	0
Semantic error	13	10.40	0	0	14	19.44	0	0
Semantically unrelated error	1	0.80	0	0	0	0	0	0
Semantically unrelated non-word	0	0	0	0	0	0	0	0
Semantic-than-phonological error	3	2.40	1	0.80	2	2.78	0	0
Mixed error	1	0.80	0	0	0	0	0	0
Morphological error	1	0.80	0	0	8	11.11	0	0
Unspecified error	2	1.60	0	0	3	4.17	0	0
Multiword circumlocution	0	0	0	0	0	0	0	0
Single word circumlocution	0	0	0	0	0	0	0	0
Perseveration	0	0	0	0	0	0	0	0
Visual error	3	2.40	0	0	2	2.78	0	0

Acceptable semantic alternative	15	12	0	0	11	15.28	0	0
Use-of-language error	0	0	0	0	3	4.17	0	0
Other error	5	4	1	0.80	3	4.17	0	0
No response	46	36.80	--	--	11	15.28	--	--
Correct in non-target language	--	--	9	7.20	--	--	2	2.78

Table I8

Distribution of Language Mixing Errors in French (L1) and English (L2) for BwA8

	French (L1)		English (L2)	
Language mixing errors	Number of errors	% all errors	Number of errors	% all errors
Language mixing error I	0	0	0	0
Language mixing error II: Back-translation error	4	3.20	0	0

Chapter 3:

Spoken Picture Naming Accuracy in Monolingual and Bilingual Speakers with Aphasia: Influence of Phonological Neighbourhood Within and Across Languages

(Study 2)

Introduction

Worldwide, there is a growing ageing population. According to the United Nations, one in six people in the world (16%) will be 65 or older in 2050 (United Nations, 2019). Additionally, the bilingual population is increasing, with 50% of the world's population already being bilingual (Grosjean, 2021). The growth of ageing and bilingual people across the globe increases age-related diseases like aphasia. Aphasia is an acquired language disorder caused by a brain injury such as a stroke (e.g., Schneider et al., 2021). As pointed out by Grosjean (1989) a bilingual speaker is not the sum of two monolingual speakers. However, existing theoretical models of language perception and production that are used to assess and treat aphasia are predominantly based on monolingual language processes (e.g., Dell et al., 2007; Levelt et al., 1999), and bilingual theories are still under-specified (e.g., Kroll et al., 2010) or are starting to emerge (Dijkstra et al., 2019). Hence, standardised assessment and treatment protocols for bilingual aphasia are still scarce. In turn, speech pathologists often feel overwhelmed when it comes to treatment decisions, in particular how to adapt their clinical practice to the unique characteristics of bilingual language processing to ensure the best outcomes for their clients (Rose et al., 2014).

Spoken Word Production

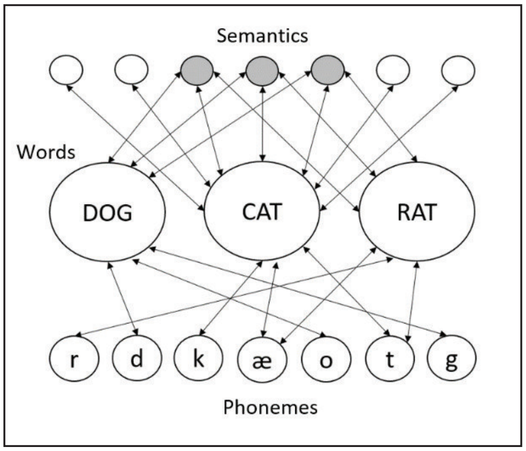
Spoken word finding difficulties are one of the main symptoms in people with aphasia and are, therefore, most commonly targeted in speech pathology interventions. Hence, spoken word production is a key area of concern to understand how language organisation varies in bilingual speakers. Models of monolingual word production in unimpaired speakers are well investigated (e.g., Dell et al., 2007; Levelt et al., 1999). These models agree on three major processing steps in spoken word production: Accessing the (a) non-lexical concept, (b) lexical semantic information, and (c) lexical form information. However, there is no consensus about the flow of information between the different levels. While some models propose an interactive information spread (e.g., Dell et al., 2007), other models like the Two-Stage model proposed by Levelt et al. (1999) assume a serial forward activation flow between levels. Models capturing the bilingual context have been published as well, for example MULTILINK (Dijkstra et al., 2019). MULTILINK is an interactive model where activation spread operates in bidirectional manner. The model includes the aspect of having more than one language within a bilingual language system. However, the MULTILINK model has a stronger focus on word recognition/comprehension rather than production.

Hence, the processing steps of spoken word production in a bilingual mental lexicon are not explained in detail.

According to the Interactive Activation Model of spoken language processing (Dell et al., 2007) three different steps/levels within an interconnected network of units or nodes are involved in monolingual word processing (see Figure 1): (a) semantic features (access of lexical-semantic information), (b) lexical selection (lemma activation at the word node level), and (c) phonological selection (activation of phonemes at the phoneme level). The model enables bidirectional connections between the semantic feature, lexical selection, and phonological selection nodes such that activated phonemes of selected words (lemmas) provide feedback to words (lemmas) with shared phonemes to the target word. While this model was initially developed for monolingual speakers, it is reasonable to assume that this can also be extended to impaired bilingual word production.

Figure 1

Interactive Activation Model of Spoken Language Processing (Dell et al., 2007)



Note. Arrows within the figure illustrate bidirectional activation.

However, more fine-grained aspects of processing a word are still under debate. For example, it remains unclear how the word selection of one word is influenced by the activation of similar-sounding word forms, so-called phonological neighbours (e.g., target *rain*, phonological neighbour *pain*).

Phonological Neighbourhood in Monolingual and Bilingual Speakers

Monolingual Speakers

Phonological neighbours differ from the target word in a single phoneme, such as (a) additions (*rain – train*), (b) deletions (*brain – rain*), (c) substitutions (*rain – pain)* (e.g., Marian, 2009). Phonological neighbourhood, referring to the set of phonological neighbours, can be further specified by density and frequency. Phonological neighbourhood density (PND) describes the number of neighbours a single word has available (e.g., *cat* has many neighbours, such as *mat* and *rat*), whereas phonological neighbourhood frequency (PNF) indicates how often each neighbour occurs in everyday language (e.g., *cat* has a higher occurrence than *mat*). Phonological neighbourhood frequency can be indicated by, for example, the individual neighbour frequency or the summed frequency of all phonological neighbours (e.g., Luce & Pisoni, 1998; Middleton & Schwartz, 2010).

In the context of monolingual speakers, it is suggested that activating a particular target word also activates its phonological neighbours (e.g., Luce et al., 1990). This can be explained by interactive speech production models, where the activation of phonological neighbours during spoken word production proceeds through feedback from the phoneme to the lexical level (e.g., Chen & Mirman, 2012; Dell & Gordon, 2003). This is only a plausible explanation in an interactive framework, and frameworks such as the Two-Stage model (e.g., Levelt et al., 1999) struggle to explain phonological similarity effects given there are no interactive links assumed between phoneme and word form level. A further question of interest is whether phonological neighbours that are activated together with the target word are more influential if they are high or low in frequency (neighbourhood frequency) and/or if there are many or only a few neighbours (neighbourhood density). It is still an open question whether and how these two factors influence word production.

Bilingual Speakers

The effects of phonological neighbourhood, including density and frequency, are less well understood in bilingual speakers. Bilingual speakers do not only have phonological neighbours within their available languages (see the explanation of PND and PNF above under monolingual speakers) but also across their languages (e.g., English *shower* and German *Bauer* [English for *farmer*]). Similar to the phonological neighbourhood within languages (PNDwithin, PNFwithin), phonological neighbourhood density (PNDacross) and frequency (PNFacross) can be determined across languages. Bilingual speakers also hold a specific form of phonological neighbours across languages, so-called cognates (e.g., Costa et al., 2005). Cognates are words with high phonological overlap and very similar or identical meaning to their non-target language translation equivalent (e.g., English *house*, German *Haus*).

In the context of bilingual speakers, simultaneous activation of the translation equivalent (cognate or no cognate) has been suggested (e.g., Costa et al., 2005). Additionally, researchers have hypothesized words of the non-target language (which do not need to be the translation equivalent) that are similar in phonological form to the word in the target language (e.g., Colomé, 2001) may be activated due to feedback between the phoneme level and word form level across both languages (e.g., Costa et al., 2006; Colomé, 2001; Colomé & Miozzo, 2010). Therefore, it is of interest (a) whether high or low-density across neighbourhood that either contains high- or low-frequency across neighbours can either facilitate or slow down the word search in a bilingual speaker, and (b) if the degree of phonological similarity across the target and non-target language translation equivalent (which can be either a cognate or not) influences word production in bilingual speakers.

PND/PNF Effects in Monolingual Speakers

Monolingual Healthy Speakers

The evidence for PND effects in picture naming is inconclusive (see Table 1). Literature report facilitatory, inhibitory and an absence of PND effects on spoken word naming. Gordon and Kurczek (2014) analysed the effect of PND on naming accuracy in picture naming in 31 adults and found no effect. These findings are in accordance with the results of studies investigating the PND effect in young adults (Vitevitch, 2002; Vitevitch et al., 2004). Another research group found higher accuracy in picture naming in 24 young adults with an increased PND (Newman & Bernstein Ratner, 2007). In contrast to these results, Newman and German (2005) found inhibitory PND effects on accuracy in 1075 individuals (717 adolescents and 358 adults) that named 44 pictures (22 with a low PND, and 22 with a high PND). New evidence from Hameau et al. (2021) suggests that the presence and direction of the effects of phonological neighbours could be influenced by the relative frequency of the target in comparison to its phonological neighbours: When the phonological neighbours were higher in frequency than their target, inhibitory effects were observed, but only for the naming of lower frequency targets. When phonological neighbours were lower in frequency compared to their target, there was a trend towards higher accuracy when naming higher frequency targets.

Only two studies considered the effect of PNF on spoken picture naming in healthy monolingual speakers and showed a facilitative phonological neighbourhood effect for correct word naming (Newman & Bernstein Ratner, 2007, Vitevitch & Sommers, 2003).

Table 1

PND/PNF Effects on Picture Naming Accuracy in Monolingual Healthy Speakers (Adults)

Study	PND effect on accuracy	PNF effect on accuracy
Gordon & Kurczek, 2014	No effect	NA
Vitevitch, 2002	No effect	NA
Vitevitch et al., 2004	No effect	NA
Newman & Bernstein Ratner, 2007	Higher accuracy	Higher accuracy
Newman & German, 2005	Less accuracy	NA
Hameau et al., 2021	Less accuracy: Naming of lower frequency targets Higher accuracy: Naming of higher frequency targets	
Vitevitch & Sommers, 2003	NA	Higher accuracy

Note. NA = Not investigated in this study, PND = Phonological neighbourhood density, PNF = Phonological neighbourhood frequency.

Monolingual Speakers with Aphasia

Studies addressing this specific question in monolingual speakers with aphasia found an increased picture naming accuracy when the target word was high in density (e.g., Gordon, 2002; Goldrick et al., 2010; Middleton & Schwartz, 2010) (see Table 2). Gordon (2002) presented a facilitation effect for higher PNDwithin in 43 participants, who named 175-line drawings of objects that varied in length and frequency. Goldrick et al. (2010) found the same effect in a single case study that included 260 pictures. Middleton and Schwartz (2010) found the PNDwithin effect on picture naming accuracy in three participants with aphasia that named 48 black-and-white pictures (24 low density/24 high density) of common everyday objects that were monosyllabic nouns. Mirman et al. (2010) published another study, where they investigated the effect of phonological neighbourhood with 175 black and white pictures in 62 people with aphasia by adding the aspect of distant (words with matching onsets, e.g., target: *salt*, distant phonological neighbour: *silt*) and close neighbours (homophones, e.g., *can* [container] and *can* [able]). They found higher naming accuracy in words with many distant phonological neighbours but less accuracy for words with near phonological neighbours. Laganaro et al. (2013) tested 21 French speakers with aphasia with 115 items and found that picture naming of words with high density elicited more phonological errors but less semantic and fewer non-word errors. We are aware of only a handful of unpublished studies (e.g., conference presentations) that reported no effects of density on spoken picture naming accuracy in people with aphasia (Palmer et al., 2018, Tichborne et al., 2021). Palmer et al. (2018) found no effect of density on spoken picture naming accuracy in three monolingual English-speaking people with aphasia who named 224 object pictures, whereas Tichborne et al. (2021) could only find PND effects on accuracy (items included: 32 colour drawings [16 high and 16 low PND words]) in one out of eight speakers with aphasia. Given that these are null effects, it is difficult to publish those data sets, but we would like to acknowledge their importance in this debate, contributing to the conclusion that there is currently inconsistent evidence base available that can inform us about the influence of phonological neighbours in bilingual word processing.

It also needs to be noted that only two of the studies above addressed the effect of phonological neighbourhood frequency on naming accuracy, with both studies finding no PNF effects (Gordon, 2002; Palmer et al., 2018).

Table 2

PND/PNF Effects on Spoken Picture Naming Accuracy in Monolingual Speakers with Aphasia

Study	PND effect on accuracy	PNF effect on accuracy
Gordon, 2002	Higher accuracy	No effect
Goldrick et al., 2010,	Higher accuracy	NA
Middleton & Schwartz, 2010	Higher accuracy	NA
Mirman et al., 2010	Higher accuracy for words with many distant PN Less accuracy for words with close PN	NA
Laganaro et al., 2013	More PE, Less SE and NWE	NA
Palmer, 2018[a]	No effect	No effect
Tichborne et al., 2021[a]	(Mostly) No effect	NA

Note. PE = Phonological errors, SE = Semantic errors, NWE = Non-word errors, PN = Phonological neighbours, NA = Not investigated in this study, PND = Phonological neighbourhood density, PNF = Phonological neighbourhood frequency.

[a] = Unpublished conference poster presentations.

PND/PNF Effects in Bilingual Speakers

Bilingual Healthy Speakers

To our knowledge, three studies investigated the influence of phonological neighbourhood on picture naming accuracy in bilingual speakers (see Table 3). In the study conducted by Marian and Blumenfeld (2006) German-English and English-German late bilinguals were compared to investigate the effects of PNDwithin. The study found that naming accuracy in German was generally higher (L1 and L2) for targets with a higher PNDwithin. Two studies examined the within- and across-effects of phonological neighbours in bilingual speakers. Sadat et al. (2016) tested early Catalan-Spanish bilinguals in Spanish and found neither PNDwithin (Spanish neighbours) nor PNDacross (Catalan neighbours) effects on accuracy if the target item was high in density. Another study that included late French-English bilingual speakers investigated the influence of PNDwithin (English neighbours) and PNDacross (French neighbours) on English picture naming (Hameau, Biedermann, & Nickels, 2021). The authors found that higher phonological neighbourhood density within and across languages had an inhibitory effect, but only for less familiar words. Conversely, for more familiar words, the effect tended to be facilitatory or even non-existent. The two studies that investigated the PNDacross effect only tested for the PNDacross effect in one direction (Sadat et al., 2016: Target Spanish, neighbours Catalan; Hameau et al., 2021: Target English, neighbours French). However, there might be effects in the other direction that should be investigated (example based on the two studies above: Sadat et al., 2016: Target Catan, neighbours Spanish; Hameau et al., 2021: Target French, neighbours English).

None of the studies mentioned above have examined the effects of phonological neighbourhood frequency within and across languages (PNFwithin or PNFacross) on picture naming accuracy.

Table 3

PND/PNF Effects on Picture Naming Accuracy in Bilingual Healthy Speakers

Study	PNDwithin effect on accuracy	PNDacross effect on accuracy	PNFwithin effect on accuracy	PNFacross effect on accuracy
Marian & Blumenfeld, 2006	Higher accuracy in L1 + L2	NA	NA	NA
Sadat et al., 2016	No effect	No effect	NA	NA
Hameau et al., 2021	Less accuracy for less familiar words Higher accuracy/no effect for familiar words		NA	NA

Note. L1 = First language, L2 = Second language, NA = Not investigated in this study, PND = Phonological neighbourhood density, PNF = Phonological neighbourhood frequency.

Bilingual Speakers with Aphasia

An unpublished conference poster presentation investigated spoken picture naming and the effect of phonological neighbourhood density and frequency in one bilingual person with aphasia (Palmer et al., 2018) (see Table 4). Neither within nor across phonological neighbourhood density and frequency proved beneficial for spoken word accuracy. However, there was a trend for less naming errors in naming pictures with high PNDwithin in the client's first language (Italian) and for less naming errors when naming pictures with high PNFwithin in the second language (English). Again, PNDacross and PNFacross were only tested in one direction (target: Italian, neighbours: English; not tested: Target English, neighbours Italian). To our knowledge, no further studies have addressed phonological neighbourhood effects across languages in bilingual people with aphasia, controlling for differing density and frequency properties of word items used.

Table 4

PND/PNF Effects on Spoken Picture Naming Accuracy in Bilingual Speakers with Aphasia

Study	PNDwithin effect on accuracy	PNDacross effect on accuracy	PNFwithin effect on accuracy	PNFacross effect on accuracy
Palmer et al., 2018[a]	No effect (Trend for higher accuracy in L1)	No effect	No effect (Weak trend for higher accuracy in L2)	No effect

Note. L1 = First language, L2 = Second language, PND = Phonological neighbourhood density, PNF = Phonological neighbourhood frequency.

[a] = Unpublished conference poster presentation.

Phonological Similarity Effects in Bilingual Speakers

Cognates (word pairs that share their meaning and have a high overlap in form e.g., tomato [English] vs Tomate [German]) are a specific form of phonological neighbours across languages in a bilingual speaker. Across the literature, there is a well-established phenomenon called the "cognate facilitation effect", whereby in healthy bilingual adults cognate words are named orally more quickly and accurately (Costa et al., 2000; Costa et al., 2005; Strijkers et al., 2010) compared to matched non-cognate stimuli. These results suggest that phonological similarity across the target word and non-target language translation equivalent might be influential on word finding in bilingual speakers.

In sum, the investigation of the effects of phonological neighbourhood on spoken picture naming in people with aphasia is scarce, especially in bilingual speakers with aphasia. Furthermore, while the effects of PND are commonly reported across different studies, the effects of PNF remain less examined in monolingual and bilingual speakers with aphasia. Hence, this study explores the effect of phonological neighbours on spoken picture naming accuracy in monolingual and bilingual speakers with aphasia.

Study Aim

The aim of this study was to investigate the influence of phonological neighbourhood on spoken picture naming accuracy in monolingual and bilingual speakers with aphasia. The influence of within-language phonological neighbours was examined for monolingual and bilingual speakers with aphasia, the influence of across-language phonological neighbours was investigated in bilingual speakers with aphasia.

Research question and prediction for monolingual speakers with aphasia

(1) Is there an influence of phonological neighbourhood density and/or phonological neighbourhood frequency within languages on picture naming accuracy in monolingual speakers with aphasia?

Given the inconsistent evidence base on phonological neighbourhood density effects on picture naming accuracy, neighbourhood density might show faciliatory, inhibitory or no effects on accuracy. Research on the influence of neighbourhood frequency is limited, while it is not feasible to draw predictions from previous research.

Research question and prediction for bilingual speakers with aphasia

(2) Is there an influence of within and/or across phonological neighbourhood density and/or frequency within and across languages on picture naming accuracy in bilingual speakers with aphasia?

Given the limited evidence base on phonological neighbourhood effects in bilingual speakers with aphasia, it is not feasible to draw predictions from previous research. Bilingual speakers with aphasia are a by nature heterogenous population and might show different effects based on individual participant factors.

The outcome of this study might help researchers and speech pathologists to better understand how similar-sounding words within and across languages affect picture naming accuracy. This will, in turn, be beneficial for composing meaningful assessment and treatment materials for monolingual and bilingual speakers with word finding difficulties in aphasia and enhance language production theories that are still underspecified for bilingual speakers (e.g., Kroll et al., 2010). Additionally, word sets for different language combinations, including phonological neighbourhood variables (within and across languages) and lexical variables, will be developed in the course of this project, that will be made available via an open-access resources to serve researchers in the future when exploring unimpaired and impaired bilingual word retrieval processes in different languages.

Participants

Monolingual and bilingual speakers with aphasia were recruited for this spoken picture naming study. Ten monolingual and eight bilingual participants were included based on the following inclusion and exclusion criteria: Post-acute or chronic aphasia (at least 3 months post-onset) and self-reported normal and/or corrected-to-normal hearing and vision. Identified potential participants with moderate to severe speech apraxia, dysarthria, other cognitive impairments (such as dementia), and/or severe language comprehension deficits were excluded. However, people with only mild cognitive impairments (e.g., attention, memory), mild dysarthria, or mild apraxia of speech were eligible to participate. Additionally, participants had to show spoken picture naming accuracy of more than 10% or less than 90% on the LEMO subtest 13 (‘LEMO 2.0 Lexikon modellorientiert. Diagnostik für Aphasie, Dyslexie und Dysgraphie’, Stadie et al., 2013) that was used as a screener across all participants. This standardised picture naming test is normed for the German language and includes ten low-frequent and ten high-frequent words. It needs to be noted that this classification may not be accurate when we translated the test into languages other than German.

Although we identified 13 potential monolingual individuals with aphasia, only ten of them were included in the study. Three participants did not meet the inclusion criteria and were excluded from participation due to various reasons (severe language impairment, unavailability/inaccessibility during the data collection, refusal to participate/request to withdraw from the project). We identified 22 potential bilingual participants. Out of the 22 potential participants, 14 bilingual speakers were excluded due to one or more of the above-stated exclusion criteria or their unavailability at the time of data collection.

All monolingual and bilingual participants received a study information letter and were given the chance to ask questions about participation (see General Appendix A). All participants needed to provide written consent for participation and for the researcher to access their demographic and medical data to underpin data analysis and interpretation (see General Appendix B). A personal data form (demographic questionnaire) designed for this study (based on the International Classification of Functioning, Disability, and Health [ICF]) was utilized to collect demographic and medical information and for the bilingual participants to collect information on the participant's bilingual language profile (see General Appendix C). The bilingual speakers additionally completed the Language Experience and Proficiency Questionnaire (LEAP-Q, Marian et al., 2007) to provide detailed information on their bilingual language profile, such as their language history, language age of acquisition and language dominance. The Language Experience and Proficiency Questionnaire is a questionnaire originally designed for healthy bilingual speakers. Consequently, the completion of the questionnaire required a specifically tailored approach since the original questions were not aphasia friendly in nature. Therefore, the researcher assisted the participant with the completion of the questionnaire by reading the questions aloud. Participants were given the opportunity to have the questions repeated or clarified as many times as needed. Additionally, support was given for example by visual aids in form of a numerical scale ranging from one to ten. To assess post-stroke language performance, thirteen subtests of the Bilingual Aphasia Test (BAT, Paradis & Libben, 1987) were administered to all monolingual participants and carried out across both languages in all bilingual speakers. The following thirteen subtests of the BAT were administered: Pointing, simple and semi-complex commands, complex commands, verbal auditory discrimination, semantic categories, synonyms, repetition, lexical decision of words and nonsense words, series, verbal fluency, naming, reading words, and reading comprehension for words. Since the BAT does not test for written naming, written naming abilities were screened by using the first 30 items of Subset 1a of the experimental picture naming task. Written naming was always administered after the experimental task to control for potential priming or repetition effects.

A comprehensive overview of the individual demographic and medical data, the background language assessment data and, for the bilingual participants, the bilingual language profile data is given in Appendix A (monolinguals) and General Appendix E (bilinguals). A summary of these data for monolingual and bilingual speakers is provided below.

This project received ethics approval from three different ethic committees (see Appendix X): Bielefeld University in Germany (EUB 2020-137-Am), Curtin University in Perth (HRE2017-0274), South Metropolitan Health Service Human Research (RGS0000003763) (see General Appendix D).

Monolingual Speakers with Aphasia

Demographic and Medical Data of all MwA

A summary of the demographic and medical data of all ten monolingual speakers with aphasia is given in Table 5. The ten participants (two female) were aged between 49 and 84 years (mean 66.75 years, SD 11.20 years). Five were monolingual German speakers, the other five were monolingual Australian-English speakers. All ten individuals were post-onset between 8 months and 25 years (mean 155.7 months [13.0 years], SD 111.7 [9.3 years]) and presented with a left hemisphere stroke. One participant (MwA5) had a stroke within the left and right hemisphere. For detailed information on stroke lesions, see Appendix A. According to medical records and the participants' self-reports, the stroke resulted in aphasia in all ten speakers.

Background Language Assessment Data of all MwA

To investigate the severity of the individual language disorder in each monolingual participant, background language assessments across expressive and receptive task were carried out (see Table 5 for a summary of spoken naming data). The pattern of language impairment across participants was consistent with the diagnosis of anomic aphasia (MwA2, MwA4, MwA5, MwA7, MwA8, MwA9, MwA10), Broca's aphasia (MwA3, MwA6) or unclassified aphasia (MwA1)[17].

Spoken picture naming was screened by Subtest 13 of the LEMO. Accuracy ranged from 45% to 90%. Thirteen subtests of the BAT were conducted to assess the language performance across language modalities (for a list of all 13 subtests see above). Based on the BAT results (Appendix A), all of the participants presented with a language impairment. Spoken picture naming accuracy within the BAT subtest ranged from 30% to 100%. For detailed results on the background language assessments of each participant see Appendix A.

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[17] Aphasia syndrome classifications are based on the following information: (i) Clinical observations during the project, (ii) the BAT and LEMO background assessment results, and (iii) speech pathology reports (if available).

Table 5

Summary Data on Background Information of all Monolingual Speakers with Aphasia

Demographic and medical data						Language background assessment data		
			Stroke				Naming results	
ID	Age [y]	Sex	Post onset [y;m]	Lesion hemisphere	Aetiology	Aphasia type[a]	BAT - % correct	LEMO - % correct
MwA1	84	Male	7;8	LH	Ischaemic	Unclassified	30	45
MwA2	75	Male	25	LH	Ischaemic	Anomic	75	75
MwA3	57	Male	19;2	LH	Ischaemic	Broca	65	85
MwA4	49	Female	8;3	LH	Haemorrhagic	Anomic	100	90
MwA5	59	Male	0;8	LH, RH	Ischaemic	Anomic	90	80
MwA6	73	Male	15	LH	Ischaemic	Broca	60	45
MwA7	63	Male	7	LH	Ischaemic	Anomic	100	65
MwA8	65	Male	11	LH	Haemorrhagic	Anomic	90	80
MwA9	49	Male	5;11	LH	Haemorrhagic	Anomic	85	90
MwA10	63	Female	2;8	LH	Ischaemic	Anomic	100	90

Note. y = Years, m = Months, LH = Left hemisphere, RH = Right hemisphere, BAT = Bilingual Aphasia Test, LEMO = Lexikon modellorientiert. Diagnostik für Aphasie, Dyslexie und Dysgraphie (Stadie et al., 2013).

[a] Aphasia syndrome classifications are based on the following information: (i) Clinical observations during the project, (ii) the BAT and LEMO background assessment results, and (iii) speech pathology reports (if available).

Bilingual Speakers with Aphasia

Demographic and Medical Data of all BwA

Table 6 summarizes the demographic and medical data of the eight bilingual speakers with aphasia. The bilingual participants (four female, four male) were aged between 55 and 75 (mean 66.1 years, SD 6.3 years) and post-onset between 11 months and 28 years (mean 119.9 months [10 years], SD 109.5 months [9.1 years]). Seven participants had a left hemisphere stroke (BwA1, BwA2, BwA3, BwA4, BwA5, BwA6, and BwA8). BwA7 had a right hemisphere stroke. Two of the seven participants with a left hemisphere stroke also had additional lesions in either the right hemisphere (BwA8) or in the right hemisphere and cerebellum (BwA2). Details on the stroke locations are provided for each participant in General Appendix E. According to the participants' self-reports and medical records, all participants experienced aphasia after their stroke.

Bilingual Language Profile Data of all BwA

Six different language profiles were presented by the bilingual participants: Dutch-German (BwA1, BwA3), Polish-German (BwA2), English-German (BwA4), English-Italian (BwA5), English-French (BwA6), and French-English (BwA7, BwA8). Dutch, Polish, English, Italian, or French were the participants' L1, either German, French, or English were classified as their L2. Seven individuals were identified as late bilinguals, since they fully immersed in their second language between the age of 17 and 35, while BwA5 was an early bilingual who acquired English and Italian from birth (see Table 6).

Pre- and post-stroke, the L2 was the dominant language in four participants (BwA1, BwA3, BwA7, BwA8), while the L1 was the dominant language in BwA4, BwA5, BwA6. The language dominance was equally distributed among languages for BwA2. The dominant language was determined by the participants' language proficiency, language exposure and use, and biographical factors (language age of acquisition, environmental languages, language of residence). Language proficiency was determined by the language background assessments, spanning across receptive and expressive tasks that were conducted with every participant (see below). Biographical factors were conducted by the LEAP-Q and the participants' self-reports. Language use and exposure were determined by an assessment that evaluated the participants' use of each language for the following eight categories: Interaction with family, interaction with friends, daily life activities (e.g., supermarket, medical appointments, restaurant), TV, radio/music, smartphone/social media/internet/computer, reading, and writing. Each category was matched by either "using mostly my L1 in this category" (one point L1, zero points L2), 'using mostly my L2 in this category' (zero points

L1, one point L2), or 'using both languages in this category' (one point L1, one point L2). Accordingly, the language use and exposure were defined by a score on a scale between zero and eight (zero = no/minor language use and exposure, eight = high language use and exposure). For detailed information on the participants' language use and exposure refer to General Appendix E.

Background Language Assessment Data of all BwA

We used various background assessments to determine the language performance of both languages in all bilingual participants (see Table 6 for a summary of spoken naming data). The language impairment pattern was consistent with the diagnosis of either anomic aphasia (BwA2, BwA3, BwA4, BwA6, BwA7, BwA8) or Broca's aphasia (BwA1, BwA5)[18].

The LEMO picture naming screener results showed 0% and 90% accuracy across participants. The language performance of the participants was evaluated across languages and modalities by the 13 subtests of the BAT as listed above. Within the BAT spoken picture naming subtest, participants showed an accuracy between 6.25% to 100%. The written naming abilities were screened in each language in each participant by the first 30 items of Subset 1a of the experimental task (always administered after the experimental picture naming task to control for potential priming or repetition effects). For a detailed outcome of all background language assessments in all participants, see General Appendix E. All participants reported a parallel language recovery across their languages.

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[18] Aphasia syndrome classifications are based on the following information: (i) Clinical observations during the project, (ii) the BAT and LEMO background assessment results, and (iii) speech pathology reports (if available).

Table 6

Summary Data on Background Information of all Bilingual Speakers with Aphasia

Demographic and medical data						Bilingual language profile data				Language background assessment data					
			Stroke								Naming results				
											BAT		LEMO		
											% correct		% correct		
ID	Age [y]	Sex	Post-Onset [y;m]	Lesion hemisphere	Aetiol	L1	L2	Dominant language	L2 AoA	Aphasia type[f]	L1	L2	L1	L2	Recovery pattern
BwA1	55	F	10;4	LH	Isch[g]	Dutch	German^	L2	23	Broca	65	90	30	55	parallel
BwA2	66	M	0;11	Cereb, LH, RH[a]	Isch[g]	Polish	German^	L1/L2	35	Anomic	95	60	85	60	parallel
BwA3	64	M	30/28[b]/14	LH	Isch[h]	Dutch	German^	L2	25	Anomic	80	60	75	50	parallel
BwA4	75	F	2;9	LH	Isch[h]	English^	German	L1	27	Anomic	100	80	80	65	parallel
BwA5	64	M	4/1;8/1;3[b]	LH	Isch[g]	English^[d]	Italian[d]	L1: EN[e]	From birth	Broca	62.5	6.25	30	0	parallel[i]
BwA6	65	F	8	LH	Isch[g]	English^	French	L1	17	Anomic	94.74	89.47	75	65	parallel
BwA7	66	M	16	RH	Isch[g]	French	English^	L2	28	Anomic	95	95	80	80	parallel
BwA8	74	F	12;8[b]/9/0;3[c]	LH, RH	Isch[h]	French	English^	L2	28	Anomic	100	100	85	90	parallel

Note. y = Years, F = Female, M = Male, m = Months, LH = Left hemisphere, RH = Right hemisphere, Cereb = Cerebellum, Aetiol = Aetiology, Isch = Ischaemic stroke, ^ = Dominant language, AoA = Age of acquisition.

[a] See further important information about lesions in General Appendix E.

[b] Stroke that resulted in aphasia.

[c] BwA8 suffered a mild stroke after recruitment. Neither the patient nor its carers reported any change in her communication after the mild stroke. Testing did not commence until three months after this stroke.

[d] Parallel language acquisition.

[e] English and Italian are the BwA5's first languages, and English is the BwA5's dominant language pre-stroke and post-stroke.

[f] Aphasia syndrome classifications are based on the following information: (i) Clinical observations during the project, (ii) the BAT and LEMO background assessment results, and (iii) speech pathology reports (if available).

[g] Based on medical records.

[h] Based on the participant's self-report.

[i] Based on the participant's background assessment result across production and comprehension modalities.

Experimental Task

Research Design

This picture naming study consists of a case series design, including ten monolingual and eight bilingual speakers with aphasia. Aphasia is a heterogenous language disorder that can affect each modality (speech production, language comprehension, writing, reading) and can be caused by, for example, a stroke (Schwartz & Dell, 2010). While many variables have to be considered in a monolingual speaker with aphasia, an even greater number of influencing factors are at play when exploring bilingualism in a speaker with aphasia. They vary, for example, their available languages, language dominance and language age of acquisition. Based on these factors, a case series approach that considers these individual differences across participants is the most suitable research methodology (Howard et al., 2015). The experimental task investigated spoken picture naming accuracy across monolingual and bilingual speakers with aphasia, with a particular focus on how accuracy patterns are influenced by the target's word phonological neighbourhood within (monolinguals and bilingual speakers with aphasia) and across languages (bilingual speakers with aphasia).

Method

Materials

Picture stimuli were obtained from MultiPic (Duñabeitia et al., 2018). This database offers 750 standardised noun images for seven languages (Dutch-Belgium, Dutch-Netherlands, English-British, French, German, Italian, and Spanish). Item lists were created for each language (monolingual speakers with aphasia) or each language combination (bilingual speakers with aphasia). Pictures for the final item list were chosen based on their name agreement (consensus on the name of an image [Alario et al., 2004]). Only pictures with a name agreement of 80% or above were included. Name agreement values were unavailable for Polish using the MultiPic database. Therefore, the Polish-German item set included all German items with an 80% name agreement for German and Polish. A native Polish speaker translated all German targets to define the Polish target response[19]. It is

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[19] Duñabeitia et al. (2022) published additional data on Polish name agreement for 500 out of 750 noun pictures of their MultiPic database. Based on this, not all of the 422 items of the Polish-German item list had an 80% name agreement for Polish. Furthermore, of the 422 included items, 13 items were translated differently by

acknowledged that some of these items may not meet the 80% name agreement criteria for Polish.

The monolingual item lists included either 423 items (German item list) or 440 items (English item list). The lists of items for the different language combinations had between 331 and 422 entries each, depending on the respective language combination. The item list for each language/language combination was divided into two sets and further subdivided into three subsets (Set 1: Subset 1a, Subset 1b, Subset 1c; Set 2: Subset 2a, Subset 2b, Subset 2c), which allowed the participants for breaks during the naming sessions. The subsets included between 70 and 74 items for each monolingual item set. Subsets for bilingual participants included 55 to 71 items. The order of items in a subset was quasi-randomised. To avoid priming or interference effects, items that had a semantic relation, the same target onset, and/or the same word form in compound words were separated from each other. Table 7 presents the number of items per item set/subset for each language and language combination. For a detailed list that names every item of an item list for each language and language combination, see Appendix B.

Table 7

Number of Included Items per Language and Language Combination

Language/ Language-combination	Item-lists (n)	Item-sets	Subsets (with n per subset)
German	423	Set 1	1a (n=71), 1b (n=71), 1c (n=70)
		Set 2	2a (n=71), 2b (n=70), 2c (n=70)
English	440	Set 1	1a (n=73), 1b (n=73), 1c (n=74)
		Set 2	2a (n=72), 2b (n=74), 2c (n=74)
Dutch-German	347 each language	Set 1: Dutch	1a (n=58), 1b (n=58), 1c (n=58)
		Set 2: Dutch	2a (n=58), 2b (n=58), 2c (n=57)
		Set 1: German	1a (n=58), 1b (n=58), 1c (n=58)
		Set 2: German	2a (n=58), 2b (n=58), 2c (n=57)
Polish-German[a]	422[a] each	Set 1: Polish	1a (n=71), 1b (n=71), 1c (n=70)

Duñabeitia et al. (2022) than by the native speaker of our study. Since data collection and data analysis was already completed with the publication of the 2022 study, we proceeded with the translation of our study. As a result, the name agreement values for the 13 items, that were translated differently, were not included in the Polish item list for our study. For details see Appendix B.

	language	Set 2: Polish	2a (n=70), 2b (n=70), 2c (n=70)
		Set 1: German	1a (n=71), 1b (n=71), 1c (n=70)
		Set 2 German	2a (n=70), 2b (n=70), 2c (n=70)
English-German	331 each	Set 1: English	1a (n=55), 1b (n=55), 1c (n=55)
	language	Set 2: English	2a (n=56), 2b (n=55), 2c (n=55)
		Set 1: German	1a (n=55), 1b (n=55), 1c (n=55)
		Set 2 German	2a (n=56), 2b (n=55), 2c (n=55)
English-Italian	356 each	Set 1: English	1a (n=60), 1b (n=59), 1c (n=60)
	language	Set 2: English	2a (n=59), 2b (n=59), 2c (n=59)
		Set 1: Italian	1a (n=60), 1b (n=59), 1c (n=60)
		Set 2: Italian	2a (n=59), 2b (n=59), 2c (n=59)
English-French	365 each	Set 1: English	1a (n=61), 1b (n=61), 1c (n=60)
	language	Set 2: English	2a (n=61), 2b (n=61), 2c (n=61)
		Set 1: French	1a (n=61), 1b (n=61), 1c (n=60)
		Set 2: French	2a (n=61), 2b (n=61), 2c (n=61)

Note. [a] German Item-list for both languages, one item was excluded for culturally sensitive reasons.

Predictor Values. We obtained a number of predictor values (experimental and control predictors) for each included item. Experimental predictors included values for PNDwithin/PNFwithin (monolingual item lists and bilingual item lists) and for PNDacross/PNFacross/phonological similarity (bilingual items lists). Furthermore, all items were given control predictor values (different lexical variables) that are known to impact picture naming (e.g., imageability). For a description of how values were collected, see below.

Experimental Predictors: PNDwithin, PNFwithin. We used the CLEARPOND database (Marian et al., 2012) to determine the PNDwithin and PNFwithin values for the Dutch, German, English, and French items. A PNDwithin value collected in CLEARPOND reflects the number of phonological neighbours to a target. The PNFwithin value describes the mean frequency of the available neighbours to the target. For the collected PNFwithin values we applied a logarithmic base 10 transformation to the PNFwithin values as commonly used in linguistic research. PNDwithin and PNFwithin values for Polish and Italian were unavailable, and no appropriate accessible tools were identified to collect these values. Hence, we could not analyse the influence of these values.

Experimental Predictors: PNDacross, PNFacross. Again, we used the CLEARPOND database (Marian et al., 2012) to collect PNDacross and PNFacross values for all items included in this study. Across neighbourhood values for the following target languages were collected (see Table 8):

Table 8

Collected Across Neighbourhood Values for Different Target Languages Collected via CLEARPOND

Target language	Collected across neighbourhood values
Dutch	German PNDacross and PNFacross values
German	Dutch PNDacross and PNFacross values
	English PNDacross and PNFacross values
Polish	German PNDacross and PNFacross values[20]
English	German PNDacross and PNFacross values
	French PNDacross and PNFacross values
Italian	English PNDacross and PNFacross values[2]
French	English PNDacross and PNFacross values

All collected PNDacross values represent the target's number of cross-linguistic phonological neighbours. The PNFacross value represents the mean frequency of available cross-linguistic neighbours to the target. The collected PNFacross values were transformed into base 10 logarithm values as commonly used in linguistic research.

Experimental Predictor: Phonological Similarity. We used alineR (Downey et al., 2017) to determine a phonological similarity value for each item. AlineR[21] is an open-source R software to calculate feature-weighted based linguistic distance or similarity across item pairs. Both words were transferred into their IPA script to calculate the similarity value of the target word and the non-target language equivalent. Diacritic signs and suprasegmental signs

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[20] Polish and Italian are both languages that are not included in the CLEARPOND database. However, CLEARPOND allows for the collection of PNDacross and PNFacross values of their provided languages (Dutch, English, French, German and Spanish) for target languages that are not provided in the database. The Polish and Italian targets IPA were used to obtain X-SAMPA (Extended Speech Assessment Methods Phonetic Alphabet) codes. With the X-SAMPA codes relevant across neighbours were collected in CLEARPOND.

[21] AlineR identifies features using ASCII (American Standard Code for Information Interchange). ASCII is the most widely used character encoding format for textual data on computers and the internet. In ASCII-encoded data, there are distinct values assigned to 128 alphabetic, numeric, special characters, and control codes. Acceptable encodings consist of lowercase letters ranging from ‘a’ to ‘z’ and further modifiers (dental, palato-alveolar, retroflex, palatal, spirant, nasal, aspirated, long, front, central) to indicate features.

were removed from both IPA scripts to run the calculation in R (R Core Team, n.d.). Every item pair was manually entered into the program. Since not all IPA signs were provided by the alineR software, the calculation of the similarity of some item pairs included some change of IPA signs (e.g., ɑ = a; ʁ = r, ʀ; ə = e). The similarity was not calculated if an item-pair needed a change of more than two IPA signs.

Control Predictors: Lexical Variables. In addition to the experimental predictors, we obtained a range of control predictors for all items. The control predictors consisted of a set of lexical variables, defined by Alario et al. (2004), that are known to have an impact on picture naming: Spoken word form frequency, syllable length, phoneme length, age of acquisition, familiarity, imageability, and visual complexity. Spoken word form frequency defines how often an item/word is used. The two measures for word lengths are number of syllables and number of phonemes. The lexical variable age of acquisition defines when a word is typically learned by the wider population, and familiarity refers to how familiar a concept is. Imageability reflects how easily people can form a mental image of a word (it is easier if you have already stored an image in your memory from previous experience). The last lexical variable, visual complexity, reflects the number of details in an image; more detail reflects increased processing (see Alario et al. 2004 for an overview and more detailed definitions). Table 9 presents an overview of all accessed sources to collect values for the different lexical variables.

Item lists for all languages and language combinations in Appendix B present all experimental and control predictors values.

Table 9

References of Lexical Variables per Language

Lexical variables	Sources lexical variables per language					
	Dutch	German	Polish	English	Italian	French
Spoken word form frequency	Keuleers et al., 2010	Brysbaert et al., 2011	Mandera et al., 2015	van Heuven et al., 2014	Crepaldi et al., 2015	Desrochers & Thompson, 2009
Syllable length	Nederlands woordenboek, n.d.	Martin-Luther-Universität Halle-Wittenberg, n.d.	Wikisłownik, 2023	Wilson, 1988	Olivetti, n.d.	Lexique - Boris New & Christophe Pallier, n.d.
Phoneme length	Nederlands woordenboek, n.d.	Martin-Luther-Universität Halle-Wittenberg, n.d.	Wikisłownik, 2023	WordReference.com, n.d.	Olivetti, n.d.	Le Dictionnaire, n.d.
Age of acquisition	Brysbaert et al., 2014	Birchenough et al., 2017	Imbir, 2016	Johnston et al., 2010	Montefinese et al., 2019	Alario & Ferrand, 1999
Familiarity	Shao & Stiegert, 2016	Schröder et al., 2012	Duñabeitia et al., 2022 [a]	Johnston et al., 2010	Montefinese et al., 2014	Alario & Ferrand, 1999

Imageability	Shao & Stiegert, 2016	Võ et al., 2009	Imbir, 2016	Scott et al., 2019	Montefinese et al., 2014	Desrochers & Thompson, 2009
Visual complexity	Duñabeitia et al., 2018	Duñabeitia et al., 2018	Duñabeitia et al., 2018[b]	Duñabeitia et al., 2018	Duñabeitia et al., 2018	Duñabeitia et al., 2018

Note. Number of phonemes was collected by the International Phonetic Alphabet (IPA).

[a] The native speaker in this study translated 14 out of the 422 items differently to Duñabeitia et al. (2022). We continued our work with our translation since data collection and analysis were already completed. The familiarity values for these 13 items are therefore not included in the final Polish item list. For more details, see Appendix B.

[b] Visual complexity norms were not available for Polish. Visual complexity values of the German items were taken. This approach was acceptable since the visual complexity values showed a high cross-linguistic correlation (r > .90) and can therefore be applied to Polish (Duñabeitia et al., 2022).

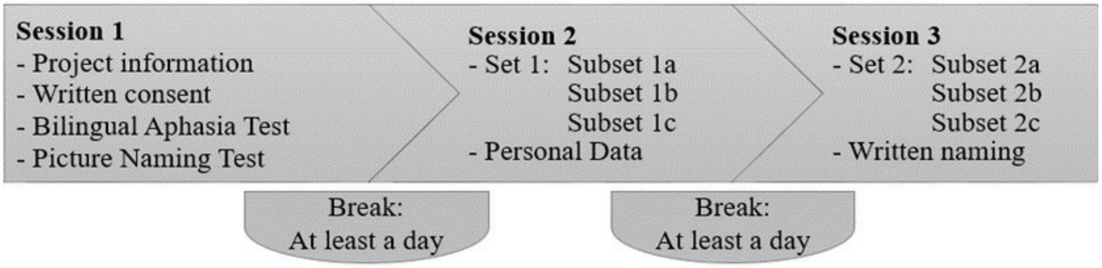
Procedure

The procedure was different for the monolingual and bilingual speakers with aphasia. Monolinguals underwent at least three sessions, while bilinguals were tested for at least six sessions.

Monolingual Participants. Each monolingual participant was tested at least three times with each session lasting around 60 to 90 minutes. Sessions were scheduled over period of at least a week, with a break of at least one day between the picture naming sessions. Figure 2 visualises the study procedure for the monolingual participants.

Figure 2

Study Procedure Monolingual Speakers with Aphasia



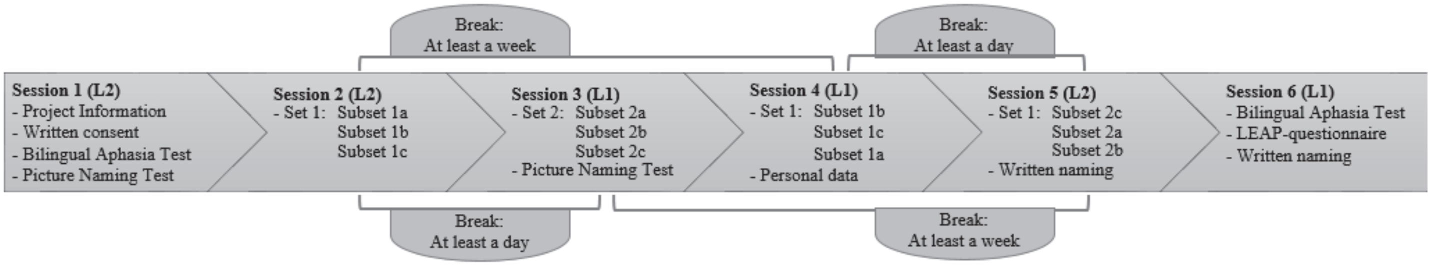
In the first session, the monolingual speakers with aphasia conducted the BAT and the LEMO picture naming test. Session two and session three consisted of the experimental picture naming task in the participant's available language. Session two comprised naming Set 1, which was composed of three subsets (Subset 1a, Subset 1b, Subset 1c: All subset consisted of an equal number of items). Additionally demographic and medical data were collected. Within the third session, the participant named the items of the second naming set, again the set was divided into three subsets (Subset 2a, Subset 2b, Subset 2c: All subset consisted of an equal number of items). The picture naming task in session three was followed by the written naming task of the first 30 items of Subset 1a.

Due to fatigue and/or level of task tolerance, the timeline was slightly modified for two monolingual speakers with aphasia. The picture naming task was spread over four sessions for MwA6 (Session 2: Subset 1a and Subset 1b, Session 3: Subset 1c and 2a, Session 4: Subset 2b, Session 5: Subset 2c) and spread over three sessions for MwA8 (Session 2: Subset 1a and 1b, Session 3: Subset 1c and 2a, Session 4: Subset 2b and 2c).

Bilingual Participants. Each bilingual participant was tested for at least six times. One individual session lasted for approximately 60 to 90 minutes The six sessions were scheduled over a minimum of three weeks, including a day of rest between sessions with different items in the same language. Sessions with the same item set, that were named in a different language, were scheduled with a break of at least one week to avoid priming effects. Figure 3 visualises the study procedure for the bilingual speakers with aphasia.

Figure 27

Study Procedure Bilingual Speakers with Aphasia (Starting the Study in the Participant's L2)



Note. L1 = First language, L2 = Second language. The figure is an example of a study procedure starting in a participant's L2. If the study started in a participant's L1, the following session were accordingly adjusted.

The BAT and the LEMO picture naming test were administered in the first session in the participants' second language. The first session was followed by four picture naming session across the two languages of the bilingual participant. To maintain language mode and avoid language switching, a naming session was always held in one language. Session two (Item set 1) and session five (Item set 2) were naming sessions in the participant's second language. Accordingly, session three (Item set 1) and session four (Item set 2) were naming sessions for the participant's first language. To minimize order effects, the order of the subsets of item set 1 and item set 2 was alternated in session four and session five. Additionally, the following data were collected during different sessions: LEMO picture naming test in the participants first language (session three), demographic and medical data (session four), written naming in the participants' second language (session five). The last session of the experimental task (session six) included the administration of the BAT[22] and the written naming screener in the participant's first language. Additionally, the LEAP-Q was administered to capture the bilingual language profile of the participant.

Four bilingual participants (BwA2, BwA4, BwA5, BwA7) received an adapted/ modified presentation procedures due to the onset of fatigue, language impairment and/or level of task tolerance. The adaptation consisted of a split of session six into two sessions (BwA2, BwA4, BwA7). For BwA5 the picture naming sessions in Italian were split across three sessions (session 2: Subset 2a and Subset 2b, session 3: Subset 2c and Subset 1a, session 6: Subset 1c and Subset 1b).

As illustrated in Figure 2 and Figure 3, the written naming task was always conducted after the picture naming task to prevent any possible priming or repetition effects for the spoken modality, that constituted the main task.

Items to name were shown on a laptop using the DMDX software (Forster & Forster, 2003). Instructions for the picture naming task were given verbally by the examiner and were additionally displayed on the screen. The participants were instructed to name the picture with a single name as fast and accurately as possible. For bilingual participants, instructions were always given in the language according to the language associated to the session. A practice round, including five items[23], was included before each subset. Each trial began with a 250ms fixation cross at the centre of the screen, followed by the appearance of the target picture in the centre of the screen and the start of the audio recording. The examiner stopped the audio recording and moved to the next item by using the keyboard. When the participant named the picture or indicated to move on to the next item, pictures were removed from the screen. As soon as the next item appeared, the audio recording started again. The division of

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[22] Training to conduct the BAT in Italian/Polish was given to a family member of BwA2 and BwA5 since the experimenter could not speak Italian or Polish. The family member administered the BAT in the presence of the researcher. The examiner was fluent in all other evaluated languages, so no family member was needed to conduct the BAT for any other participant.

[23] Items were taken from MultiPic and were not included in the item list of the experimental task since they had a name agreement of 79% or less.

a naming set into three subsets allowed for two breaks of five to ten minutes within a naming session.

Data Analysis

Transcription and Error Coding

The DMDX software (Forster & Forster, 2003) generated a WAV-audio file for every single item during the naming task. This audio file was used to transcribe and code the verbal response as correct or incorrect. Incorrect responses were assigned with an error code to define the error type (the detailed error type coding is not part of this study; see General Appendix F for the error types guideline that was used to analyse incorrect response by their error type). For consistency across transcription and error types coding a guideline was developed. Additionally, examiners involved in the process received a transcription and error code training, including a check in session for questions after the analysis of the first naming set. The transcription and error coding for the different languages was always carried out by a native or proficient speaker of the respectively language. Difficulties during the process were discussed with a second examiner and presented to a third person to reach consensus for unsolved issues.

The first complete attempt made within the first 10 seconds after the onset of the picture was coded as correct or incorrect. A first complete attempt was defined as follows: A consonant-vowel or vowel-consonant response (schwa was not considered a vowel) that was uninterrupted and had either a downward/upward intonation or level intonation followed by a noticeable pause (one second). An attempt that was self-interrupted or a minimal vowel-consonant or consonant-vowel response (schwa was not considered a vowel), followed directly by another utterance, was defined as fragment and was not coded as a complete attempt. Responses that were given in the participant’s dialect or accent, that were filler words (e.g., ‘uhm’), or that were automatism (e.g., ‘oh god’) were not penalised as incorrect response. The usage of a determiner was not coded. Additionally, a number of response variations were allowed without incorrect coding: Addition of a prepositional phrase (e.g., target ‘can’, response ‘can of peas’), addition of a modifier[24] (e.g., target ‘bone’, response ‘dog's bone’), addition of a type of X where X is the target (e.g., target ‘banana’, response ‘type of banana’), and negation of the target (e.g., target ‘banana’, response ‘not a banana’).

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[24] A response that included the addition of a modifier component that resulted in a compound word was considered an acceptable alternative.

Logistic Regression. Logistic regression analyses were carried out preceded by correlational analysis using the analysis software jamovi (The jamovi project, n.d.). Analyses were run for each monolingual and bilingual speaker with aphasia for each of their languages to examine the presence and direction of any effect of phonological neighbourhood on picture naming accuracy. Additionally, further lexical variables known to be influencing picture naming such as spoken word form frequency, number pf phonemes, number of syllables, age of acquisition, imageability, familiarity, visual complexity were added in order to control for their contribution to the result patterns. Analysis to examine effects for phonological neighbourhood density and frequency on accuracy of lexical retrieval across languages were conducted for bilingual speakers with aphasia and followed the steps of the monolingual analysis, with addition of the across neighbours.

Multicollinearity. We examined the potential for multicollinearity (cut-off: r > .7) (Field, 2017) among all experimental predictors (PNDwithin, PNFwithin, PNDacross, PNDacross, phonological similarity) and control predictors (spoken word form frequency, number of phonemes, number of syllables, age of acquisition, imageability, familiarity, visual complexity). Pearson's r correlation matrix (Appendix C) revealed high levels of multicollinearity between several predictors, especially and unsurprisingly the PND and PNF predictors. To avoid multicollinearity between the PND and PNF predictors, we ran individual regression analyses for each PND and PNF predictor, always the phonological similarity predictor included for the analysis of the bilingual speakers. Additionally, the Pearson's r correlation matrix revealed high levels of multicollinearity between the word length variables, number of phonemes, and number of syllables for all languages (r > .7). For French, familiarity and frequency were highly correlated (r = .831). We decided to exclude the predictors number of syllables and frequency from the analyses to minimize potentially problematic levels of multicollinearity[25]. After excluding syllables and frequency, regression analyses were run for all monolinguals and bilingual speakers. Result revealed further multicollinearity for analyses involving the word lengths measure number of phonemes. Since the predictor number of phonemes had no effect on accuracy across the participants[26] justification was given to leave number of phonemes out of the model. Furthermore, we monitored multicollinearity by using the variance inflation factor (VIF). Problematic levels of multicollinearity are reported with a value above 5 (Hutcheson, 1999). After removing the

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[25] Both phonemes and syllables can be considered measures of word length, and familiarity and frequency are measures of frequency (Nickels & Howard, 1995).

[26] Except of one single analysis out of 16 analyses (BwA2 Polish).

variables number of syllables, number of phonemes and frequency, the experimental and control variables had a VIF of 2.85 or less across all analyses. For correlation matrix details see Appendix C.

Results

Monolingual Speakers with Aphasia

Summary Data

Naming Accuracy. Summarized accuracy naming data of all ten monolingual speakers with aphasia are presented in Table 10 and Table 11. Accuracy across the participants ranged from 17.97% to 82.50%.

Experimental Predictors Affecting L1 Accuracy. Effects of within-language phonological neighbourhood density and frequency across analyses were observed for one participant. MwA5 showed significant PNDwithin and PNFwithin effects on naming accuracy (PNDwithin: p = .019, OR = 1.276, 95% CI [1.041, 1.56]; PNFwithin: p = .004, OR = 7.420, 95% CI [1.924, 28.62]). Detailed results of the logistic regression analyses per experimental predictor (PNDwithin, PNFwithin) for all participants are given in Table 10 and Table 11.

PNDwithin Affecting Accuracy

The results of the binomial logistic regression models examining the PNDwithin predictor on accuracy across all participants are shown in Table 10. The overall percentage of accuracy of model classification across all analyses was between 63.5% and 91.9% (cut-off < 50%).

The predictor *PNDwithin* significantly predicted picture naming accuracy in one participant (MwA5: p = .019, OR = 1.276, 95%-CI[1.041, 1.56].

Age of acquisition, familiarity and imageability were significant control predictors of accuracy in five participants (age of acquisition: MwA2: p = .033, OR = 0.354, 95%-CI[0.136, 0.920]; MwA6: p = .004, OR = 0.426, 95%-CI[0.237, 0.766]; MwA8: p = .050, OR = 0.571, 95%-CI[0.326, 0.999] / familiarity: MwA9: p = .016, OR = 0.567, 95%-CI[0.357, 0.899] / imageability: MwA5: p = .037, OR = 7.084, 95%-CI[1.122, 44.71]). See Appendix C for regression analyses details.

Table 10

Accuracy and Logistic Regression Data (PNDwithin Predictor) for all Monolingual Speakers with Aphasia

		Accuracy							Significance of Model coefficients (p) – Predictors				
Participant	Language	N items	N items correct	% correct	Model test	R^2_{CS}	R^2_N	AC	AoA	Fam	Image	VC	PNDwithin
MwA1	German	423	76	17.97%	$\chi^2(5)=2.24$, $p=.816$	.029	.043	70.3%	.242	.508	.875	.564	.424
MwA2	German	423	189	44.68%	$\chi^2(5)=11.2$, $p=.048$*	.140	.188	63.5%	.033*	.850	.112	.105	.150
MwA3	German	423	203	47.99%	$\chi^2(5)=17.9$, $p=.003$*	.186	.214	71.6%	.065	.132	.481	.507	.122
MwA4	German	423	344	81.32%	$\chi^2(5)=8.79$, $p=.118$	.112	.260	91.9%	.082	.809	.892	.249	.450
MwA5	German	423	284	67.14%	$\chi^2(5)=14.7$, $p=.012$	.180	.284	81.1%	.520	.630	.037*	.940	.019*
MwA6	English	440	128	29.09%	$\chi^2(5)=21.0$, $p<.001$*	.084	.116	68.8%	.004*	.876	.406	.461	.903
MwA7	English	440	311	70.68%	$\chi^2(5)=4.32$, $p=.504$	.018	.028	78.3%	.522	.898	.925	.362	.388
MwA8	English	440	298	67.05%	$\chi^2(5)=9.32$, $p=.097$	.038	.058	78.3%	.050*	.189	.056	.371	.486
MwA9	English	440	341	77.50%	$\chi^2(5)=8.16$, $p=.148$	.033	.059	85.4%	.076	.016*	.579	.264	.292
MwA10	English	440	363	82.50%	$\chi^2(5)=6.06$, $p=.300$	.025	.043	84.2%	.115	.933	.303	.921	.645

Note. R^2_{CS} = Cox and Snell's R^2, R^2_N = Nagelkerke's, AC = Accuracy of model classification, AoA = Age of acquisition, Fam = Familiarity, Image = Imageability, VC = Visual complexity, PNDwithin = Phonological neighbourhood density within language.

PNFwithin Affecting Accuracy

Table 11 lists the results of the binomial logistic regression models examining the PNFwithin predictor on accuracy across all monolingual participants. The overall percentage of accuracy of model classification across analyses was between 58.9% and 93.2% (cut-off 50%).

The *PNFwithin* factor significantly predicted picture naming accuracy in one participant (MwA5: p = .004, OR = 7.420, 95%-CI[1.924, 28.62].

The control predictors age of acquisition, familiarity, and imageability significantly predicted accuracy in five participants (age of acquisition: MwA4: p = .034, OR = 0.176, 95%-CI[0.035, 0.874]; MwA6: p = .004, OR = 0.408, 95%-CI[0.221, 0.751] / familiarity: MwA9: p = .014, OR = 0.559, 95%-CI[0.351, 0.890], imageability: MwA5: p = .043, OR = 6.143, 95%-CI[1.059, 35.63]; MwA8: p = .054, OR= 3.050, 95%-CI[0.980, 9.50]). See Appendix C for details of the regression analyses.

Table 11

Accuracy and Logistic Regression Data (PNFwithin Predictor) for all Monolingual Speakers with Aphasia

		Accuracy							Significance of Model coefficients (p) – Predictors				
Participant	Language	N items	N items correct	% correct	Model test	R^2_{CS}	R^2_N	AC	AoA	Fam	Image	VC	PNFwithin
MwA1	German	423	76	17.97%	$\chi^2(5)=3.13$, p=.679	.042	.061	74.0%	.694	.566	.459	.650	.191
MwA2	German	423	189	44.68%	$\chi^2(5)=8.57$, p=.127	.111	.149	58.9%	.195	.763	.319	.149	.380
MwA3	German	423	203	47.99%	$\chi^2(5)=15.1$, p=.010*	.187	.258	68.5%	.058	.124	.553	.432	.172
MwA4	German	423	344	81.32%	$\chi^2(5)=9.72$, p=.084	.125	.288	93.2%	.034*	.609	.973	.212	.548
MwA5	German	423	284	67.14%	$\chi^2(5)=19.2$, p=.002*	.231	.362	86.3%	.472	.957	.043*	.663	.004*
MwA6	English	440	128	29.09%	$\chi^2(5)=21.1$, p<.001*	.084	.116	69.6%	.004*	.887	.450	.481	.777
MwA7	English	440	311	70.68%	$\chi^2(5)=5.47$, p=.361	.023	.035	78.3%	.755	.912	.793	.402	.169
MwA8	English	440	298	67.05%	$\chi^2(5)=9.29$, p=.098	.038	.058	77.9%	.068	.184	.054*	.385	.495
MwA9	English	440	341	77.50%	$\chi^2(5)=9.12$, p=.104	.037	.066	85.4%	.134	.014*	.499	.303	.148
MwA10	English	440	363	82.50%	$\chi^2(5)=6.21$, p=.286	.026	.044	84.2%	.063	.936	.449	.995	.546

Note. R^2_{CS} = Cox and Snell's R^2, R^2_N = Nagelkerke's, AC = Accuracy of model classification, AoA = Age of acquisition, Fam = Familiarity, Image = Imageability, VC = Visual complexity, PNFwithin = Phonological neighbourhood frequency within language.

Bilingual Speakers with Aphasia

Summary Data

Naming Accuracy. Accuracy naming data of all bilingual speakers with aphasia across their languages are summarised in Tables 12-15. Accuracy in the participants' L1 (either dominant or non-dominant language) ranged between 20.22% and 86.03%. Accuracy in the participants' L2 (either dominant or non-dominant language) was between 0% and 80.27%.

Experimental Predictors Affecting L1 and L2 Accuracy. Among all regression analyses across participants and languages, phonological neighbourhood effects were found for five participants (BwA2, BwA3, BwA6, BwA7, and BwA8). BwA2 showed significant PNFwithin and phonological similarity effects on picture naming accuracy in his dominant L2 German. BwA3 exhibited phonological similarity effects in his non-dominant L1 Dutch in the within-language analyses (PNDwithin, PNFwithin). BwA6 again presented phonological similarity effects on accuracy in her non-dominant language French (L2) in the within-language (PNDwithin, PNFwithin) and across-language analyses (PNDacross, PNFacross). Phonological similarity and PNFwithin effects in the within-language analyses were presented by BwA7 in his non-dominant language L1 French. BwA8 displayed PNFwithin effects in her non-dominant L1 French. Detailed information on the logistic regression results per experimental predictor (PNDwithin, PNFwithin, PNDacross, PNFacross – always including the phonological similarity predictor) for all participants across their languages are given below.

PNDwithin/Phonological Similarity Affecting L1 and L2 Accuracy

Table 12 summarises the results of the binomial logistic regression model examining the PNDwithin and the phonological similarity predictor on L1 and L2 naming accuracy across all participants. The overall percentage of accuracy of model classification across all analyses was between 61.2% and 91.0% (cut-off 50%).

The *PNDwithin* predictor showed no significant effect on accuracy across the participants' first and second languages. The *phonological similarity* significantly predicted picture naming accuracy in three participants always in their non-dominant language (BwA3 [L1]: p = .049, OR = 1.011, 95%-CI[1.000, 1.02]; BwA7 [L1]: p = .043, OR = 1.019, 95%-CI[1.001, 1.04], (BwA6 [L2]: p = .005, OR = 1.020, 95%-CI[1.006, 1.035]).

When adding the control predictors to the model, age of acquisition and imageability significantly predicted accuracy in five participants in either their L1 or L2 (age of acquisition: BwA1: L2 dominant, p = .010, OR = 0.146, 95%-CI[0.341, 0.629]; BwA6: L2 non-dominant, p < .001, OR = 0.103, 95%-CI[0.029, 0.369]; BwA8: L1 non-dominant, p < .001, OR = 0.125, 95%-CI[0.037, 0.415] / imageability: BwA4: L2 non-dominant, p = .013, OR = 23.126, 95%-CI[1.914, 279.397]; BwA7: L1 non-dominant, p = .052, OR = 3.436, 95%-CI[0.992, 11.90]). Familiarity and visual complexity did not predict accuracy. Full details of the regression analyses can be found in Appendix C.

Table 12

Accuracy and Logistic Regression Data (PNDwithin and Phonological Similarity Predictor) for all Bilingual Speakers with Aphasia

				Accuracy							Significance of Model coefficients (p) – Predictors					
Participants with language profile			N items	N items correct	% correct	Dom	Model test	R^2_{CS}	R^2_N	AC	AoA	Fam	Image	VC	PNDwithin	PS
BwA1	L1	DUT	347	142	40.92	L2	χ^2(6)=8.54, p=.201	.068	.091	61.2%	.059	.743	.649	.854	.251	.524
	L2	GER^a	347	203	58.50		χ^2(6)=16.4, p=.012*	.258	.380	83.6%	.010*	.370	.641	.202	.988	.398
BwA2	L1	POL^a	422	285	67.54	L2							n/a^b			
	L2	GER^a	422	168	39.81		χ^2(6)=4.72, p=.580	.077	.103	62.7%	.723	.558	.468	.974	.802	.135
BwA3	L1	DUT	347	186	53.60	L2	χ^2(6)=9.11, p=.167	.073	.101	66.9%	.139	.754	.530	.517	.109	.049*
	L2	GER^a	347	209	60.23		χ^2(6)=4.69, p=.585	.082	.117	69.1%	.962	.469	.334	.841	.192	.149
BwA4	L1	ENG^a	331	265	80.06	L1	χ^2(6)=2.31, p=.889	.014	.026	87.6%	.530	.965	.954	.867	.290	.257
	L2	GER	331	195	58.91		χ^2(6)=9.71, p=.137	.173	.237	68.6%	.631	.798	.013*	.540	.290	.785
BwA5	L1	ENG^a	356	72	20.22	ENG	χ^2(6)=11.9, p=.063	.064	.092	72.5%	.058	.969	.106	.997	.759	.852
	L1	ITA	356	0	0								n/a^c			
BwA6	L1	ENG^a	365	314	86.03	L1	χ^2(6)=7.37, p=.288	.041	.089	91.0%	.113	.557	.920	.476	.103	.106
	L2	FRE	365	189	51.78		χ^2(6)=36.5, p<.001*	.262	.356	74.2%	<.001*	.611	.810	.479	.401	.005*
BwA7	L1	FRE	365	254	69.59	L2	χ^2(6)=20.3, p=.002*	.156	.263	85.8%	.128	.576	.052*	.109	.119	.043*
	L2	ENG^a	365	262	71.78		χ^2(6)=7.08, p=.314	.039	.068	84.8%	.646	.521	.068	.555	.330	.281
BwA8	L1	FRE	365	240	65.75	L2	χ^2(6)=24.3, p<.001*	.184	.260	78.3%	<.001*	.115	.535	.699	.292	.271
	L2	ENG^a	365	293	80.27		χ^2(6)=14.8, p=.022*	.079	.134	84.3%	.081	.657	.456	.699	.890	.406

Note. DUT = Dutch, GER = German, POL = Polish, ENG = English, ITA = Italian, FRE = French, Dom = Language dominance, R^2_{CS} = Cox and Snell's R^2, R^2_N = Nagelkerke's, AC = Accuracy of model classification, AoA = Age of acquisition, Fam = Familiarity, Image = Imageability, VC = Visual complexity, PNDwithin = Phonological neighbourhood density within language, PS = Phonological similarity score.

[a] Dominant language.

[b] CLEARPOND (Marian et al., 2012) was used to collect the values of PND/PNFwithin and PND/PNFacross. The database provides data for the following languages: English, Dutch, French, German, and Spanish. Therefore, PNDwithin language data for Polish were not available.

[c] BwA5 experienced severe naming difficulties in Italian with naming accuracy of 0% (0/356). Therefore, a logistic regression analysis was not possible to run for the participant's non-dominant L1.

PNFwithin/Phonological Similarity Affecting L1 and L2 Accuracy

Table 13 lists the regression results of the PNFwithin and phonological similarity predictors on L1 and L2 naming accuracy for all participants. The accuracy of model classification with a cut-off of 50%, ranged between 61.2% and 91.0% across analyses.

PNFwithin significantly predicted accuracy in the non-dominant L1 for two participants (BwA7: L1 non-dominant, p = .033, OR = 2.913, 95%-CI[1.092, 7.76], BwA8: L1 non-dominant, p = .040, OR = 2.265, 95%-CI[1.039, 4.933]) and in the dominant L2 for one participant (BwA2: L2 dominant, p = .042, OR = 2.97, 95%-CI[1.043, 8.44]). *Phonological similarity* was a significant predictor of picture naming accuracy in L1 in two participants (BwA3: L1 non-dominant, p = .043, OR = 1.012, 95%-CI[1.000, 1.02]; BwA7: L1 non-dominant, p = .020, OR = 1.023, 95%-CI[1.004, 1.04]) and for L2 in two further participants (BwA2: L2 dominant, p = .023, OR = 1.02, 95%-CI[1.003, 1.04]; BwA6: L2 non-dominant, p = .008, OR = 1.020, 95%-CI[1.005, 1.034]. These effects were found in either the dominant (BwA2) or the non-dominant language (BwA3, BwA6, Bw9).

Furthermore, age of acquisition and imageability (control predictors) predicted accuracy in five participants in their L1 or L2 (age of acquisition: BwA1: L2 dominant, p = .008, OR = 0.139, 95%-CI[0.032, 0.601]; BwA6: L2 non-dominant, p < .001, OR = 0.103, 95%-CI[0.029, 0.366]; BwA8: L1 non-dominant, p < .001, OR = 0.126, 95%-CI[0.037, 0.426] / imageability: BwA4: L2 non-dominant, p = .014, OR = 10.294, 95%-CI[1.828, 225.257], BwA7: L2 dominant, p = .043, OR = 3.903, 95%-CI[1.004, 14.59]. See Appendix C for full analyses details.

Table 13

Accuracy and Logistic Regression Data (PNFwithin and Phonological Similarity Predictor) of all Bilingual Speakers with Aphasia

				Accuracy							Significance of Model coefficients (p) – Predictors					
Participants with language profile			N items	N items correct	% correct	Dom	Model test	R^2_{CS}	R^2_N	AC	AoA	Fam	Image	VC	PNFwithin	PS
BwA1	L1	DUT	347	142	40.92	L2	$\chi^2(6)$=8.98, p=.174	.072	.096	61.2%	.062	.751	.584	.817	.182	.391
	L2	GER[a]	347	203	58.50		$\chi^2(6)$=16.5, p=.011*	.260	.383	81.8%	.008*	.406	.606	.197	.722	.466
BwA2	L1	POL[a]	422	285	67.54	L2					n/a[b]					
	L2	GER[a]	422	168	39.81		$\chi^2(6)$=9.61, p=.142	.150	.201	64.4%	.576	.424	.286	.751	.042*	.023*
BwA3	L1	DUT	347	186	53.60	L2	$\chi^2(6)$=8.72, p=.190	.069	.097	68.6%	.127	.714	.587	.531	.123	.043*
	L2	GER[a]	347	209	60.23		$\chi^2(6)$=3.57, p=.735	.063	.089	70.9%	.746	.430	.430	.757	.404	.218
BwA4	L1	ENG[a]	331	265	80.06	L1	$\chi^2(6)$=1.04, p=.984	.006	.012	88.2%	.703	.854	.895	.884	.617	.436
	L2	GER	331	195	58.91		$\chi^2(6)$=9.37, p=.154	.168	.229	70.6%	.711	.839	.014*	.444	.353	.959
BwA5	L1	ENG[a]	356	72	20.22	ENG	$\chi^2(6)$=11.9, p=.065	.063	.091	72.5%	.068	.975	.106	.993	.899	.786
	L1	ITA	356	0	0						n/a[c]					
BwA6	L1	ENG[a]	365	314	86.03	L1	$\chi^2(6)$=4.30, p=.637	.024	.053	91.0%	.094	.530	.794	.498	.722	.276
	L2	FRE	365	189	51.78		$\chi^2(6)$=35.9, p<.001*	.259	.352	74.2%	<.001*	.596	.768	.454	.666	.008*
BwA7	L1	FRE	365	254	69.59	L2	$\chi^2(6)$=22.6, p<.001*	.171	.289	85.0%	.101	.516	.064	.106	.033*	.020*
	L2	ENG[a]	365	262	71.78		$\chi^2(6)$=9.07, p=.170	.049	.087	84.8%	.924	.504	.043*	.669	.087	.177
BwA8	L1	FRE	365	240	65.75	L2	$\chi^2(6)$=, p<.001*	.208	.294	75.8%	<.001*	.121	.581	.653	040*	.099
	L2	ENG[a]	365	293	80.27		$\chi^2(6)$=14.8, p=.022*	.079	.134	84.3%	.098	.667	.485	.711	.909	.455

Note. DUT = Dutch, GER = German, POL = Polish, ENG = English, ITA = Italian, FRE = French, Dom = Language dominance, R^2_{CS} = Cox and Snell's R^2, R^2_N = Nagelkerke's, AC = Accuracy of model classification, AoA = Age of acquisition, Fam = Familiarity, Image = Imageability, VC = Visual complexity, PNFwithin = Phonological neighbourhood frequency within language, PS = Phonological similarity score.

[a] Dominant language.

[b] CLEARPOND (Marian et al., 2012) was used to collect the values of PND/PNFwithin and PND/PNFacross. The database provides data for the following languages: English, Dutch, French, German, and Spanish. Therefore, PNFwithin language data for Polish were not available.

[c] BwA5 experienced severe naming difficulties in Italian with naming accuracy of 0% (0/356). Therefore, a logistic regression analysis was not possible to run for the participant's non-dominant L1.

PNDacross/Phonological Similarity Affecting L1 and L2 Accuracy

Table 14 presents the results of the binomial logistic regression model examining the PNDacross and phonological similarity effects. Results are listed for L1 and L2 naming accuracy across all participants. The accuracy of model classification across all regression analyses ranged from 57.9% to 91.0% (cut-off 50%).

The *PNDacross* predictor showed no significant effect on accuracy across the participants' first and second languages. Picture naming accuracy for the non-dominant L2 was significantly predicted by *phonological similarity* in one participant (BwA6: L2 non-dominant, p = .005, OR=1.020, 95%-CI[1.006, 1.033].

The control predictors age of acquisition and imageability significantly predicted accuracy in six participants in either their L1 or their L2 (age of acquisition: BwA1: L1 non-dominant, p = .049, OR = 0.674, 95%-CI[0.455, 0.999]; BwA1: L2 dominant, p = .010, OR = 0.152, 95%-CI[0.036, 0.634]; BwA3: L1 non-dominant, p = .042, OR = 0.652, 95%-CI[0.432, 0.985]; BwA6: L2 non-dominant, p < .001, OR = 0.104, 95%-CI[0.029, 0.368]; BwA8: L1 non-dominant, p < .001, OR = 0.123, 95%-CI[0.037, 0.406] / imageability: BwA4 L2 non-dominant.015* OR=22.886, 95%-CI[1.821, 287.582]). Familiarity and visual complexity did not show an effect. Full details of the analyses can be found in Appendix C.

Table 14

Accuracy and Logistic Regression Data (PNDacross and Phonological Similarity Predictor) of all Bilingual Speakers with Aphasia

Participants with language profile			N items	Accuracy		Dom	Model test	R^2_{CS}	R^2_{N}	AC	Significance of Model coefficients (p) – Predictors					
				N items correct	% correct						AoA	Fam	Image	VC	PNDacross	PS
BwA1	L1	DUT	347	142	40.92	L2	$\chi^2(6)=7.88$, p=.247	.063	.084	57.9%	.049*	.778	.614	.875	.414	.766
	L2	GER[a]	347	203	58.50		$\chi^2(6)=16.6$, p=.011*	.260	.383	83.6%	.010*	.382	.689	.189	.715	.346
BwA2	L1	POL[a]	422	285	67.54	L2	$\chi^2(6)=9.50$, p=.147	.044	.064	70.0%	.743	.070	.181	.756	.751	.841
	L2	GER[a]	422	168	39.81						n/a[b]					
BwA3	L1	DUT	347	186	53.60	L2	$\chi^2(6)=6.99$, p=.321	.056	.078	66.1%	.042*	.728	.442	.466	.388	.162
	L2	GER[a]	347	209	60.23		$\chi^2(6)=5.18$, p=.521	.089	.128	67.3%	.687	.615	.348	.997	.265	.207
BwA4	L1	ENG[a]	331	265	80.06	L1	$\chi^2(6)=1.51$, p=.959	.009	.017	87.6%	.488	.966	.988	.909	.559	.382
	L2	GER	331	195	58.91		$\chi^2(6)=11.8$, p=.066	.207	.283	66.7%	.830	.507	.015*	.580	.208	.951
BwA5	L1	ENG[a]	356	72	20.22	ENG					n/a[c]					
	L1	ITA	356	0	0						n/a[d]					
BwA6	L1	ENG[a]	365	314	86.03	L1	$\chi^2(6)=6.71$, p=.348	.037	.082	91.0%	.100	.554	.914	.520	.241	.184
	L2	FRE	365	189	51.78		$\chi^2(6)=36.7$, p<.001*	.264	.358	75.0%	<.001*	.524	.782	.438	.339	.005*
BwA7	L1	FRE	365	254	69.59	L2	$\chi^2(6)=17.2$, p=.009*	.134	.225	84.2%	.094	.568	.060	.131	.723	.094
	L2	ENG[a]	365	262	71.78		$\chi^2(6)=7.87$, p=.248	.043	.075	84.8%	.612	.512	.056	.546	.241	.298
BwA8	L1	FRE	365	240	65.75	L2	$\chi^2(6)=23.3$, p<.001*	.176	.250	76.7%	<.001*	.133	.572	.666	.670	.394
	L2	ENG[a]	365	293	80.27		$\chi^2(6)=14.8$, p=.022*	.079	.134	84.3%	.083	.661	.468	.704	.971	.406

Note. DUT = Dutch, GER = German, POL = Polish, ENG = English, ITA = Italian, FRE = French, Dom = Language dominance, R^2_{CS} = Cox and Snell's R^2, R^2_{N} = Nagelkerke's, AC = Accuracy of model classification, AoA = Age of acquisition, Fam = Familiarity, Image = Imageability, VC = Visual complexity, PNDacross = Phonological neighbourhood density across languages, PS = Phonological similarity score.

[a] Dominant language.

[b] CLEARPOND (Marian et al., 2012) was used to collect the values of PND/PNFwithin and PND/PNFacross. The database provides data for the following languages: English, Dutch, French, German, and Spanish. Therefore, German neighbourhood data for Polish targets could be collected. However, Polish neighbourhood data for German targets were not available.

[c] Italian neighbourhood data for English targets were not available, using CLEARPOND (Marian et al., 2012).

[d] BwA5 experienced severe naming difficulties in Italian with naming accuracy of 0% (0/356). Therefore, a logistic regression analysis was not possible to run for the participant's non-dominant L1.

PNFacross/Phonological Similarity Affecting L1 and L2 Accuracy

The results of the examination of the PNFacross and phonological similarity predictor of L1 and L2 naming accuracy across all participants can be found in Table 15. The regression model's accuracy of model classification across all analyses was between 62.0% and 91.0% (cut-off 50%).

The *PNFacross* predictor showed no significant effect on accuracy across the participants' first and second languages. Picture naming accuracy for the non-dominant L2 was significantly predicted by *phonological similarity* in one participant (BwA6: L2 non-dominant, p = .007, OR = 1.019, 95%-CI[1.005, 1.033]).

Age of acquisition and imageability significantly predicted accuracy in five bilingual speakers with aphasia when entered as control predictors into the regression model (age of acquisition: BwA1: L1 non-dominant, p = .046, OR = 0.670, 95%-CI[0.453, 0.992]; BwA1: L2 dominant, p = .014, OR = 0.168, 95%-CI[0.040, 0.699]; BwA6: L2 non-dominant, p < .001, OR = 0.102, 95%-CI[0.029, 0.362]; BwA8: L1 non-dominant, p < .001, OR = 0.125, 95%-CI[0.038, 0.413]; BwA8: L2 dominant, p = .052, OR = 0.434, 95%-CI[0.187, 1.01] / imageability: BwA4: L2 non-dominant, p = .014, OR = 21.939, 95%-CI[1.859, 258.888]). Familiarity and visual complexity did not contribute significantly to accuracy. See Appendix C for full analyses details.

Table 15

Accuracy and Logistic Regression Data (PNFacross and Phonological Similarity Predictor) of all Bilingual Speakers with Aphasia

				Accuracy							Significance of Model coefficients (p) – Predictors					
Participants with language profile			N items	N items correct	% correct	Dom	Model test	R^2_{CS}	R^2_N	AC	AoA	Fam	Image	VC	PNFacross	PS
BwA1	L1	DUT	347	142	40.92	L2	χ^2(6)=7.71, p=.260	.062	.082	62.0%	.046*	.772	.613	.917	.465	.736
	L2	GER[a]	347	203	58.50		χ^2(6)=17.9, p=.006*	.278	.409	83.6%	.014*	.267	.782	.208	.335	.353
BwA2	L1	POL[a]	422	285	67.54	L2	χ^2(6)=9.92, p=.128	.046	.066	70.0%	.799	.065	.190	.775	.477	.878
	L2	GER[a]	422	168	39.81							n/a[b]				
BwA3	L1	DUT	347	186	53.60	L2	χ^2(6)=6.39, p=.381	.052	.072	68.6%	.076	.732	.536	.458	.728	.133
	L2	GER[a]	347	209	60.23		χ^2(6)=2.95, p=.816	.052	.074	69.1%	.596	.499	.522	.812	.750	.297
BwA4	L1	ENG[a]	331	265	80.06	L1	χ^2(6)=1.84, p=.934	.012	.020	87.6%	.527	.945	.970	.833	.409	.347
	L2	GER	331	195	58.91		χ^2(6)=10.4, p=.108	.185	.252	70.6%	.848	.578	.014*	.695	.205	.900
BwA5	L1	ENG[a]	356	72	20.22	ENG						n/a[c]				
	L1	ITA	356	0	0							n/a[d]				
BwA6	L1	ENG[a]	365	314	86.03	L1	χ^2(6)=5.25, p=.512	.029	.064	91.0%	.104	.578	.824	.452	.325	.244
	L2	FRE	365	189	51.78		χ^2(6)=35.9, p<.001*	.259	.352	75.0%	<.001*	.599	.776	.461	.665	.007*
BwA7	L1	FRE	365	254	69.59	L2	χ^2(6)=17.2, p=.009*	.133	.224	84.2%	.095	.553	.060	.131	.763	.096
	L2	ENG[a]	365	262	71.78		χ^2(6)=8.51, p=.203	.047	.082	84.2%	.693	.484	.063	.615	.151	.314
BwA8	L1	FRE	365	240	65.75	L2	χ^2(6)=, p<.001*	.183	.259	77.5%	<.001*	.128	.581	.622	.322	.332
	L2	ENG[a]	365	293	80.27		χ^2(6)=14.6, p=.023*	.079	.134	84.7%	.052*	.773	.341	.501	.202	.441

Note. DUT = Dutch, GER = German, POL = Polish, ENG = English, ITA = Italian, FRE = French, Dom = Language dominance, R^2_{CS} = Cox and Snell's R^2, R^2_N = Nagelkerke's, AC = Accuracy of model classification, AoA = Age of acquisition, Fam = Familiarity, Image = Imageability, VC = Visual complexity, PNFacross = Phonological neighbourhood frequency across languages, PS = Phonological similarity score.

[a] Dominant language.

[b] CLEARPOND (Marian et al., 2012) was used to collect the values of PND/PNFwithin and PND/PNFacross. The database provides data for the following languages: English, Dutch, French, German, and Spanish. Therefore, German neighbourhood data for Polish targets could be collected. However, Polish neighbourhood data for German targets were not available.

[c] Italian neighbourhood data for English targets were not available, using the database CLEARPOND (Marian et al., 2012).

[d] BwA5 experienced severe naming difficulties in Italian with naming accuracy of 0% (0/356). Therefore, a logistic regression analysis was not possible to run for the participant's non-dominant language.

Discussion

This study investigated the impact of phonological neighbours on accuracy in spoken picture naming in monolingual and bilingual speakers with aphasia, using a logistic regressions analysis. Hereby, the influence of phonological neighbourhood density and frequency within language (PNDwithin, PNFwithin) was investigated for both speaker groups, and additionally across languages (PNDacross, PNFacross, phonological similarity) for the bilingual speaker group.

The pattern that emerged for monolingual speakers showed no effects of phonological neighbourhood within language for nine participants. Only one participant (MwA5, see Table 16) showed increased accuracy with higher phonological neighbourhood (higher PNDwithin and PNFwithin).

Table 16

Phonological Neighbourhood Effect on Accuracy in all Monolingual Speakers with Aphasia

	Phonological neighbourhood effect on accuracy	
Participant	PNDwithin effect on accuracy	PNFwithin effect on accuracy
MwA1	×	×
MwA2	×	×
MwA3	×	×
MwA4	×	×
MwA5	✓	✓
MwA6	×	×
MwA7	×	×
MwA8	×	×
MwA9	×	×
MwA10	×	×

Note. × = No effect on picture naming accuracy, ✓ = Effect on picture naming accuracy.

Five bilingual participants (BwA2, 3, 6, 7, and 8, see Table 17) showed increased picture naming accuracy with higher phonological neighbourhood (PNFwithin and phonological similarity) in the within-language analyses. The effect was only evident in the participants' non-dominant/weaker language for five participants. For the across-language analyses, minimal effects were observed: Only BwA6 showed an increased accuracy when phonological similarity between languages was high, again this was observed for her non-dominant language. Further, across-language phonological neighbourhood analyses (PNDacross, PNFacross, phonological similarity) revealed no effects on picture naming accuracy.

This suggests that a high PNFwithin and high phonological similarity (across the target and non-target language equivalent word) potentially facilitates accuracy in bilingual speakers with aphasia only within their non-dominant language. Hence, language dominance might be a crucial factor when investigating neighbourhood effects in bilingual speakers with aphasia.

Table 17

Phonological Neighbourhood Effects on Accuracy in all Bilingual Speakers with Aphasia

			Phonological neighbourhood effects			
			Within-language analyses		Across-language analyses	
Participants			PNDwithin	PNFwithin	PNDacross	PNFacross
BwA1	L1	Dutch	×	×	×	×
	L2	German^	×	×	×	×
BwA2	L1	Polish^	×	×	×	×
	L2	German^	×	PNF: ✓, PS: ✓	×	×
BwA3	L1	Dutch	PS: ✓	PS: ✓	×	×
	L2	German^	×	×	×	×
BwA4	L1	English^	×	×	×	×
	L2	German	×	×	×	×
BwA5	L1	English^	×	×	×	×
	L1	Italian	×	×	×	×
BwA6	L1	English^	×	×	×	×
	L2	French	PS: ✓	PS: ✓	PS: ✓	PS: ✓
BwA7	L1	French	PS: ✓	PNF: ✓, PS: ✓	×	×
	L2	English^	×	×	×	×
BwA8	L1	French	×	PNF: ✓	×	×
	L2	English^	×	×	×	×

Note. ^ = Dominant language, × = No effect on picture naming accuracy, ✓ = Effect on picture naming accuracy, PS = Phonological similarity, PNF = Phonological neighbourhood frequency.

Phonological Neighbourhood Effects in the Mental Lexicon

Monolingual Speakers with Aphasia

The majority of included monolingual participants showed no PNDwithin/PNFwithin effect on their picture naming accuracy outcome. Merely one single monolingual speaker with aphasia (MwA5) displayed density *and* frequency effects on accuracy.

Previous studies, that investigated these neighbourhood effects in monolingual unimpaired and impaired speakers were inconclusive. In monolingual healthy speakers, no effects on accuracy were reported for density (Gordon & Kurczek, 2014; Vitevitch, 2002; Vitevitch et al., 2004), facilitatory effects were found for density and frequency (Newman & Bernstein Ratner, 2007; Hameau et al., 2021), inhibitory effects were detected for density (Newman & German, 2005) and for density and frequency (Hameau et al., 2021). In monolingual speakers with aphasia no effects were found for density (Palmer, 2018; Tichborne et al., 2021) and frequency (Palmer, 2018; Gordon, 2002), faciliatory effects were revealed for density (Gordon, 2002; Goldrick et al., 2010; Middleton & Schwartz, 2010; Mirman et al., 2010: Laganaro et al., 2013), and inhibitory effects were reported for density (Mirman et al., 2010; Laganaro et al., 2013).

In the context of comparing our findings to previous research, our results align with three studies' reporting no phonological density effects on accuracy in healthy monolinguals (Gordon & Kurczek, 2014; Vitevitch, 2002; Vitevitch et al., 2004). Additionally, our findings are consistent with three studies that revealed no density effects in monolingual speakers with aphasia (Palmer, 2018; Tichborne et al., 2021).

Since most research in this field mainly focussed on phonological neighbourhood effects in relation to density; only a limited number of studies incorporated neighbourhood frequency values. Therefore, we incorporated in our examination phonological neighbourhood frequency as a predictor. Our results for frequency effects align with previous research that found no frequency effects on accuracy in monolingual speakers with aphasia (Palmer et al., 2018; Gordon, 2002).

In comparison to studies that have shown different patterns, our study included a significantly larger number of items to examine phonological neighbourhood effects. While the previous studies with facilitatory and inhibitory outcomes examined phonological neighbourhood effects with 48 to 260 pictures that were mostly black and white drawings, our study specifically included 423 items for the monolingual German speakers and 440 items for the monolingual English speakers with aphasia. These items consisted of coloured objects that varied in word lengths and consonant-vowel structures in both languages.

Consequently, our item material was much larger in comparison to earlier studies and we also matched for factors that underpin spoken word production, and are therefore more sensitive to capture potential neighbourhood effects driven by density and frequency (further theoretical implications will be discussed later in this section).

Bilingual Speakers with Aphasia

Four bilingual participants (BwA3, 6, 7 and 8) showed higher picture naming accuracy in the within-language analyses for items that were higher in frequency and/or had a high phonological similarity to the non-target language word, always in their non-dominant language, regardless of whether the non-dominant language was the participant's L1 or L2. BwA2 showed the same effect, however in his dominant L2 German. It is important to mention, that the dominance of the participant's languages was equally distributed across his L1 and L2. The bilingual language profile of BwA2 could provide an explanation for why the participant showed the effects in German (L2): His language proficiency, which is part of the construct of language dominance, is slightly higher in Polish (L1). Therefore, effects in his dominant language may have been driven by his lower proficiency in his dominant language German.

For the across-language analyses, only BwA6 showed phonological neighbourhood effects (phonological similarity); however, again, higher accuracy was observed in their non-dominant language.

When comparing our result to previous research on bilingual healthy speakers, it needs to be acknowledged that published research is scarce and inconclusive. Researchers have found facilitatory effects for neighbourhood density within languages (Marian & Blumenfeld, 2006; Hameau et al., 2021) and neighbourhood density across languages (Hameau et al., 2021). Furthermore, inhibitory effects on accuracy were reported for density within and density across language neighbours (Hameau et al., 2021), while another study found neither density within and nor density across effects on picture naming accuracy (Sadat et al., 2016). It is noteworthy, that all these findings from previous research are based on density effects, while neighbourhood frequency within and across languages has remained unexplored in the bilingual population with aphasia. We, therefore, included this aspect in our study.

The study conducted by Marian and Blumenfeld (2006), including German-English and English-German late bilinguals, also reported that naming accuracy in German was generally higher (L1 and L2) for targets with a higher phonological neighbourhood density within languages and deducted that language proficiency played a more important role in lexical access than the language age of acquisition. This additional finding is in accordance with our research that assumes that phonological neighbourhood effects in bilinguals need to be considered in the context of the bilingual language profile since our effects were always observed in the non-dominant/weaker language, and this was regardless of whether the language was the L1 or L2 (so regardless of the language age of acquisition).

Evidence-based findings on phonological neighbourhood effects in bilingual speakers with aphasia are limited. Only an unpublished single case study investigated this effect, controlling for frequency *and* density (Palmer et al., 2018). Palmer et al. (2018) found no effects of density and frequency, neither within nor across languages. The findings of the across language analyses are in line with our findings, while the result of the within-language analyses differ: Our study found phonological neighbourhood effects in the non-dominant/weaker language in five out of eight participants. However, phonological neighbourhood effects on accuracy were also not consistently found among the bilingual speakers in this study. This could indicate that the nature of the underlying language deficit (locus of breakdown in lexical processing) is different from those that showed neighbourhood effects. This rationale can potentially account for the absence of phonological neighbourhood effects in the non-dominant language of the single case study conducted by Palmer et al. (2018).

A further noteworthy aspect regarding the previous research in this field among healthy and language-impaired bilingual speakers is, that the projects have only conducted the across-analyses in one language direction. However, it needs to be acknowledged that across phonological neighbourhood effects can manifest in both directions (L1 to L2, L2 to L1). Consequently, the current study addressed this limitation and examined across neighbourhood effects in both directions.

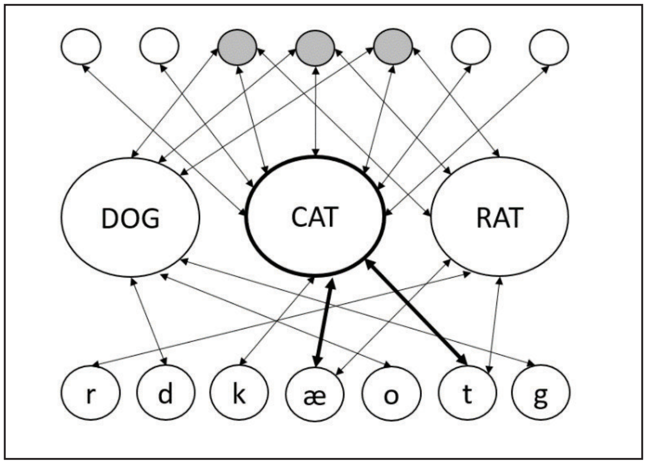
Observed Effects in the Context of a Monolingual Word Production Model. We assumed potential beneficial effects for word retrieval accuracy when the target word owns a high phonological neighbourhood, an assumption that was presented by others as well (Gordon & Kurczek, 2014). While we tested this assumption for monolingual speakers with aphasia, we were specifically interested if this is true for bilingual speakers, so whether within-language (PNDwithin, PNFwithin) and across-language phonological neighbours (PNDacross, PNFacross, phonological similarity) will affect accuracy in bilingual speakers with aphasia.

The present study's findings in bilingual speakers with aphasia do verify that the bidirectional activation between phonemes and lemmas, as outlined in the Interaction

Activation Model of spoken language production (Dell et al., 2007, see Figure 4), can have a facilitatory effect on accuracy within the non-dominant/weaker language of a bilingual speaker with aphasia. An explanation for why there is this effect in the non-dominant/weaker language: There are differences in the strength of processing (between dominant and non-dominant languages) and these differences in processing strengths can be an explanation for the differences in phonological neighbourhood effects regarding language dominance. This would imply, processing pathways are more robust in the dominant language compared to the processing pathway in the non-dominant language, and therefore the effects of phonological neighbours may not emerge in the dominant language.

Figure 10

Activation Model of Spoken Language Production (e.g., Dell et al., 2007)



Note. Production of a target word (*cat*) facilitated by the within-language phonological neighbour *rat.* The arrows in the model feature bidirectional activation.

Among the monolingual speakers with aphasia, nine participants exhibited no phonological neighbourhood effect on accuracy. An explanation could lie in the nature of the phonological neighbourhood effects we observed in the bilingual population. Effects have been exclusively observed in the bilingual speakers' non-dominant/weaker languages. However, monolinguals only speak in their dominant language since no other language is available. The absence of neighbourhood effects among these participants can therefore be explained by their language profile: Higher accuracy by increased activation between lemma and phonemes to the target has only been observed in a non-dominant language for bilingual speakers, which does not exist in monolingual speakers.

As already mentioned, neighbourhood effects of the participants in our study (BwA2, BwA3, BwA6, BwA7, BwA8) were also driven by the phonological similarity across item pairs (target word and non-target language transition equivalent): Accuracy of the target word was facilitated by the activation of the non-target language equivalent with high phonological similarity to the target word. This aligns with the evidence discussed in relation to the 'cognate facilitation effects': A number of studies demonstrated a well-established phenomenon whereby cognate words[27] are named faster and more accurately compared to non-cognate words (e.g., Costa et al., 2000; Costa et al., 2005; Strijkers et al., 2010). This phenomenon is based on the semantic and phonological overlap (simultaneous activation of the word form of the translation equivalent in the non-target language) for cognates (Costa et al., 2005). Although non-target language equivalents that facilitated accuracy in our study were not all cognates, they had a high phonological similarity to the target word (in addition to semantic overlap). Therefore, these non-target language equivalents have a high level of 'cognateness' that boosts accuracy of the target word via semantic and phonological word form level activation.

Effects in the Context of a Bilingual Language Model. The MULTILINK model (Dijkstra et al., 2019) can offer an explanation for the increased accuracy of target words through the activation of semantic and phonological word forms of non-target language words. MULTILINK is a computational bilingual localist-connectionist model. The model's network architecture is layered and the key representational structure is a lexical network. Hence, MULTILINK is an interactive model where activation spread operates in a bidirectional manner. While the MULTILINK model has a stronger focus on word recognition/ comprehension rather than production, it can still offer an explanation of the cognateness effect observed in our study. A key aspect of the MULTILINK model is bidirectional activation that operates between the different linguistic levels and between languages during word processing. The integration of multiple languages within the model acknowledges that the bilingual language network includes more than one language. With the assumed bidirectional activation between languages in the bilingual language network, it becomes possible to explain how the activation of semantic and phonological word forms from the non-target language can enhance the activation of the target word.

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[27] Refer to the introduction for a detailed explanation; cognates are words with high overlap in the form to their non-target language translation equivalent (e.g., English *house*, German *Haus*).

Conclusion

To conclude, we could demonstrate in this study that phonological neighbourhood effects (PNFwithin, phonological similarity) on picture naming accuracy are only evident in bilingual speakers with aphasia when they name pictures in their non-dominant/weaker language. The findings help us to better understand the bilingual language network: Bilingual speakers seem to benefit from the activation of phonological neighbours *within* their languages when speaking in the non-dominant/weaker language (since the activation of the words and phonemes of the neighbourhood words boost the activation of the target word). As such, there is a compelling rationale for considering these factors when enhancing picture naming accuracy and diagnosing and treating bilingual speakers with aphasia in speech pathology. Material for assessment and/or treatment in the bilingual speakers' non-dominant/weaker language can be consciously chosen, e.g., holding phonological neighbourhood features that facilitate naming accuracy. It remains an open question why monolingual speakers do not show within neighbourhood effects, why more research on the conditions under which these phonological neighbourhood effects do emerge in people with aphasia is needed. However, importantly, we need to remind ourselves that bilinguals are not just two monolingual speakers and that the influence of bilingual language profile is an important factor to consider in bilingual word production.

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Appendices

Appendix A

Background Information Monolingual Speakers with Aphasia

Background Information MwA1

Data Medical Records and Self-Reports – MwA1

Demographic and Medical Data. MwA1 was an 84-year-old German speaker (male) who worked as a technician until retirement. He had a stroke seven years and eight months prior to the start of the project. His CT scan showed a left middle cerebral artery infarct due to a heart attack six days before the stroke, resulting in aphasia.

Language Related Data. MwA1 was diagnosed with fluent but severe Wernicke's aphasia, dysphagia and a right hemiparesis immediately post-onset, resulting in hospitalisation for six weeks. After his stroke, MwA1 received regular outpatient occupational therapy, physiotherapy, speech pathology, and a three-week speech pathology rehabilitation once a year. Medical statements dated from the start of the project reported unclassified aphasia, characterised by phonological jargon, word finding difficulties, phonological paraphasias, recurring utterances, and neologisms. His main strategy to compensate for his word finding difficulties was using written communication, a better-preserved modality.

Background Language Assessments – MwA1

There was no syndrome-specific pattern observed for his language impairment. Hence, we categorised his aphasia as 'unclassified aphasia' (based on clinical observations and the background assessment results). Table A1 shows MwA1's language performance in German on various background assessments spanning across receptive and expressive tasks. The LEMO subtest spoken naming resulted in impaired naming abilities with an accuracy of 45% (LEMO score: 9/20). MwA1 showed a language impairment in the BAT (BAT score: 104/174) with an accuracy of 30% within the spoken naming BAT subtest (BAT naming score: 6/20). MwA1 showed impaired written naming abilities with an accuracy of 36.37% (first 30 items of Subset 1a of the experimental naming task: Written naming score: 11/30). His naming accuracy for written naming was higher compared to the spoken naming accuracy of these 30 items (spoken naming score: 5/30, accuracy 16.67%).

Table A1

Language Background Assessment Data MwA1

	German	
Background assessment	Raw score	% correct
Bilingual Aphasia Test (BAT) – Receptive tasks		
Pointing (n=10)	9	90
Simple and semi-complex commands (n=10)	10	100
Complex commands (n=20)	2	10
Verbal auditory discrimination (n=18)	13	72.22
Semantic categories (n=5)	3	60
Synonyms (n=5)	1	20
Lexical decision of words and nonsense words (n=30)	25	83.33
Lexical decision of words (n=20)	18	90
Lexical decision of nonwords (n=10)	7	70
Reading comprehension for words (n=10)	7	70
Bilingual Aphasia Test (BAT) – Expressive tasks		
Repetition of words and nonsense words (n=30)	15	50
Repetition of words (n=20)	12	60
Repetition of nonwords (n=10)	3	30
Series (n=3)	1	33.33
Verbal fluency (n=3)	3	100
Spoken Naming (n=20)	6	30
Reading Aloud (n=10)	9	90
Overall BAT-score	*104*	
LEMO 2.0 – Spoken Naming (Subtest 13)		
Naming: Total (n=20)	9	45
High frequency (n=10)	4	40
Low frequency (n=10)	5	50
Naming-Subset 1a (items 1-30)		
Written naming (n=30)	11	36.67
Spoken naming (n=30)	5	16.67

Background Information MwA2

Data Medical Records and Self-Reports – MwA2

Demographic and Medical Data. MwA2 was a 75-year-old German speaker (male), who worked as a banker prior to his stroke. The participant was 25 years post-onset with the start of the project. He had a left hemisphere infarct in the middle cerebral artery while he was out for a run. The stroke resulted in aphasia.

Language Related Data. According to medical records, the participant's stroke resulted in severe aphasia post-onset, with verbal production abilities reduced to only yes- and no-responses and hemiparesis on the right side. After rehabilitation of three months, the participant returned home and received outpatient physiotherapy, occupational therapy and speech pathology. With the start of the project, all types of outpatient therapies were ongoing. At the start of the project, medical data reported anomic aphasia characterised by moderate word finding difficulties.

Background Language Assessments – MwA2

The pattern of language impairment was consistent with fluent anomic aphasia (based on clinical observations and the background assessment results). Table A2 shows MwA2's language performance in German. The participant's naming accuracy within the LEMO subtest spoken naming was 75% (LEMO score: 15/20). MwA2 showed a language impairment in the BAT (BAT score: 128/174), with a spoken naming accuracy of 75% within the spoken naming BAT subtest (BAT naming score: 15/20). The participant showed written naming accuracy of 46.67% (first 30 items of Subset 1a of the experimental naming task: Written naming score: 14/30). His naming accuracy for written naming was similar to the spoken naming accuracy when comparing the naming accuracy of these 30 items (spoken naming score: 15/30, accuracy 50%).

Table A2

Language Background Assessment Data MwA2

	German	
Background assessment	Raw score	% correct
Bilingual Aphasia Test (BAT) – Receptive tasks		
Pointing (n=10)	10	100
Simple and semi-complex commands (n=10)	9	90
Complex commands (n=20)	5	25

Verbal auditory discrimination (n=18)	14	77.78
Semantic categories (n=5)	1	20
Synonyms (n=5)	3	60
Lexical decision of words and nonsense words (n=30)	27	90
Lexical decision of words (n=20)	19	95
Lexical decision of nonwords (n=10)	8	80
Reading comprehension for words (n=10)	9	90
Bilingual Aphasia Test (BAT) – Expressive tasks		
Repetition of words and nonsense words (n=30)	20	66.67
Repetition of words (n=20)	18	90
Repetition of nonwords (n=10)	2	20
Series (n=3)	3	100
Verbal fluency (n=3)	2	66.67
Spoken Naming (n=20)	15	75
Reading Aloud (n=10)	10	100
Overall BAT-score	*128*	
LEMO 2.0 – Spoken Naming (Subtest 13)		
Naming: Total (n=20)	15	75
High frequency (n=10)	9	90
Low frequency (n=10)	6	60
Naming-Subset 1a (items 1-30)		
Written naming (n=30)	14	46.67
Spoken naming (n=30)	15	50

Background Information MwA3

Data Medical Records and Self-Reports – MwA3

Demographic and Medical Data. MwA3 was a 57-year-old German speaker (male), who worked as a master butcher and business economist prior to his stroke. He returned as a marginal employee to the same company post-onset. Mwa3's medical history reported a left middle cerebral artery infarct_19 years and two months prior to this study. The stroke resulted in aphasia.

Language Related Data. Medical records reported global aphasia and apraxia of speech immediately post-onset. The participant went through different rehabilitation programs after his hospitalisation, including a four-week intensive speech pathology rehabilitation a number of times (not more than once a year). Ongoing occupational therapy, physiotherapy and speech pathology were reported. At the start of the study, medical data reported Broca's aphasia. His spontaneous speech appeared in a telegram style and was reduced to one- to two-word sentences, with moderate to severe word finding difficulties and difficulties with reading and writing. Additionally, mild apraxia of speech, mild facial paresis, mild hemiparesis right and a mild sensitivity disorder (face) were reported.

Background Language Assessments – MwA3

MwA3's language impairment was consistent with a non-fluent Broca's aphasia (based on clinical observations and the background assessment results). Table A3 lists the results of different background assessments. The participant was screened with impaired naming abilities within the LEMO subtest spoken naming with an accuracy of 85% (LEMO score: 17/20). MwA3 showed a language impairment across the 13 subtests of the BAT (BAT score: 123/174). Spoken naming within the BAT was impaired with an accuracy of 65% (BAT naming score: 13/20). MwA3's written naming accuracy across the first 30 items of Subset 1a of the experimental naming task was 33.33% (written naming score: 10/30). The participant showed higher naming accuracy for spoken naming compared to written naming across these 30 items (spoken naming score: 17/30, accuracy 56.67%).

Table A3

Language Background Assessment Data MwA3

	German	
Background assessment	Raw score	% correct
Bilingual Aphasia Test (BAT) – Receptive tasks		
Pointing (n=10)	10	100
Simple and semi-complex commands (n=10)	6	60
Complex commands (n=20)	2	10
Verbal auditory discrimination (n=18)	14	77.78
Semantic categories (n=5)	5	100
Synonyms (n=5)	4	80
Lexical decision of words and nonsense words (n=30)	27	90
Lexical decision of words (n=20)	20	100
Lexical decision of nonwords (n=10)	7	70
Reading comprehension for words (n=10)	9	90
Bilingual Aphasia Test (BAT) – Expressive tasks		
Repetition of words and nonsense words (n=30)	27	90
Repetition of words (n=20)	20	100
Repetition of nonwords (n=10)	7	70
Series (n=3)	1	33.33
Verbal fluency (n=3)	2	66.67
Spoken Naming (n=20)	13	65
Reading Aloud (n=10)	3	30
Overall BAT-score	*123*	
LEMO 2.0 – Spoken Naming (Subtest 13)		
Naming: Total (n=20)	17	85
High frequency (n=10)	9	90
Low frequency (n=10)	8	80
Naming-Subset 1a (items 1-30)		
Written naming (n=30)	10	33.33
Spoken naming (n=30)	17	56.67

Background Information MwA4

Data Medical Records and Self-Reports – MwA4

Demographic and Medical Data. MwA4 was a 49-year-old German speaker (female) who was trained as an office junior and worked as a typist in the medical sector until retirement post-stroke. The participant was eight years and three months post-onset with the start of the project. MwA4 had a left frontal and temporal intracerebral haemorrhage, which resulted in aphasia.

Language Related Data. The participant's stroke resulted in mixed aphasia, dyscalculia, dyslexia, and a hemiparesis right. Additionally, impaired concentration, attention, memory and orientation abilities were reported. MwA4 underwent two rehabilitation programs after her hospitalisation. At the start of the study, medical data reported anomic aphasia with ongoing speech pathology addressing her mild word finding difficulties.

Background Language Assessments – MwA4

MwA4's pattern of language impairment was consistent with the diagnosis of fluent anomic aphasia (based on clinical observations and the background assessment results). Her language performance was tested across different assessments spanning receptive and expressive tasks (see Table A4). The LEMO subtest spoken naming resulted in naming accuracy of 90% (LEMO score: 18/20). Overall BAT results showed a language impairment for MwA4 (BAT score: 163/174). The accuracy of spoken naming within the BAT was 100% (BAT naming score: 20/20). MwA4 showed impaired written naming abilities with an accuracy of 80% (first 30 items of Subset 1a of the experimental naming task: Written naming score: 24/30). Naming accuracy across written and spoken naming was equally distributed when comparing the naming accuracy of these 30 items (spoken naming score: 24/30, accuracy 80%).

Table A4

Language Background Assessment Data MwA4

	German	
Background assessment	Raw score	% correct
Bilingual Aphasia Test (BAT) – Receptive tasks		
Pointing (n=10)	10	100
Simple and semi-complex commands (n=10)	9	90

Complex commands (n=20)	17	85
Verbal auditory discrimination (n=18)	17	94.44
Semantic categories (n=5)	5	100
Synonyms (n=5)	4	80
Lexical decision of words and nonsense words (n=30)	28	93.33
Lexical decision of words (n=20)	20	100
Lexical decision of nonwords (n=10)	8	80
Reading comprehension for words (n=10)	10	100
Bilingual Aphasia Test (BAT) – Expressive tasks		
Repetition of words and nonsense words (n=30)	28	93.33
Repetition of words (n=20)	20	100
Repetition of nonwords (n=10)	8	80
Series (n=3)	3	100
Verbal fluency (n=3)	3	100
Spoken Naming (n=20)	**20**	**100**
Reading Aloud (n=10)	9	90
Overall BAT-score	*163*	
LEMO 2.0 – Spoken Naming (Subtest 13)		
Naming: Total (n=20)	**18**	**90**
High frequency (n=10)	9	90
Low frequency (n=10)	9	90
Naming-Subset 1a (items 1-30)		
Written naming (n=30)	24	80
Spoken naming (n=30)	24	80

Background Information MwA5

Data Medical Records and Self-Reports – MwA5

Demographic and Medical Data. Participant MwA5 was a 59-year-old German speaker (male), who worked as a building and footpath cleaner for 20 years prior to his stroke. The participant was eight months post-onset with the start of the project. One week prior to the stroke MwA5 had a transient ischemic attack. He had multiple infarcts localised in the left and right hemisphere, the main infarct was localised in the middle cerebral artery left. The stroke resulted in aphasia.

Language Related Data. Immediately after the stroke, non-fluent aphasia and mild dysarthria were reported. Additionally, the participant was diagnosed with hemiparesis, neglect and apraxia on the right body side. The non-fluent aphasia was specified by a reduced spoken output (mostly yes- and no-responses), severe word finding difficulties, comprehension difficulties and impaired reading and writing abilities. After hospitalization, the participant followed nine weeks of rehabilitation and self-reported a language recovery for his verbal language output and reading abilities. At the start of the project, medical data reported mild aphasia, including mild word finding difficulties and moderate writing impairments

Background Language Assessments – MwA5

MwA5's pattern of language impairment was consistent with fluent anomic aphasia (based on clinical observations and the background assessment results). The participant's language performance was tested across various background assessments (see Table A5). His accuracy on spoken picture naming (LEMO subtest spoken naming) was screened with 80% (LEMO score: 16/20 [80% correct]). MwA5 showed a language impairment across the 13 BAT subtests (BAT score: 145/174). Spoken naming within the BAT was impaired; the participant presented an accuracy of 90% (BAT naming score: 18/20). Written naming accuracy was 26.67% (30 items of Subset 1a of the experimental naming task: Written naming score: 8/30). MwA5's written naming accuracy was lower than the spoken naming accuracy of these 30 items (spoken naming score: 23/30, accuracy 76.67%).

Table A5

Language Background Assessment Data MwA5

	German	
Background assessment	Raw score	% correct
Bilingual Aphasia Test (BAT) – Receptive tasks		
Pointing (n=10)	10	100
Simple and semi-complex commands (n=10)	8	80
Complex commands (n=20)	7	35
Verbal auditory discrimination (n=18)	16	88.89
Semantic categories (n=5)	5	100
Synonyms (n=5)	2	40
Lexical decision of words and nonsense words (n=30)	28	93.33
Lexical decision of words (n=20)	20	100
Lexical decision of nonwords (n=10)	8	80
Reading comprehension for words (n=10)	9	90
Bilingual Aphasia Test (BAT) – Expressive tasks		
Repetition of words and nonsense words (n=30)	27	90
Repetition of words (n=20)	20	100
Repetition of nonwords (n=10)	7	70
Series (n=3)	3	100
Verbal fluency (n=3)	2	66.67
Spoken Naming (n=20)	18	90
Reading Aloud (n=10)	10	100
Overall BAT-score	*145*	
LEMO 2.0 – Spoken Naming (Subtest 13)		
Naming: Total (n=20)	16	80
High frequency (n=10)	7	70
Low frequency (n=10)	9	90
Naming-Subset 1a (items 1-30)		
Written naming (n=30)	8	26.67
Spoken naming (n=30)	23	76.67

Background Information MwA6

Data Medical Records and Self-Reports – MwA6

Demographic and Medical Data. MwA8 was a 73-year-old English speaker (male) from Australia who immigrated from Sri Lanka to Australia at the age of eight years with his family. MwA8 had a stroke in the left hemisphere 15 years prior to the study when he was on vacation. The stroke resulted in aphasia.

Language Related Data. At the start of the study, medical records reported moderate aphasia (with moderate to severe impaired expressive output and moderate comprehension impairment) based on the Western Aphasia Battery (WAB). The participant used an augmentative and alternative communication device (iPad).

Background Language Assessments – MwA6

The participant's pattern of language impairment was consistent with non-fluent Broca's aphasia (based on clinical observations and the background assessment results). Table A6 shows MwA6's language performance in English on various background assessments spanning receptive and expressive tasks. The LEMO subtest spoken naming resulted in impaired naming abilities with an accuracy of 45% (LEMO score: 9/20). MwA6 showed a language impairment in the BAT (BAT score: 117/174), with an accuracy of 60% within the spoken naming subtest (BAT naming score: 12/20). MwA6 showed impaired written naming abilities with an accuracy of 30% (first 30 items of Subset 1a of the experimental naming task: Written naming score: 9/30). When comparing the naming accuracy of these 30 items for written and spoken naming, there is a better outcome for spoken naming (spoken naming score: 12/30, accuracy 40%).

Table A6

Language Background Assessment Data MwA6

	English	
Background assessment	Raw score	% correct
Bilingual Aphasia Test (BAT) – Receptive tasks		
Pointing (n=10)	10	100
Simple and semi-complex commands (n=10)	7	70
Complex commands (n=20)	0	0
Verbal auditory discrimination (n=18)	14	77.78
Semantic categories (n=5)	1	20

Synonyms (n=5)	2	40
Lexical decision of words and nonsense words (n=30)	26	86.67
Lexical decision of words (n=20)	16	80
Lexical decision of nonwords (n=10)	10	100
Reading comprehension for words (n=10)	9	90
Bilingual Aphasia Test (BAT) – Expressive tasks		
Repetition of words and nonsense words (n=30)	22	73.33
Repetition of words (n=20)	18	90
Repetition of nonwords (n=10)	4	40
Series (n=3)	2	66.67
Verbal fluency (n=3)	2	66.67
Spoken Naming (n=20)	12	60
Reading Aloud (n=10)	10	100
Overall BAT-score	*117*	
LEMO 2.0 – Spoken Naming (Subtest 13)		
Naming: Total (n=20)	9	45
Naming-Subset 1a (items 1-30)		
Written naming (n=30)	9	30
Spoken naming (n=30)	12	40

Background Information MwA7

Data Medical Records and Self-Reports – MwA7

Demographic and Medical Data. MwA7 was a 63-year-old English speaker (male) from Australia, who was born and raised in the United States and worked as an insurance broker prior to the stroke. The participant had a left middle cerebral artery infarct seven years before the study, followed by a car accident. The stroke resulted in aphasia.

Language Related Data. Immediately after the stroke, the participant was diagnosed with expressive and receptive aphasia, a hemiparesis right and apraxia. A left vocal fold paresis and subsequent dysphonia following surgery for left carotid endarterectomy were managed by an otolaryngologist and Botox treatments. At the start of the study, medical data reported mild to moderate expressive aphasia, mild alexia, some reading comprehension difficulties and mild pragmatic difficulties. At times, great functional and social communication skills with a tangential conversational discourse were reported.

Background Language Assessments – MwA7

The pattern of language impairment was consistent with the diagnosis of fluent anomic aphasia (based on clinical observations and the background assessment results). Table A7 shows MwA7's language performance across receptive and expressive tasks. The participant's naming accuracy within the LEMO subtest spoken naming was 65% (LEMO score: 13/20). MwA7 showed a language impairment in the BAT (BAT score: 152/174); however, his spoken naming accuracy within the BAT subtest was 100% (BAT naming score: 20/20). The participant showed written naming accuracy of 90% (first 30 items of Subset 1a of the experimental naming task: Written naming score: 27/30). Written naming accuracy is higher in comparison to the spoken naming accuracy of these 30 items (spoken naming score: 21/30, accuracy 70%).

Table A7

Language Background Assessment Data MwA7

	English	
Background assessment	Raw score	% correct
Bilingual Aphasia Test (BAT) – Receptive tasks		
Pointing (n=10)	10	100
Simple and semi-complex commands (n=10)	10	100
Complex commands (n=20)	9	45

Verbal auditory discrimination (n=18)	12	66.67
Semantic categories (n=5)	4	80
Synonyms (n=5)	5	100
Lexical decision of words and nonsense words (n=30)	29	96.67
Lexical decision of words (n=20)	20	100
Lexical decision of nonwords (n=10)	9	90
Reading comprehension for words (n=10)	10	100
Bilingual Aphasia Test (BAT) – Expressive tasks		
Repetition of words and nonsense words (n=30)	27	90
Repetition of words (n=20)	19	95
Repetition of nonwords (n=10)	8	80
Series (n=3)	3	100
Verbal fluency (n=3)	3	100
Spoken Naming (n=20)	20	100
Reading Aloud (n=10)	10	100
Overall BAT-score	*152*	
LEMO 2.0 – Spoken Naming (Subtest 13)		
Naming: Total (n=20)	13	65
Naming-Subset 1a (items 1-30)		
Written naming (n=30)	27	90
Spoken naming (n=30)	21	70

Background Information MwA8

Data Medical Records and Self-Reports – MwA8

Demographic and Medical Data. Participant MwA8 was a 65-year-old English speaker (male) from Australia. MwA8 had a left-sided basal ganglia haemorrhage 11 years prior to this study, which resulted in aphasia.

Language Related Data. According to medical records, the participant had aphasia, dysarthria and right-sided hemiparesis after the stroke. At the start of the project medical records reported mild dysarthria and mild aphasia, which was characterised by word finding difficulties and some mild to moderate reading (comprehension) difficulties.

Background Language Assessments – MwA8

MwA8's language impairment was consistent with fluent anomic aphasia (based on clinical observations and the background assessment results). His language performance in English was tested on various background assessments spanning receptive and expressive tasks (see Table A8). The participant was screened with impaired naming abilities within the LEMO subtest spoken naming with an accuracy of 80% (LEMO score: 16/20). MwA8 showed a language impairment across the 13 subtests of the BAT (BAT score: 134/174). Spoken naming within the BAT was impaired, with an accuracy of 90% (BAT naming score: 18/20). MwA8's written naming accuracy across the first 30 items of Subset 1a of the experimental naming task was 46.67% (written naming score: 14/30). When comparing the written naming results to the spoken naming results of the same 30 items, spoken naming accuracy is higher in comparison to the written naming accuracy (spoken naming score: 18/30, accuracy 60%).

Table A8

Language Background Assessment Data MwA8

	English	
Background assessment	Raw score	% correct
Bilingual Aphasia Test (BAT) – Receptive tasks		
Pointing (n=10)	10	100
Simple and semi-complex commands (n=10)	9	90
Complex commands (n=20)	8	40
Verbal auditory discrimination (n=18)	10	55.56
Semantic categories (n=5)	4	80

Synonyms (n=5)	5	100
Lexical decision of words and nonsense words (n=30)	28	93.33
Lexical decision of words (n=20)	20	100
Lexical decision of nonwords (n=10)	8	80
Reading comprehension for words (n=10)	10	100
Bilingual Aphasia Test (BAT) – Expressive tasks		
Repetition of words and nonsense words (n=30)	22	73.33
Repetition of words (n=20)	20	100
Repetition of nonwords (n=10)	2	20
Series (n=3)	1	33.33
Verbal fluency (n=3)	2	66.67
Spoken Naming (n=20)	18	90
Reading Aloud (n=10)	7	70
Overall BAT-score	*134*	
LEMO 2.0 – Spoken Naming (Subtest 13)		
Naming: Total (n=20)	16	80
Naming-Subset 1a (items 1-30)		
Written naming (n=30)	14	46.67
Spoken naming (n=30)	18	60

Background Information MwA9

Data Medical Records and Self-Reports – MwA9

Demographic and Medical Data. MwA9 was a 49-year-old English speaker (male) from Australia, who worked as a computer technician and in stock retail prior to his stroke. After the stroke, he returned to work in an op shop twice a week. The participant was five years and 11 months post-onset with the start of the project. While living in Canada he had a left parietal intracerebral haemorrhage, which resulted in aphasia.

Language Related Data. While the participant lived in Canada, he had a stroke that resulted in aphasia and hemiparesis. The aphasia was characterized by reduced expressive output (only yes- and no-responses) and impaired reading abilities. The participant's comprehension abilities were unimpaired, writing was possible in capital letters. Eight months after rehabilitation in Canada MwA9 returned to Australia, his home country. At the start of the project, medical data diagnosed MwA9 with severe hemiparesis and mild aphasia, which was mainly that was characterised by word finding difficulties.

Background Language Assessments – MwA9

MwA9's pattern of language impairment was consistent with the diagnosis of fluent anomic aphasia (based on clinical observations and the background assessment results). His language performance was tested across different assessments spanning receptive and expressive tasks (see Table A9). The LEMO subtest spoken naming resulted in naming accuracy of 90% (LEMO score: 18/20). Overall BAT results showed a language impairment for MwA9 (BAT score: 145/172[28]). The accuracy of spoken naming within the BAT was 85% (BAT naming score: 17/20). MwA9 showed impaired written naming abilities with an accuracy of 80% (first 30 items of Subset 1a of the experimental naming task: Written naming score: 24/30). When comparing the naming accuracy of these 30 items for written and spoken naming, the participant showed a higher accuracy for written naming (spoken naming score: 20/30, accuracy 66.67%).

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[28] Overall score is 145/172 and not 145/174 (based on the exclusion of two items, see Table A9)

Table A9

Language Background Assessment Data MwA9

	English	
Background assessment	Raw score	% correct
Bilingual Aphasia Test (BAT) – Receptive tasks		
Pointing (n=10)	10	100
Simple and semi-complex commands (n=10)	8	80
Complex commands (n=20)	6	30
Verbal auditory discrimination (n=18; this version n=17[a])	13	76.47
Semantic categories (n=5; this version n=4[a])	4	100
Synonyms (n=5)	5	100
Lexical decision of words and nonsense words (n=30)	27	90
Lexical decision of words (n=20)	18	90
Lexical decision of nonwords (n=10)	9	90
Reading comprehension for words (n=10)	10	100
Bilingual Aphasia Test (BAT) – Expressive tasks		
Repetition of words and nonsense words (n=30)	29	96.67
Repetition of words (n=20)	20	100
Repetition of nonwords (n=10)	9	90
Series (n=3)	3	100
Verbal fluency (n=3)	3	100
Spoken Naming (n=20)	17	85
Reading Aloud (n=10)	10	100
Overall BAT-score	*145*[b]	
LEMO 2.0 – Spoken Naming (Subtest 13)		
Naming: Total (n=20)	18	90
Naming-Subset 1a (items 1-30)		
Written naming (n=30)	24	80
Spoken naming (n=30)	20	66.67

[a] One item was excluded (pronunciation error by the researcher).

[b] Overall score is 145/172 and not 145/174 (based on the exclusion of two items, see [a]).

Background Information MwA10

Data Medical Records and Self-Reports – MwA10

Demographic and Medical Data. MwA10 was a 63-year-old English speaker (female) from Australia, who worked as a secretary at a bank until retirement after her stroke. MwA10 had a vascular stroke in the left hemisphere (two days after stomach surgery) two years and eight months prior to this study. The stroke resulted in aphasia.

Language Related Data. Immediately after the stroke, the participant was diagnosed with upper limb hemiplegia and aphasia, characterised by limited expressive output (yes- and no-responses, thank you-response). At the start of the project, medical data reported mild aphasia with mild word finding difficulties being present.

Background Language Assessments – MwA10

MwA10's pattern of language impairment was consistent with fluent anomic aphasia (based on clinical observations and the background assessment results). The language performance was tested across various background assessments (see Table A10). Her accuracy on spoken picture naming (LEMO subtest spoken naming) was screened with 90% (LEMO score: 18/20). MwA10 showed a language impairment across the 13 BAT subtests (BAT score: 164/174). However, spoken naming within the BAT was not impaired, the participant presented an accuracy of 100% (BAT naming score: 20/20). Written naming accuracy was 70% (30 items of subset 1a of the experimental naming task: Written naming score: 21/30). The participant's written naming accuracy was similar to the spoken naming accuracy when comparing the accuracy results of these 30 items (spoken naming score: 22/30, accuracy 73.33%).

Table A10

Language Background Assessment Data MwA10

	English	
Background assessment	Raw score	% correct
Bilingual Aphasia Test (BAT) – Receptive tasks		
Pointing (n=10)	10	100
Simple and semi-complex commands (n=10)	10	100
Complex commands (n=20)	18	90
Verbal auditory discrimination (n=18)	16	88.89
Semantic categories (n=5)	4	80

Synonyms (n=5)	5	100
Lexical decision of words and nonsense words (n=30)	28	93.33
Lexical decision of words (n=20)	20	100
Lexical decision of nonwords (n=10)	8	80
Reading comprehension for words (n=10)	10	100
Bilingual Aphasia Test (BAT) – Expressive tasks		
Repetition of words and nonsense words (n=30)	27	90
Repetition of words (n=20)	20	100
Repetition of nonwords (n=10)	7	70
Series (n=3)	3	100
Verbal fluency (n=3)	3	100
Spoken Naming (n=20)	20	100
Reading Aloud (n=10)	10	100
Overall BAT-score	3 *164*	100
LEMO 2.0 – Spoken Naming (Subtest 13)		
Naming: Total (n=20)	18	90
Naming-Subset 1a (items 1-30)		
Written naming (n=30)	21	70
Spoken naming (n=30)	22	73.33

Appendix B

Item Lists for all Included Languages and Language Combinations

Due to size of Appendix B (167 pages) item lists for all included languages and language combinations of all monolingual and bilingual speakers with aphasia are to find on the Open Science Framework Platform under the following link: https://osf.io/23zpc/

Appendix C

Logistic Regression Results for the Monolingual and Bilingual Speakers with Aphasia

The result of the regression analyses of all monolingual and bilingual speakers with aphasia are to find on the Open Science Framework Platform under the following link: https://osf.io/23zpc/

The results of the regression analyses also include the correlation matrix of the different languages and language-combinations. Refer to the following results for the correlation matrix of the different languages and language-combinations: German (MwA1), English (MwA6), Dutch-German (BwA1), Polish-German (BwA2), English-German (BwA4), English-Italian (BwA5), French-English (BwA6).

Chapter 4:

Accuracy Pattern and Language Mixing Errors in Compound Word Picture Naming in Bilingual Speakers with Aphasia

(Study 3)

Introduction

Bilingual Compounds – A Window into Bilingual Word Organisation

In psycholinguistic research, the investigation of compound words (e.g., *bedroom*: A word that consists of two free-open morphemes [*bed* and *room*]) is of special interest, since they are a 'back door' into the working mechanisms and architecture of the mental lexicon within the language system (Downing, 1977). Moreover, they are considered as gateways to understand the linguistic representations and grammatical processing of words (Libben, 2006).

The same applies to the investigation of language processing in people with an acquired language disorder such as aphasia. The examination of word access via spoken picture naming tasks is a common methodology when working with people with aphasia as it can give valuable insight into the mental lexicon within and, in the bilingual case, across language system(s). Many aphasiologists have drawn on this methodology and formed hypotheses about how word storage may work, what constitutes a word unit, and what mechanisms need to be in place to access a word successfully. Frameworks about bilingual word organization have been proposed by, for example, Kroll et al. (2010), Abutalebi and Green (2007), Costa et al. (2006) but their theories remain underspecified compared to the monolingual context. However, in an increasingly bilingual world, more sophisticated bilingual language models are emerging (e.g., the MULTILINK model proposed by Dijkstra et al., 2019) but are still imprecise when it comes to detailed morphological processing, like in compound words.

Investigating compound production more in word picture naming in bilingual speakers with aphasia can further enhance our understanding of the bilingual language system and more specifically the bilingual mental lexicon, which is still not fully understood. To the best of our knowledge, only one study has investigated compound picture naming in bilingual speakers with aphasia to date (Jarema et al., 2010). The following introduction provides an overview of the linguistic characteristics of compound words, empirical evidence from (impaired) monolingual speakers regarding monolingual word processing in the Two-Stage Model (Levelt et al., 1999), empirical evidence in relation to the model from impaired bilingual speakers and, finally, the research questions for this study.

Compound Words and Their Linguistic Characteristics

A compound word, independent of whether being a monolingual or bilingual speaker, is defined by the combination of two or more free-standing morphemes (e.g., free open class morphemes are *bed* and *room*; a morpheme is the smallest meaning-carrying unit in language). This combination of two independent morphemes creates a new word form that is lexically (morphologically) complex (e.g., *bedroom*) (e.g., Jarema et al., 2010). In contrast, simple words consist of a single morpheme that cannot be further broken down into smaller meaningful units (e.g., *fish*). A compound word can be formed by different word constituents. These constituents can be words of different word classes (nouns, verbs, adjectives, prepositions), that can be combined to form a compound word (Lorenz & Zwitserlood, 2014). However, the most common type of compound is a noun-noun compound, like *bedroom* or *sunflower*. All compound words consist of a morphological modifier constituent and a morphological head constituent, with the head constituent specifying the syntactic and morphological features (e.g., grammatical class, gender, case, number inflection) of the compound word.

Additionally, the head constituent represents the basic meaning of the full compound word, while the modifier constituent modifies or specifies the meaning of the head constituent (Lorenz & Zwitserlood, 2014). In most languages, compounds follow the right-hand head rule, with the rightmost constituent forming the morphological head (e.g., English, German). However, some languages also contain head-initial compound words (e.g., French, Italian) or have exclusively head-initial compound words available (e.g., Hebrew).

In addition, compound words can either be semantically transparent, opaque, or semi-transparent in meaning. Semantically transparent compounds are characterized by a close connection between the meaning of the whole word and the meanings of the individual constituents (e.g., *bedroom* = room for a bed). In contrast, the meaning of opaque compounds cannot be derived from the meanings of the two individual constituents (e.g., *hotdog*). Semi-transparent compound words are neither completely transparent nor completely opaque: One constituent may be relatively transparent while the other is relatively opaque (e.g., *sunflower*) (e.g., Lorenz, 2008).

Representation of Compound Words in the Monolingual Mental Lexicon According to Healthy Language Production Model

Models of monolingual word production in unimpaired speakers (e.g., Dell et al., 2007; Levelt et al., 1999) can offer insights into the representation of compound words within the mental lexicon. There is consensus about the three major steps in monolingual word production: Accessing (a) the non-lexical concept level, followed by (b) the lexical semantic/ syntactic level, and subsequently (c) the lexical phonological word form level. The Two-Stage Model proposed by Levelt et al. (1999) signifies lexical processing in two steps: The lemma level and the phonological word form level. Grammatical properties of words are stored at the lemma level (e.g., word class, gender, tense, etc.), while the word form level represents the phonological structure of the word (e.g., syllable number and structure, phoneme types, etc). The lemma level serves therefore as an intermediate level between the lexical-semantic and the phonological level (Levelt et al., 1999) (see Figure 1).

The Two-Stage Model for word production provides our theoretical framework (even though a monolingual one), in which we explore the representation of simple and compound words in the monolingual context (see Figure 1). The reason we chose this framework lies in the detail of its morphological processing steps. Levelt et al. (1999) propose that while simple words are processed via a single-lemma-single-word form route, compound words have a single-lemma-multiple-word form representation. This implies that compound words are holistically stored at the lemma level[29], however, the individual constituents are stored separately (in a de-composed manner) at the word form level (see Figure 1). However, the one-lemma-multiple-word-form representation has been recently challenged with recent neuropsychological evidence (e.g., Lorenz et al., 2022) and will be discussed further below.

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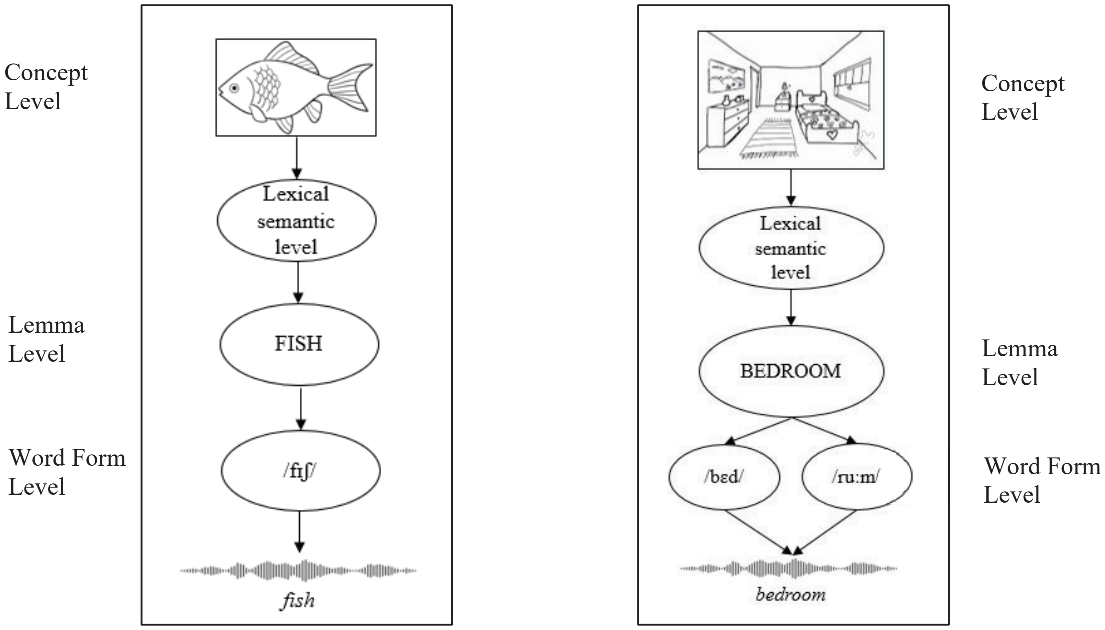
[29] Please refer to Levelt et al. (1999) for some proposed exceptions.

Figure 1

Levelt et al.'s (1999) Monolingual Two-Stage Assumption for Word Processing of a Simple Word (Fish) and a Compound Word (Bedroom)



Empirical Evidence for the Single-Lemma-Multiple Word Form Account from Healthy and Language-Impaired Speakers

Numerous studies have investigated the representation of compound words in the mental lexicon, focusing on how compound words and their constituents are stored and accessed across the different lexical levels and combined for word production. A number of studies found evidence supporting the single-lemma-multiple-word form route during word production as proposed by Levelt et al. (1999) across healthy speakers (Lüttmann et al., 2011; Lorenz et al., 2018; Lorenz & Zwitserlood, 2016) and speakers with aphasia (e.g., Semenza et al., 1997; Badecker, 2001). Semenza et al. (1997) investigated the naming of compounds and monomorphemic words involving 36 Italian speakers with aphasia. The omission of the verb constituent in compound words with a verb-noun structure led to the assumption of a separate entry of the constituents during lexical access. Badecker (2001) also investigated picture naming and naming-to-definition for compound and monomorphemic words in an English speaker with aphasia. Based on the participant's error pattern (substitutions of constituents, e.g., target *downpour*, response *down storm*), a single-lemma-multiple word form representation of compound words in the mental lexicon has been suggested.

However, the current understanding of the representation of compound words in the mental lexicon is also derived from research in monolingual healthy speakers. Lüttmann et al. (2011) for instance, conducted two picture-word-interference experiments with 20 German-speaking people to test for composition during compound production. Findings revealed that target (e.g., bedroom) and distractor words (e.g., bathroom) with shared morphemes facilitated naming, which provides evidence for the activation of a single lemma node and a composition of the constituents at the word form level in the mental lexicon. Furthermore, Lorenz et al. (2018) examined noun compounds and distractors (morphological, semantic, unrelated) in a picture-word interference paradigm in young and older German speakers. Distractors showed the following effect: Speeded naming for constituent distractors (*bed* or *room* for *bedroom*), inhibition processes for distractors categorically associated with the compound word (*sleep* for *bedroom*), and no effects for distractors categorially associated with the first constituent of the compound (*chair* for *bedroom*). Results were consistent across age groups, suggesting that compound words are stored holistically at the lemma level but independently at the word form level, unaffected by age-related factors. These findings were further supported by the same research lab a few years earlier (Lorenz & Zwitserlood, 2016) however, they also suggested that some compound words might be represented separately at the lemma level and not only at the word form level ('multiple-lemma-multiple-word from representation', see further explanation below). This contrary account of compound word representation is discussed below.

Empirical Evidence for the Multiple-Lemma-Multiple Word Form Account from Healthy and Language-Impaired Speakers

The 'multiple-lemma-multiple-word from representation' account challenges the 'single-lemma-multiple-word representation' account proposed by Levelt et al. (1999), which was suggested by Marelli et al. (2012). Marelli et al. (2012) conducted a single case study with an Italian speaker with acquired dyslexia. The individual had more difficulty in reading verbs than nouns; the verb constituent of a verb-noun compound was particularly difficult. Within the spoken picture naming task, including verb-noun and noun-noun compound items, a similar pattern was found, suggesting a multiple-lemma representation of compounds in the mental lexicon. Moreover, a study by Lorenz et al. (2022) investigated the lexical representation and processing of noun compounds. Participants were speakers with aphasia and unimpaired controls (age-matched). A picture naming task was administered in German, a language with grammatical gender and different gender types (masculine, feminine and neuter). These items required three different grammatical determiners (der, die, das). The activation of compound constituents at lemma level during production was investigated in the scope of the study. This was achieved by using primes that were congruent in gender with the compound head, the compound modifier, or incongruent with both. Results showed that congruency between the prime and target at the head level facilitates performances across groups, on the other hand, the modifier congruent prime showed contrasting effects (facilitatory and inhibitory). The results suggest that lemmas of both constituents and their grammatical gender are activated during compound word retrieval, supporting the theory of a multiple-lemma representation of compounds in the mental lexicon. These findings were also supported by Döring et al. (2022) who tested 36 German speakers in a picture-naming experiment. Categories of noun compound words were determined based on their first constituents, while the compounds themselves did not have semantic relationships. Additionally, pictures representing only the first constituent of the compound were shown as a control condition. Time taken to name words within categories increased progressively, indicating greater interference during the selection of words from the lexicon. This cumulative effect of semantic interference was also observed for compound words. These findings suggest that when producing compound words, the lemmas associated with the first constituent of the compound are activated. The authors conclude, therefore, that these results support the ‘multiple-lemma representation account’.

However, since research on the multiple-lemma-multiple-word form account is rare, the theoretically framework of this study is the account that proposes a single-lemma-multiple-word form representation of compound words in the mental lexicon, as proposed by Levelt et al. (1999).

Compound Processing in Monolingual Speakers with Aphasia

Accuracy

Various linguistic factors such as word length and word complexity influence accuracy in picture naming, and can either facilitate or hinder lexical retrieval. Unsurprisingly, people with aphasia experience specific difficulties with the lexical retrieval of compound words due to their morphological complexity (Jarema et al., 2010). These findings have been reported by multiple research groups: Compound word lexical retrieval is more challenging for people with aphasia than the retrieval of simple words, due to their morphologically more complex structure, resulting in more naming errors (e.g., Badecker, 2001; Blanken, 2000; Lorenz et al., 2014; Lorenz & Zwitserlood, 2014).

One explanation for the advantage observed for simple words may be that there are more complex retrieval processes for compound words than for simple words (e.g., Lorenz et al., 2014); there are for example more nodes to select on word form level for compound words than simple words.

Error Types

Furthermore, the examination of compound words in people with aphasia has focussed on error types in lexical retrieval. Since compound words are part of people's stored lexical representations, picture naming errors in compound words manifest the same error types observed in morphologically simple words. These errors include, for example, semantic errors (e.g., target: *greenhouse*, response: *plant*) or phonological errors (e.g., target: *greenhouse*, response: *greelhouse*) (e.g., Blanken, 2000). However, due to the linguistic characteristics and morphological complexity associated with compound words, a specific error type, known as "constituent error", can be observed in compound picture naming in people with aphasia. Constituent errors can affect a/the constituent(s) of the compound word and can be observed as a substitution of constituents (e.g., target *doorbell* response *doorknock*) (Badecker, 2001; Blanken, 2000; Delazer & Semenza, 1998; Mäkisalo et al., 1999) or omission of constituents (e.g., target *sunflower*, response *sun*) (Blanken, 2000; Delazer & Semenza, 1998; Hlttmair-Delazer et al., 1994). Among these constituent error types, the substitution of a constituent is more common or will be occurring more frequently in comparison to an omission in compound (Jarema et al., 2010).

The distribution of these two constituent errors, with substitutions of constituents occurring more frequently than omissions of constituents (resulting in the production of a simple word), can explain another phenomenon that has been reported by various studies, the so-called "compound effect": People with aphasia often maintain the knowledge of the structure of compound words (morphosyntactic information at lemma-level) and how to build compounds, however, they have difficulties in retrieving the complete phonological form (e.g., Semenza & Mondini, 2010; Chiarelli et al., 2007; Semenza et al., 1997). This effect indicates that although people with aphasia may experience difficulties with the production of compound words, they can retain the morphological knowledge (e.g., is it a compound word or simple word), the knowledge of the target's word structure (e.g., is it a noun-noun or a verb-noun compound), and the word formation rules of the languages (e.g., how to build a compound word). This observed compound effect suggests that the knowledge of the compound word morphological structure is stored separately from the phonological word form of the compound word. In the framework of the Two-Stage Model (Levelt et al., 1999, see Figure 1) the compound effect supports a preserved lemma level where morphosyntactic information can be accessed while experiencing difficulties with retrieving the phonological word form level (Semenza et al., 2011). This is in alignment with the ‘lemma theory’ of Levelt et al. (1999), which positions the lemma level as holding an important role in the production of compound words (refer to further explanation and discussion of Levelt et al. [1999] below). However, these findings relate to the monolingual context, what the bilingual compound representation entails has hardly been studied.

Compound Processing in Bilingual Speakers with Aphasia

Jarema et al. (2010) are the only researchers that investigated compound processing in bilingual speakers with aphasia.[30] The study examined compound processing performance across a reading, repetition, and translation task in three French-English bilingual speakers with aphasia, always in both languages. All three participants grew up and still lived in a French-English environment. Two participants were classified as English-dominant speakers and presented a generally higher accuracy in the English compound processing tasks. The third participant was a more balanced bilingual speaker, with generally higher accuracy in French, respectively a similar accuracy across available languages. Moreover, the study investigated the influence of specific structural properties of compound words on lexical access procedures in people with aphasia. This study’s aim was to clarify previous inconclusive research findings, firstly, whether a constituent is more vulnerable to impairment due to its position (first or second constituent) in the compound word (e.g., Hlttmair-Delazer et al., 1994; Delazer & Semenza, 1998; Blanken, 2000). Secondly, the role of the headedness constituent was explored, and whether the advantaged status of the head constituent influences compound processing in people with aphasia (known as the ‘headedness effect’; assuming that the head constituent has a privileged role in lexical access)? Some studies reported a head constituent advantage (e.g., Blanken, 2000; Marelli et al., 2009), others a non-head advantage (e.g., Hlttmair-Delazer et al., 1994), or no significant headedness effect at all (e.g., Delazer & Semenza, 1998). The findings of Jarema et al. (2010) revealed an interaction between the constituent’s position in the compound word and the headedness of the compound word in two participants (neither of the effects acted alone). However, the third participant did not show any effect (neither an effect for a constituent’s

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[30] The same authors published an abstract in 2007 (Jarema et al., 2007) that presents the 2010 study, but with only two of the three participants that were included in the study of 2010.

position in the compound word nor a headedness effect). Furthermore, Jarema et al. (2010) examined the influence of the grammatical category (adjective-noun or noun-adjective compound vs. noun-noun compound) and between-language phonological similarity (cognates, non-cognates) on compound processing. The grammatical category did not have any influence on error rate; however, cognates showed a faciliatory effect across the participants which is consistent with previous research on healthy participants (e.g., Costa et al., 2000) and language impaired populations (e.g., Kohnert, 2004; Lalor & Kirsner, 2001; Roberts & Deslauriers, 1999).

Influence of the Bilingual Context (in Compound) Word Naming in Bilingual Speakers with Aphasia

When looking at word naming in bilingual speakers with aphasia, regardless of whether it is a compound word or not, it is important to consider the bilingual language profile, which has an influence on accuracy and error types occurring. Hence, the following paragraph will introduce specific error types, that are related to bilingual speakers with aphasia and further aspects of the bilingual language profile (e.g., language age of acquisition and non-selective activation of languages within a bilingual language network) that might influence word production.

Language Mixing in Bilingual Speakers with Aphasia. Language mixing errors are error types, that are specifically associated to bilingual speakers with aphasia. They refer to the use of words from multiple languages within the same utterance. Language mixing errors have not been investigated in compound picture naming in bilingual people with aphasia so far. The language mixing phenomenon can take several forms: Naming the non-target language translation equivalent word (e.g. target *cat*, response *Katze* [German equivalent to cat), blending a word by combining the root from one language with a suffix/prefix from another language (e.g. target *witnesses*, response *witnessen* [the response is influenced by the word Zeugen [German word for witnesses]), combining syllables from different languages within a single word (e.g., target *potato*, response *kartato* [response includes the first syllable of Kartoffel; German for potato]), or applying the phonological or intonation rules of one language to a word from another language (e.g., target *thermometer*, while the intonation rules of *Thermometer* [German word for thermometer] are applied) (e.g., Cargneuletti et al, 2019). However, it is important to acknowledge that the phenomena of producing the target word in the non-target language translation equivalent can also be seen as a strategy to compensate for lexical retrieval difficulties in the target language or to name a picture where the associated word has never been known in the target language but in the other language (e.g., Neumann et al., 2017). In turn, the error of naming a picture in the non-target language translation equivalent can be classified as a specific error type and not as a language mixing error. Findings on language mixing errors in bilingual speakers with aphasia suggested that there is a higher likelihood that language mixing errors are produced by a bilingual speaker with aphasia when the available languages present structural similarities (e.g., Abutalebi et al., 2009; Kurland & Falcon, 2011).

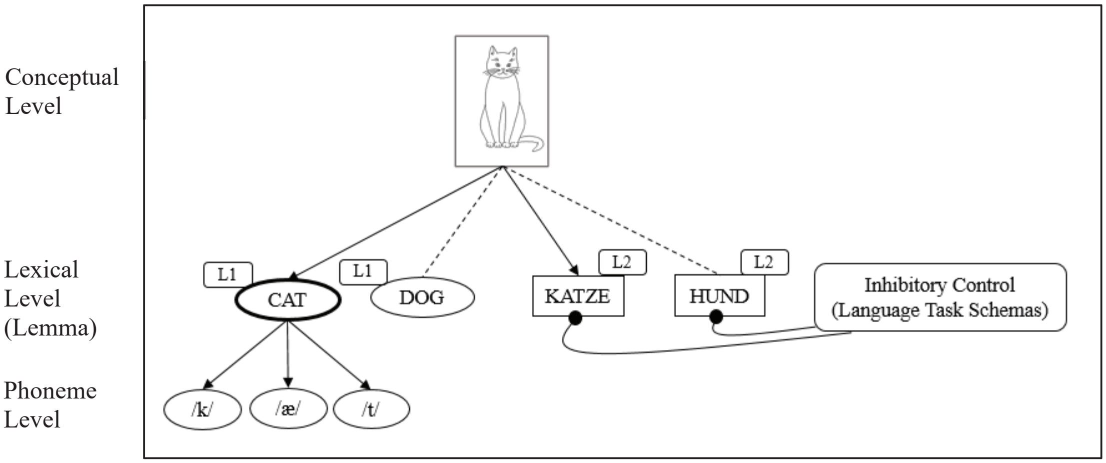
The Bilingual Profile. When investigating compound picture naming in the context of bilingual speakers with aphasia, bilingual profiles are important to be considered. Bilingual speakers are a heterogenous population by nature. They bring unique bilingual profiles that differ, for example, in languages spoken, language dominance (multifactorial construct of language proficiency, language use and exposure, biographical aspects [environmental languages, age of acquisition, language of residence]), and language age of acquisition (age of learning the available languages). Language dominance and language age of acquisition are both known to influence accuracy of a bilingual speaker with aphasia (e.g., Khachatryan et al., 2016). However, some research suggests that language dominance is a better predictor for lexical access in bilingual speakers with a language disorder than the age of acquisition of the available languages (e.g., Kiran & Tuchtenhagen, 2005). This finding aligns with findings in healthy bilingual speakers, where it has been shown that language proficiency and language dominance are influencing lexical access (e.g., Kotz & Elston-Güttler, 2004).

Non-Selective Language Activation and Inhibition Processes in a Bilingual Language System. Another difference that distinguishes bilingual speakers from monolingual speakers, is the presence of a language system that holds more than one language. This means the bilingual language network might have additional tasks, for example the reported non-selective activation of the available languages. Non-selective activation refers to a bilingual language system that involves two or more languages during production: Not only the target language/word is activated but also the non-target language/word. Non-selective activation of language in bilingual speakers has been found in healthy people (e.g., Moon & Jiang, 2012; Libben et al., 2017) but also in a bilingual population with language impairments (e.g., Gray & Kiran, 2013).

This parallel activation goes along with the presence of inhibition processes in bilingual speakers, which are necessary to suppress the non-target languages while speaking in the target language. A well-known model that explains inhibition mechanisms in a bilingual language network is the Inhibitory Control Model by Green (1998) (see Figure 2). According to the model, the bilingual speech production system comprises multiple levels of control and lexical nodes containing language markers that assign them to a particular language. The model proposes that language production in bilinguals consists of an interplay of inhibition, control schemata, and a supervisory attentional system. The supervisory attentional system regulates tasks while additionally activating, maintaining, and updating the language task schema (see Figure 2). The selection of the correct word form gets ensured by the language system that marks lemmas associated with the concept. However, this is not sufficient to guarantee correct word selection. A key aspect of the model is the inhibition and therefore deactivation of lemmas without language tags to suppress the non-target language. Another important feature of the model is the aspect that overcoming inhibition is more difficult for strongly activated words compared to words with less activation. Based on this, the Greens model predicts that the dominant language in a bilingual speaker requires greater inhibition processes. The existence of a language network that holds more than one language and the associated non-selective activation and inhibition processes contribute to the complexity and specific language processing aspects in bilingual speakers, including those with aphasia.

Figure 2

The Production of the Word 'Cat' in an English-German Bilingual Speaker in the Inhibitory Control Model (Green, 1998), Adapted Model from Schwieter & Ferreira (2013)



In sum, when it comes to compound word processing in bilingual speakers with aphasia, research is scarce. Limited research has investigated the accuracy of compound words in bilingual speakers with aphasia including crucial influencing factors like the heterogeneity of bilingual profiles. Furthermore, although it is known that bilingual speakers exhibit specific error types that are related to their bilingual profile (language mixing errors), these error types have not yet been studied in the context of compound words in bilingual individuals with aphasia. Therefore, the present study aims to examine both accuracy and language mixing errors in bilingual speakers with aphasia in compound word naming by taking into account influencing factors such as the bilingual language profile and its impact on word processing, to further inform theories on bilingual word processing.

Study Aim

Our goal is to further inform theories of bilingual language processing by investigating accuracy in compound picture naming in bilingual speakers with aphasia, both across and within language. In the within-language analysis, compound accuracy will be compared to simple word accuracy. Additionally, the study will focus on language mixing errors in compound naming across bilingual participants. The bilingual language profile (e.g., language age of acquisition, language dominance) and phonological similarity across languages will be taken into account.

Research questions and predictions

(1) Do accuracy patterns differ when bilingual speakers with aphasia name compound pictures across their languages taking into account their bilingual language?
We predicted a different accuracy pattern on compound picture naming between languages depending on the bilingual language profile (e.g., language age of acquisition, language dominance).

(2) Does the morphological complexity of words influence accuracy in bilingual speakers with aphasia?
We predict that for accuracy analyses within languages, the accuracy is higher for simple words than compound words based on previous research, that found higher accuracy for words with a less complex morphological structure compared to compound words.

(3) Do language mixing errors occur in compound picture naming in bilingual speakers with aphasia and is the occurrence of language mixing errors influenced by phonological similarity across languages?
We predict that language mixing errors will occur and that the errors might be influenced by the bilingual language profile. We predict more language mixing errors occurring with high phonological similarity across languages, based on research that found a more likelihood of language mixing errors in bilingual speakers with aphasia when the available languages present structural similarities.

In sum, this might help researchers and speech pathologists to better understand bilingual language processing and related influencing factors. Additionally, the development of picture and word materials for different language combinations (in addition to the guide to define and code language mixing errors) might offer a resource for future research in this field (open access).

Participants

Bilingual speakers with aphasia were recruited for the experimental compound picture naming task. Eight bilingual participants with post-stroke aphasia were included according to the following inclusion criteria: Post-acute or chronic stroke with aphasia, self-reported normal or corrected-to-normal hearing and vision. Exclusion criteria consisted of the following: Moderate to severe apraxia of speech, dysarthria or other cognitive impairments (e.g., dementia), and/or severe comprehension deficits (reported by a speech pathologist). However, participants presenting with mild cognitive impairments (e.g., attention, memory), mild dysarthria, or mild apraxia of speech were included. In addition, each participant's picture naming accuracy needed to be more than 10% and less than 90% tested by the spoken naming subtest (Subtest 13) of the 'LEMO 2.0 Lexikon modellorientiert. Diagnostik für Aphasie, Dyslexie und Dysgraphie' (Stadie et al., 2013). The subtest included 20 items that were normed for the German language (ten high frequent and ten low frequent words). Items were translated into the participants' respective languages to use the LEMO subtest as a screener in the spoken languages of the participants. It is acknowledged that the frequency classification might not be accurate when translated into languages other than German. During the recruitment process, 22 potential participants expressed interest in the study. However, 13 were excluded due to one or more of the above exclusion criteria or due to unavailability at the point of data collection.

All participants were given a study information sheet and the possibility to ask questions about the study (see General Appendix A). The bilingual speakers with aphasia were asked to provide written consent to participate in the study and to access demographic and medical data (when accessible), important information for the analysis and interpretation of the collected naming data (see General Appendix B). To gather demographic and medical data and to determine the bilingual language profile, a personal data form (demographic questionnaire) was applied (see General Appendix C). In addition, each participant was asked to complete the Language Experience and Proficiency Questionnaire (LEAP-Q, Marian et al., 2007) to gather information about the language history (language age of acquisition and language dominance). The Language Experience and Proficiency Questionnaire was originally designed for healthy bilingual speakers. Therefore, it holds a non-aphasia-friendly structure, since e.g., long and complex sentences and questions are included. The researcher assisted the participants in completing the questionnaire by reading the question aloud. Additionally, participants could always ask for a repetition or a further clarification of the question. As an additional tailored approach, a visual aid in the form of a numerical scale from one to ten was given. A number of background assessments were carried out in both of the participant's languages to determine the individual post-stroke language performance. Thirteen subtests of the Bilingual Aphasia Test (BAT, Paradis & Libben, 1987) were conducted in the participant's L1 and L2 to assess language impairments across different modalities: Pointing, simple and semi-complex commands, complex commands, verbal auditory discrimination, semantic categories, synonyms, repetition and lexical decision of words and nonsense words, series, verbal fluency, naming, reading words, and reading comprehension for words. Since the BAT does not cover written naming, we screened for written naming abilities using the first 30 items of Subset 1a of the experimental naming task.

For detailed information on the individual demographic and medical data, bilingual language profile data, and background language assessment data per participant, see General Appendix E. A summary of this data across participants is given below.

The ethics committees of Bielefeld University in Germany (EUB 2020-137-Am), Curtin University Perth (HRE2017-0274), and the South Metropolitan Health Service Human Research (RGS0000003763) obtained approval for this study (see General Appendix D).

Demographic and Medical Data of all Bilingual Speakers with Aphasia

Table 1 presents a summary of the demographic and medical data of all bilingual participants. The eight bilingual speakers with aphasia (four females and four males) were aged between 55 years and 75 years (mean 66.1 years, SD 6.27 years) and post-onset between 11 months and 28 years (mean 119.9 months [10 years], SD 109.5 months [9.13 years])[31]. BwA1, BwA2, BwA3, BwA4, BwA5, BwA6, and BwA8 presented with a left hemisphere stroke. BwA7 had a right-hand hemisphere stroke. Two of the seven participants with a left hemisphere stroke had additional lesions in either their right hemisphere (BwA8) or the right hemisphere and cerebellum (BwA2). For detailed information on the stroke lesions, see General Appendix E. According to the participant's medical records and self-reports, all of them experienced aphasia after their stroke.

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[31] Three participants had experienced multiple strokes. To calculate the mean post-onset time, only the stroke that resulted in the language impairment (determined by medical data and the participants' self-reports) was considered (see Table 1).

Bilingual Language Profile Data of all Bilingual Speakers with Aphasia

The included participants had six different language profiles: Dutch-German (BwA1, BwA3), Polish-German (BwA2), English-German (BwA4), English-Italian (BwA5), English-French (BwA6), French-English (BwA7, BwA8). This means the first language was either Dutch, Polish, English, Italian, or French; the second language was either German, French, or English (see Table 1).

Seven of the eight bilingual speakers with aphasia were classified as late bilinguals. The participants reported full immersion in L2 between the age of 17 and 35 by living in the country of their L2 (excluding classroom language experience). BwA5 was the only early bilingual, who experienced parallel language acquisition of English and Italian from birth.

The bilingual profile assessment (participants' self-reports, results of the LEAP-Q [Marian et al., 2007], background language assessments) was carried out to determine the dominant language for each participant. The L2 was the dominant language pre- and post-stroke for four participants (BwA1, BwA3, BwA7, BwA8), the L1 was the dominant language pre- and post-stroke for three participants (BwA4, BwA5, BwA6). The language dominance was equally distributed among languages for BwA2. The dominant language was determined by the participants' language proficiency, language exposure and use, and biographical factors (language age of acquisition, environmental languages, language of residence). Language proficiency was determined by the language background assessments, spanning across receptive and expressive tasks that were conducted with every participant (see below). Biographical factors were conducted by the LEAP-Q and the participants' self-reports. Language use and exposure were determined as per followed: Each language of a participant received a score to determine the language use and exposure ratio of the two languages available (based on the participants' self-reports and the results of the LEAP-Q). The score could range from zero to eight for each language (zero = no/minor language use and exposure, eight = high language use and exposure). The score was determined by considering eight categories: Interaction with family, interaction with friends, daily life activities (e.g., supermarket, medical appointments, restaurant), TV, radio/music etc., smartphone/social media/internet/computer, reading, and writing. Each category was matched by either 'using mostly my L1 in this category' (one-point L1, zero points L2), 'using mostly my L2 in this category' (zero points L1, one-point L2) or 'using both languages in this category' (one-point L1, one-point L2). Hence, a language use and exposure score was calculated, indicating language use and exposure with a score between zero and eight. See General Appendix E for detailed information on language use and exposure per participant.

Background Language Assessments Data of all Bilingual Speakers with Aphasia

To determine the severity of the participants' language disorders, a number of background language assessments were carried out across both languages in each participant. The pattern of language impairment was consistent with the diagnosis of anomic aphasia (BwA2, BwA3, BwA4, BwA6, BwA7, BwA8) or Broca's aphasia (BwA1, BwA5)[32].

The LEMO spoken naming subtest screened the participant's spoken picture naming: Accuracy within this subtest ranged from 0% to 90%. Thirteen subtests of the BAT were administered to assess the participant's language performance across languages and across modalities: Pointing, simple and semi-complex commands, complex commands, verbal auditory discrimination, semantic categories, synonyms, repetition and lexical decision of words and nonsense words, series, verbal fluency, naming, reading words, and reading comprehension for words. The results of the BAT showed a language impairment for all participants in both languages. Spoken naming accuracy within the BAT subtest was distributed between 6.25% and 100%. Since the BAT does not include a written naming test, written naming abilities were screened for each participant across 30 items for both languages. The 30 items consisted of item 1 to item 30 of subset 1a of the experimental naming test. Written naming was administered after the experimental task to control for potential priming or repetition effects. General Appendix E presents details on the background language results per participant.

Finally, the bilingual recovery pattern was captured: All participants self-reported a parallel recovery pattern across their languages.

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[32] Aphasia syndrome classifications are based on the following information: (i) Clinical observations during the project, (ii) the BAT and LEMO background assessment results, and (iii) speech pathology reports (if available).

Table 1

Summary Data on the Background Information of all Bilingual Speakers with Aphasia

Demographic and medical data						Bilingual language profile data				Language background assessment data					
			Stroke								Naming results				
											BAT % correct		LEMO % correct		
ID	Age [y]	Sex	Post-Onset [y;m]	Lesion hemisphere	Aetiol	L1	L2	Dominant language	L2 AoA	Aphasia types[f]	L1	L2	L1	L2	Recovery pattern
BwA1	55	F	10;4	LH	Isch[g]	Dutch	German^	L2	23	Broca	65	90	30	55	parallel
BwA2	66	M	0;11	Cereb, LH, RH[a]	Isch[g]	Polish	German^	L1/L2	35	Anomic	95	60	85	60	parallel
BwA3	64	M	30/28[b]/14	LH	Isch[h]	Dutch	German^	L2	25	Anomic	80	60	75	50	parallel
BwA4	75	F	2;9	LH	Isch[h]	English^	German	L1	27	Anomic	100	80	80	65	parallel
BwA5	64	M	4/1;8/1;3[b]	LH	Isch[g]	English^[d]	Italian	L1: EN[e]	From birth	Broca	62.5	6.25	30	0	parallel[i]
BwA6	65	F	8	LH	Isch[g]	English^	French	L1	17	Anomic	94.74	89.47	75	65	parallel
BwA7	66	M	16	RH	Isch[g]	French	English^	L2	28	Anomic	95	95	80	80	parallel
BwA8	74	F	12;8[b]/9/0;3[c]	LH, RH	Isch[h]	French	English^	L2	28	Anomic	100	100	85	90	parallel

Note. y = Years, F = Female, M = Male, m = Months, LH = Left hemisphere, RH = Right hemisphere, Cereb = Cerebellum, Aetiol = Aetiology, isch = ischaemic stroke, ^ = dominant language, AoA = Age-of-acquisition.

[a] See further important information about lesions in General Appendix E.

[b] Stroke that resulted in aphasia.

[c] BwA8 suffered a mild stroke after recruitment. Neither the client nor her carers reported any change in her communication after the mild stroke. Testing did not commence until three months after this stroke.

[d] Parallel language acquisition.

[e] English and Italian are the BwA5's first languages, and English is the BwA5's dominant language pre-stroke and post-stroke.

[f] Aphasia syndrome classifications are based on the following information: (i) Clinical observations during the project, (ii) the BAT and LEMO background assessment results, and (iii) speech pathology reports (if available).

[g] Based on medical records.

[h] Based on the participant's self-report.

[i] Based on the participant's background assessments, including comprehension tasks.

Experimental Task

Research Design

A case series design was carried out to examine spoken picture naming in compound words in eight bilingual speakers with aphasia. Aphasia is a heterogeneous language disorder arising from various neurological disorders, that can affect all language modalities. When investigating bilingual speakers with aphasia, even greater heterogeneity occurs; since two bilingual people are never the same, they will differ, for example, in their language history, language age of acquisition and language dominance. Therefore, our study design, which accounts for these intra-individual differences across the participants, is appropriate (e.g., Schwartz & Dell, 2010; Howard et al., 2015). The study examined spoken picture naming accuracy for compound words (e.g., bedroom) and compared them to accuracy data of simple words (e.g., fish) that were matched for word length and word form frequency. Language mixing errors (e.g., schlafroom; language mixing error of the word Schlafzimmer [German for bedroom] and the English word bedroom) were investigated and considered by the phonological similarity across the target word and the non-target language translation equivalent.

Method

Materials

Images were taken from MultiPic (Duñabeitia et al., 2018), a database with over 750 normed noun images for various languages (Dutch-Belgium, Dutch-Netherlands, English-British, French, German, Italian, and Spanish). Item lists were developed for each included language combination in this study comprising only those images with greater than 80% name agreement (degree of agreement on a name of an image [e.g., Alario et al., 2004]) in both of the relevant languages. Since the MultiPic database did not contain Polish data, the German-Polish list included all items with an 80% name agreement in German. It is emphasised that some of the included items may not meet the 80% name agreement requirement for Polish[33].

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[33] Name agreement data for 500 out of the 750 pictures of the MultiPic database were published in 2022 by Duñabeitia et al. Based on the publication, not all included 422 items of the Polish-German item list hold a name agreement of 80% or more for Polish. Additionally, the native speaker of Polish in our study translated 13 out of the 422 items differently to Duñabeitia et al. (2022). As we had completed data collection and data analysis before the new name agreement data for Polish became available, we proceeded with our own translation.

Item lists included 331 to 422 items, depending on the language combination. These item lists contained 17 to 76 compound words (consequently 276 to 383 simple words). Table 2 lists the number of included compound words and simple words for each language combination while Appendix A presents each included compound word for each language. The included compound words were mostly noun compounds, however, across languages some verb-noun compound words and adjective-noun compound words were included (see Appendix A).

The item lists with all words included (compound and simple words) were divided into two sets that were further subdivided into three subsets (Set 1: Subset 1a, Subset 1b, Subset 1c; Set 2: Subset 2a, Subset 2b, Subset 2c). The subsets contained 55 to 71 items, and compound words were distributed across these subsets. The division of the whole item list into sets and subsets allowed for breaks between the subsets. The order of item presentation in a subset was quasi-randomised in both languages such that there were no consecutive items that were semantically related or had the same onset or word form (in the case of compound words). Items that met these criteria were distributed from each other to avoid priming and interference effects.

Table 2

Number of Items (n) per Language Combination (all Words, Simple Words, Compound Words)

		Number of items (n)		
Language-combination		All words	Simple words	Compound words
Dutch – German	Dutch	347	286	61
	German	347	288	59
Polish^ - German	Polish	422^	383	39
	German	422	346	76
English – German	English	331	293	38
	German	331	276	55
English – Italian	English	356	316	40
	Italian	356	334	22

Consequently, the name agreement data for the 13 items, that were translated differently, were not incorporated into our Polish item list. Appendix A gives more details.

English – French	English	365	322	43
	French	365	348	17

Note. ^The Polish item list is the German item list in translation since the name agreement for Polish was not available at the beginning of the study using the MultiPic (Duñabeitia et al., 2018) database.

All included compound items received values for their phonological similarity (phonological similarity of the target word to the non-target language translation equivalent [cognates included]), word length and spoken word form frequency.

The *phonological similarity* value was calculated by using alineR (Downey et al., 2017). AlineR[34] is an open-source R software (R Core Team, n.d.) calculating feature-weighted linguistic distances or similarities between pairs of items. To calculate the similarity value of the compound target word and its non-target language translation equivalent, both words were transcribed into their IPA script. All diacritic and suprasegmental signs were removed from the IPA scripts, and each item pair was manually inputted into the program. Since some IPA signs were not covered using alineR for similarity calculation, some substitutions of IPA signs (e.g., ɑ = a; ʁ = r, ʀ; ə = e) were necessary. Similarities were not calculated when an item pair needed a change of more than two IPA signs. Word lengths was defined by *phoneme lengths,* which describes the number of phonemes a compound word consists of. The compound word's IPA script was used to collect the number of phonemes. IPA scripts were collected from different sources for the different languages (Dutch: Nederlands woordenboek [n.d.], German: Martin-Luther-Universität Halle-Wittenberg [n.d.], Polish: Wikisłownik [2023], English: WordReference.com [n.d.], Italian: Olivetti [n.d.], French: Le Dictionnaire [n.d.]). *Spoken word form frequency* refers to the frequency an individual item is used in spoken language. Frequency values for all compound words were taken from different sources for the different languages (Dutch: Keuleers et al., 2010; German: Brysbaert et al., 2011; Polish: Mandera et al., 2015; English: van Heuven et al., 2014; Italian: Crepaldi et al., 2015; French: Desrochers & Thompson, 2009). All collected values are provided in Appendix A.

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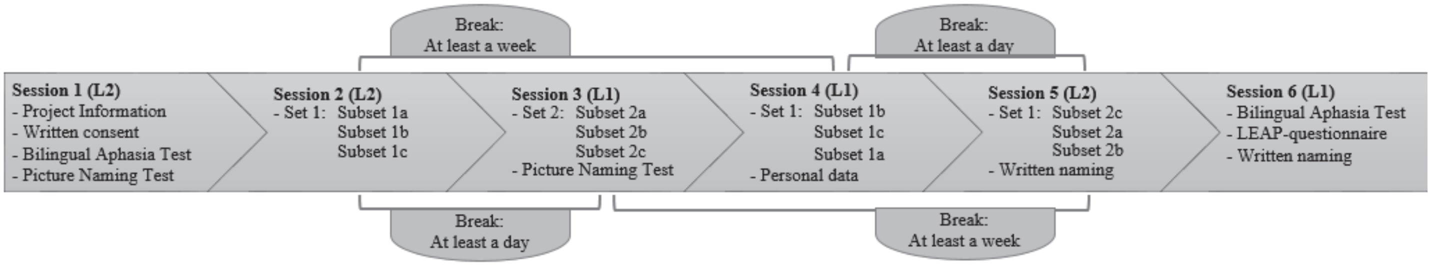
[34] AlineR utilises the American Standard Code for Information Interchange (ASCII) to identify features. ASCII is the most common character encoding format for textual data in both computers and internet. In ASCII-encoded data, there are specific values designated to 128 alphabetic, numeric, and special characters, as well as control codes. To indicate features, acceptable encodings are composed of lowercase letters within the range of 'a' to 'z', with the inclusion of additional modifiers (dental, palato-alveolar, retroflex, palatal, spirant, nasal, aspirated, long, front, central).

Procedure

All participants were tested for at least six times, including a minimum of four picture naming sessions. The sessions lasted 60 to 90 minutes each and were scheduled with a break of at least one day. To avoid priming effects, the experimental naming sessions with the same item sets across languages were parted by a minimum of a week. Figure 3 gives an example of the standard experimental task procedure for a participant that started the task in the L2. If the study started in a participant's L1, the following session was accordingly adjusted.

Figure 3

Experimental Task Procedure for a Bilingual Speaker with Aphasia



Note. The figure depicts a study procedure that begins with a participant's L2; subsequent sessions were adjusted accordingly if the study commenced with the participant's L1. L1 = First language, L2 = Second language.

The BAT and the LEMO naming subset were carried out in the first session in the participants' second language. The picture naming sessions were conducted across four sessions. Different languages were always tested in separate sessions to avoid language switching and to maintain 'language mode' for one language in one session. The L2 picture naming task was scheduled in session two and session five, the L1 picture naming task in session three and session four. To minimise potential order effects, item sets in session four and five were ordered alternated to the sequence in session two and three. The four picture naming sessions were followed by different tasks: LEMO naming subset in L1 (session three), demographic and medical data collection (session four), and written naming task[35] in L2 (session five). The study was finished by session number six, which comprised the BAT[36]

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[35] The written naming test was always administered after the experimental task to avoid for potential priming and repetition effects (see Figure 3).

[36] The researcher running the experiment always spoke at least one of the languages of the participant. An informal language broker training was provided to a family member who delivered the BAT in Polish (BwA2) and Italian (BwA5), with the researcher being present.

and the written naming test in the participant's L1, as well as the LEAP-Q to capture the participant's bilingual profile.

Four participants (BwA2, BwA4, BwA5, BwA7) received an adjusted procedure due to the onset of fatigue, the language impairment and/or level of task tolerance. Session six was split into two sessions for BwA2, BwA4, and BwA7. BwA5 named item set 1 and item set 2 in Italian across three and not two sessions (Session 2: Subset 2a and Subset 2b, Session 3: Subset 2c and Subset 1a, Session 6: Subset 1c and Subset 1b).

Items of the picture naming task were displayed on a laptop using the DMDX software (Forster & Forster, 2003). The researcher provided a verbal introduction. Additionally, the introduction was displayed on the screen (in the respective language of the naming session). Participants were asked to name the picture on the screen. Each subset started with a practice round of five[37] items. Before items appeared and the audio recording started, a fixation cross preceded for 250ms at the centre of the screen. As soon as the participant named the picture or indicated to move forward to the next item, a picture was removed and the audio-recording stopped by the researcher using the keyboard. As all naming sessions included three subsets, a session had two breaks of five to ten minutes between the subsets.

Data Analysis

Analysis of Accuracy in Compound Words

Each given response was transcribed and coded as correct or incorrect. The transcription was based on the WAV-audio file, generated by the DMDX software (Forster & Forster, 2003). All incorrect responses were further coded by error type, according to the developed error coding guideline attached in General Appendix F. Since different examiners were involved in the transcription and analysis process (not all languages were spoken by just one person), the coding guideline allowed for analysis consistency. All examiners involved were either native speakers or proficient speakers of the respective language. Each person underwent a training and a follow-up session after the transcription and coding of the first naming set. Issues with the transcription/error coding were always discussed with a second examiner, and – if needed – a third person was included to find consensus.

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[37] Items were taken from MultiPic and were not included in the item list of the experimental task since they had a name agreement of 79% or less.

The first complete attempt within the first ten seconds of the item onset was coded as correct or incorrect. A first complete attempt was defined as follows: A minimal consonant-vowel or vowel-consonant response (schwa was not considered a vowel) that was uninterrupted and had either a downward/upward intonation or level intonation followed by a noticeable pause (one second). Fragments were not coded as a first complete attempt. They were defined as follows: Attempts that were self-interrupted or that were a minimal vowel-consonant or consonant-vowel response (schwa was not considered a vowel) followed directly by another utterance. Different variations of responses were allowed without penalising the response: Usage of dialect and accent patterns, usage of filler words (e.g., 'uhm'), usage of automatism (e.g., 'oh god'), usage of a determiner before the target, the addition of a prepositional phrase (e.g., target 'can', response 'can of peas'), the addition of a modifier[38] (e.g., target 'bone, response 'dog's bone'), the addition of type of X where X is the target (e.g., target 'banana', response 'type of banana'), negation of the target (e.g., target 'banana', response 'not a banana).

The transcription and error coding were followed by an accuracy distribution analysis of the compound words across available languages for each participant (Fisher's Exact Test, two-tailed).

In a next step, compound word accuracy was compared to simple word accuracy within each participant's language. Since the simple words set contained more items than the compound words, an item set for simple words was created for each language. This item set of simple words was matched by word length (number of phonemes) and spoken word form frequency to the compound words, checked via a t-test (see Appendix B for each matched list[39]). The matching lists were used to compare the compound words' accuracy to the simple words' accuracy.

Analysis of Error Types in Compound Words

Incorrect responses were assigned with a further error code to define the error type in the target or non-target language (e.g., semantic error in the target language: Target bedroom, response sleep; semantic error in the non-target language: Target bedroom, response Schlaf [non-target language [German] word for sleep]). The categorisation of the error type

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[38] An addition of a modifier that resulted in a compound word was coded as an acceptable alternative (for the definition or error types see General Appendix F).

[39] The French matching list (simple words and compound words) was matched for word lengths and word form frequency. However, it needs to be acknowledged that a number of frequency values were not available for the compound words.

consistently referred to a whole-word analysis rather than a single constituent of the compound word. The following error types were coded to define incorrect responses in the target or non-target language:

- Phonological error
- Phonologically unrelated non-word
- Semantic error
- Semantically unrelated error
- Semantically unrelated non-word
- Semantic-then-phonological error
- Mixed error
- Morphological error
- Unspecified error
- Multiword circumlocution
- Single word circumlocution
- Visual error
- Acceptable alternative
- Use-of-language error
- Other error.

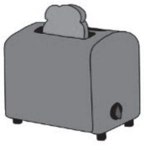
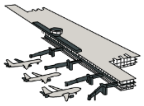
For a definition of the error types with examples for the target and non-target language see General Appendix F. Additionally to the error types that could appear in always either the target or non-target language (described above), four further error types were included to code the incorrect response: No response, correct in non-target language, language mixing error, back-translation error. For a definition with examples of these four error types see General Appendix F. For an overview of the error distribution across both languages for each participant see Appendix C to Appendix J. Furthermore, the specific distribution of phonological errors, semantic errors, no responses, constituent errors, and language mixing errors among both available languages are additionally given in the individual result section of each participant.

Language Mixing Errors in Compound Words. As described in our theoretical introduction, little is known about lexical access of morphological complex words in bilingual speakers with aphasia (see ‘Compound Processing in Bilingual Speakers with Aphasia’). Furthermore, to the best of our knowledge, language mixing errors in morphological complex words have not been investigated in bilingual speakers with aphasia yet. Therefore, we were specifically interested in all language mixing errors within compound naming. We checked for language mixing errors within the first ten seconds of the response (language mixing error category 'Within 10 seconds') and analysed additionally all language mixing errors that were given beyond the first ten seconds of a response (in case there was a response that was longer than ten seconds) (language mixing error category 'Further'). All language mixing errors in compound words were assigned a further code to define the type of language mixing error. Language mixing error types were defined by an error in the first constituent (Type A, Type B, Type C – see below), an error in the second constituent (type a type b, type c – see below) or by a literal translation error (type a type b – see below):

Table 3

Language Mixing Error Types

Error type	Explanation
Language mixing errors in the first constituent	
First constituent error – Type A 	The first constituent is exchanged by the first constituent of the equivalent non-target language compound word, e.g., bedroom $^{\text{target}}$ → Schlafroom $^{\text{response}}$ (influenced by the German word Schlafzimmer [German equivalent to bedroom]).
First constituent error – Type B 	The first constituent is partly exchanged by part of the first constituent of the equivalent non-target language compound word, e.g., Schlafzimmer $^{\text{target}}$ (the German word for bedroom) → schledzimmer $^{\text{response}}$ (influenced by the English word bedroom [English equivalent to Schlafzimmer]).
First constituent error – Type C 	The first constituent is (partly) exchanged by (part of) the equivalent non-target language word (not a compound word), e.g., weegschaal $^{\text{target}}$ (the Dutch word for scales) → scaleschaal $^{\text{response}}$ (influenced by the English word scales [English equivalent to weegschaal]).

Language mixing errors in the second constituent	
Second constituent error – Type A 	The second constituent is exchanged by the second constituent of the equivalent non-target language compound word, e.g., elbow $^{\text{target}}$ → elbogen $^{\text{response}}$ (influenced by the German word Ellenbogen [German equivalent to elbow]).
Second constituent error – Type B 	The second constituent partly exchanged by part of the second constituent of the equivalent non-target language compound word, e.g., Fingerabdruck $^{\text{target}}$ (the German word for fingerprint) → fingerabprint $^{\text{response}}$ (influenced by the English word fingerprint [English equivalent to Fingerabdruck]).
Second constituent error – Type C 	The second constituent is (partly) exchanged by (part of) the equivalent non-target language word (no compound word), e.g., broodrooster $^{\text{target}}$ (Dutch word for toaster) → broodtoaster response (influenced by the English word toaster [English equivalent to broodrooster]).
Language mixing errors by literal translation	
Literal translation error – Type A 	The target and non-target language word are compound words; the non-target language equivalent word is literally translated into the target language, e.g., Flughafen $^{\text{target}}$ (the German word for airport, literally 'fly port') → Lufthafen $^{\text{response}}$ (literal translation of the English word airport into German).
Literal translation error – Type B 	The target word is a simple word, the non-target equivalent word is a compound word, the response is a compound (literal translation of the non-target language compound word into the target language), e.g., méduse $^{\text{target}}$ (French word for jellyfish) → poisson de gellée

	$^{\text{response}}$ (literal translation of the non-target language compound word jellyfish into the target language French).

After the coding of all language mixing errors, we investigated the distribution of language mixing errors across the modifier and head constituent of a compound word (for information on the modifier and head constituent, see introduction section “Compound words and their linguistic characteristics”).

Logistics regression analysis was carried out in all bilingual speakers with aphasia to examine the influence of phonological similarity across item pairs (target word and non-target language translation equivalent) on language mixing errors in picture naming in compound words. We used the analysis software jamovi (The jamovi project, n.d.). The regression analysis was two-fold for each participant to control for similarity effects: Firstly, the regression analysis included phonological similarity and the number of phonemes. In a second step the analysis was conducted with only phonological similarity as the predictor variable. This procedure was chosen to ensure that phonological similarity effects are not related to the word lengths (number of phonemes). Since results did not show any influence of word length, the regression analysis results with only phonological similarity as experimental predictor included will be presented as the main analysis relevant for this study.

Results

Data on Accuracy and Language Mixing Errors in Compounds Across all Bilingual Speakers with Aphasia

Accuracy in Compounds: All Bilingual Speakers with Aphasia

Table 4 summarises the accuracy of naming data across eight bilingual speakers. Seven participants (BwA1, BwA2, BwA3, BwA4, BwA5, BwA6, BwA8) showed the same pattern of accuracy across each of their languages spoken: A higher compound naming accuracy was observed for their dominant language. However, two of those six participants showed a significant difference in accuracy in compound naming across their languages (BwA6: L1 English, BwA8: L2 English). While BwA7 showed a difference in accuracy across languages, accuracy was higher in the non-dominant language.

Accuracy in compound naming was compared to accuracy of a matched simple word list (matched for word length [calculated in the number of phonemes] and word form frequency, > .05) within languages for each participant[40]. Among the 16 analyses (analyses within L1 and within L2 for eight participants) accuracy of simple word naming was higher compared to the accuracy of compound naming in 12 analyses (see Table 4). Of the 12 analyses that showed higher accuracy in simple words, four analyses presented a significant difference (BwA2 L2 German dominant, BwA4 L1 English dominant, BwA6 L1 English dominant, BwA7 L2 English dominant). Among the four analyses with a different pattern, two analyses showed higher accuracy for compound words than simple words (BwA1 L1 Dutch non-dominant and BwA3 L1 Dutch non-dominant) and two analyses displayed an equal distribution of accuracy between simple and compound words (BwA1 L2 German dominant and BwA5 L1 Italian non-dominant).

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[40] See Appendix K for the accuracy analysis of all simple words versus compound words in the L1 and L2 of each participant, which is not part of the discussion, since the number of compound words and number of simple words in these analyses are not equally distributed.

Table 4

Naming Accuracy Data in Compound Words in all Bilingual Speakers with Aphasia

			Accuracy										
							Matched list[d]						
			All Compounds				Simple words			Compounds			Simple words vs
				N total		L1 vs L2		N total			N total		compound words
ID	Languages		N items	correct	% correct	p (2-tailed)[c]	N items	correct	% correct	N items	correct	% correct	p value (2-tailed)
BwA1	L1	NL	61	17	27.87	p=.274	30	6	20.00	30	11	36.67	p=.252
	L2	GE[b]	59	23	38.98		30	11	36.67	30	11	36.67	p=1
BwA2	L1	PL[b]	39	19	48.72	**p<.001***	36	21	58.33	36	17	47.22	p=.479
	L2	GE[b]	76	12	15.79		63	31	49.21	63	11	17.46	**p<.001***
BwA3	L1	NL	61	27	44.26	p=.591	30	14	46.67	30	16	53.33	p=.797
	L2	GE[b]	59	30	50.85		30	18	60.00	30	15	50.00	p=.604
BwA4	L1	EN[b]	38	21	55.26	p=.218	38	31	81.58	38	21	55.26	**p=.025***
	L2	GE	55	22	40.00		30	18	60.00	30	14	46.67	p=.438
BwA5[a]	L1	EN[b]	40	2	5.00	p=.535	40	5	12.50	40	2	5.00	p=.432
	L1	IT	22	0	0.00		22	0	0.00	22	0	0.00	p=1
BwA6	L1	EN[b]	43	33	76.74	**p=.001***	43	41	95.35	43	33	76.74	**p=.030***
	L2	FR	17	5	29.41		17	6	35.29	17	5	29.41	p=1
BwA7	L1	FR	17	9	52. 94	p=1	17	11	64.71	17	9	52.94	p=.728
	L2	EN[b]	43	22	51.16		43	35	81.40	43	22	51.16	**p=.007***
BwA8	L1	FR	17	6	35.29	**p=.007***	17	7	41.18	17	6	35.29	p=1
	L2	EN[b]	43	32	74.42		43	33	76.74	43	32	74.42	p=1

Note. ID = Participant, NL = Dutch, GE = German, PL = Polish, EN = English, IT = Italian, FR = French. Bold represents significant results.

[a] = Early parallel bilingual speaker, both languages (English and Italian) are L1.

[b] = Dominant language.

[c] = Fisher's Exact Test, two-tailed.

[d] = See method section 'Data analysis' for matching lists (lists of compound words and simple words that were matched for word lengths [number of phonemes] and spoken word form frequency).

Error Types in Compounds: All Bilingual Speakers with Aphasia

The participants' incorrect responses were specified by error type. The most frequently occurring error types, including phonological errors, semantic errors, no responses, constituent errors, and language mixing errors are presented in Table 6 across participants and languages. Among the bilingual participants, the distribution of the most common errors and language mixing errors was different which can be recognized by looking at which type of error occurs most frequently among the individual participants (some participants showed the same occurrence of multiple error types across their languages): Eight times no responses, seven times constituent errors, three times semantic errors, one time phonological errors, and one time language mixing errors[41]. See Appendix C to Appendix J for a detailed list of all error types.

Language Mixing Errors in Compounds. Language mixing errors in compounds were analysed in more detail for all bilingual speakers with aphasia. Table 7 summarises the results in detail per participant for language mixing errors within and beyond the first ten seconds of the given responses (please be aware that Table 6 presents language mixing errors only within the first ten seconds of all responses). Language mixing errors occurred in both languages in two participants (BwA1 and BwA3), in one of the languages in four participants (BwA4, BwA6, BwA7 and BwA8), and in no language in two participants (BwA2 and BwA5). All six participants that presented language mixing errors showed these errors in their non-dominant language regardless of whether the non-dominant language was their L1 or L2. Two participants (BwA1 and BwA3) additionally showed language mixing errors in their dominant language (L2 German). In total, 41 errors were observed across all participants (see Table 5). These language mixing errors were further classified into different error types (first constituent errors: 14 errors, second constituent errors: 9 errors, literal translation errors: 18 errors).

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[41] No responses (BwA1 L1 and L2, BwA4 L2, BwA5 L1 and L2, BwA7 L1 and L2, BwA8 L1), Constituent error (BwA2 L1 and L2, BwA4 L2, BwA6 L1 und L2, BwA7 L1, BwA8 L2), Semantic errors: BwA3 L1, BwA4 L1, BwA7 L1), Phonological errors (BwA3 L2), Language mixing errors (BwA3 L1).

Table 5

Number of Language Mixing Error Types Across all Participants

Language mixing error (error type)	Number of errors across participants	Example error type
First constituent error	14	bedroom ^{target} → <u>Schlaf</u>room ^{response} (influenced by the German word Schlafzimmer [German equivalent to bedroom])
Second constituent error	9	elbow ^{target} → el<u>bogen</u> ^{response} (influenced by the German word Ellenbogen [German equivalent to elbow])
Literal translation error	18	méduse ^{target} (French word for jellyfish) → poisson de gellée ^{response} (literal translation of the non-target compound jellyfish into the target language French)

BwA1 and BwA3 produced errors in the first and second constituent related to errors in the modifier constituent (first constituent) and head constituent (second constituent) of the compound word. BwA1 presented a higher number of language mixing errors in the modifier constituent (in comparison to the number of errors in the head constituent) in both of her available languages. BwA3 displayed no difference in the distribution of errors across the modifier constituent and head constituent within his languages.

In the last step, language mixing errors were analysed according to the influence of phonological similarity across item pairs (phonological similarity of target and non-target equivalent). Only one participant (BwA1, Dutch-German bilingual, dominant language = German [L2]) showed a significant effect of phonological similarity: The number of language mixing errors increased with a higher phonological similarity across item pairs.

Table 6

Summary Data of Error Types in Bilingual Speakers (Within the First ten Seconds of Responses)

							Error types									
				Accuracy			Phonological		Semantic		No response		Constituent		Language Mixing[b]	
ID	Language profile		N items	N items correct	% correct	L1vs L2 p(2tailed)	N total errors	% errors	N total errors	% errors	N total errors	% errors	N total errors	% errors	N total errors	% errors
BwA1	L1	DUT	61	17	27.87	p=.274	1	2.27	6	13.64	16	36.36	1	2.27	3	6.82
	L2	GER[a]	59	23	38.98		3	8.33	1	2.78	9	25.00	4	11.11	7	19.45
BwA2	L1	POL[a]	39	19	48.72	**p<.001***	--	--	6	30	2	10	7	35	--	--
	L2	GER[a]	76	12	15.79		6	9.38	8	12.5	11	17.19	16	25	--	--
BwA3	L1	DUT	61	27	44.26	p=.591	1	3.23	5	16.13	2	6.45	4	12.90	5	16.13
	L2	GER[a]	59	30	50.85		9	31.03	2	6.90	2	6.90	5	17.24	4	13.79
BwA4	L1	ENG[a]	38	21	55.26	p=.218	--	--	5	29.41	4	23.53	1	5.88	--	--
	L2	GER	55	22	40.00		3	9.09	2	6.06	5	15.15	5	15.15	2	6.06
BwA5	L1[b]	ENG[a]	40	2	5	p=.535	--	--	7	18.42	13	34.21	3	7.89	--	--
	L1[b]	ITA	22	0	0		--	--	--	--	9	40.91	--	--	--	--
BwA6	L1	ENG[a]	43	33	76.74	**p=.001***	--	--	1	10.00	1	10.00	5	50.00	--	--
	L2	FRE	17	5	29.41		--	--	2	16.67	2	16.67	3	25.00	--	--
BwA7	L1	FRE	17	9	52. 94	p=1	--	--	1	12.50	1	12.50	1	12.50	--	--
	L2	ENG[a]	43	22	51.16		--	--	1	4.76	6	28.57	5	23.81	--	--
BwA8	L1	FRE	17	6	35.29	**p=.007***	--	--	1	9.09	4	36.36	2	18.18	--	--
	L2	ENG[a]	43	32	74.42		--	--	1	9.09	2	18.18	3	27.27	--	--

Note. DUT = Dutch, GER = German, POL = Polish, ENG = English, ITA = Italian, FRE = French, grey = Most frequent error types observed.

[a] Dominant language.

[b] Language mixing error within the first 10 seconds of a response.

Table 7

Summary Data of Language Mixing Errors (LM Errors) in Bilingual Speakers with Aphasia

							LM errors: Distribution across error types									LM errors:		
				LM errors (n)			First constituent error (n)			Second constituent error (n)			Back translation error (n)			Distribution across modifier and head		Phonological similarity (PS) effect p value
			LD	All	Within 10s	Further[b]	a	b	c	a	b	c	a	b		Modifier	Head	LM errors (PS) vs other responses (PS)[c]
BwA1	L1	NL	L2	6	3	3	3	--	--	1	--	--	1	1		3/6	1/6	p = .938
	L2	GE[a]		8	7	1	3	2	--	1	1	--	1	--		5/8	2/8	**p = .031***
BwA2	L1	PL[a]	L2								n/a							
	L2	DE[a]									n/a							
BwA3	L1	NL	L2	11	5	6	3	--	1	3	--	1	3	--		4/11	4/11	p = .916
	L2	GE[a]		4	4	--	1	--	1	2	--	--	--	--		2/4	2/4	p = .832
BwA4	L1	EN[a]	L1								n/a							
	L2	GE		2	2	--	--	--	--	--	--	--	2	--		--	--	p = .577
BwA5	L1	EN[a]	EN								n/a							
	L1	IT									n/a							
BwA6	L1	EN[a]	L1								n/a							
	L2	FR		4	1[a]	3	--	--	--	--	--	--	1	3		--	--	p = .608
BwA7	L1	FR	L2	3	--	3	--	--	--	--	--	--	--	3		--	--	p = .675
	L2	EN[a]									n/a							
BwA8	L1	FR	L2	3	--	3	--	--	--	--	--	--	1	2		--	--	p = .810
	L2	EN[a]									n/a							

Note. NL = Dutch, GE = German, PL = Polish, EN = English, IT = Italian, FR = French, LD = Language dominance, LM errors = Language mixing errors, PS = Phonological similarity.

[a] Literal translation error of type b, therefore not in Table 6.

[b] This category includes the following LM errors: LM errors after ten seconds, LM errors that were a second error code, literal translation errors of type b. These LM errors are not included in the error types table of each individual participant (see Appendix C to Appendix J).

[c] Logistic regression analysis, significance of model coefficients (p): Phonological similarity (experimental predictor).

Data on Accuracy and Language Mixing Errors in Compounds in Bwa1

Accuracy in Compounds in Dutch (L1) and German (L2) – BwA1

As shown in Table 4 above, BwA1 showed an accuracy of 27.87% (n = 17/61) for the Dutch compounds item set and 38.98% (n = 23/59) for the German compounds item set. No significant difference was observed in the compounds' accuracy across languages.

Naming accuracy within languages was higher for compound words compared to simple words in Dutch (L1). In the participant's L2 German, compound word naming and simple word naming accuracy were equally distributed.

Error Types/Language Mixing Errors in Compounds in Dutch (L1) and German (L2) – BwA1

Dutch. Across all error types 'no responses' were the most common error type in the participant's L1 Dutch (no responses: 36.36%, semantic errors: 13.64%, language mixing errors: 6.87%, phonological errors: 2.27%, constituent errors: 2.27%).

BwA1 produced six *language mixing errors* in her non-dominant L1 Dutch (three in the category 'Within 10 seconds' and three in the category 'Further' – see Table 6 and Table 7): Three errors of language mixing in the first constituent (type a), one error of language mixing in the second constituent (type a), and two errors of literal translation of non-target to the target language (type a). Thus, the distribution of language mixing errors across the constituents showed a higher occurrence of language mixing errors in the modifier constituent: In three cases, the Dutch modifier constituent was named in German (L2 dominant), whereas in only one case, the Dutch head constituent was named in German.

The binomial logistic regression model examining the effect of phonological similarity on language mixing errors in compounds was not statistically significant, χ^2 (df = 1) = 0.01, p = .983, Cox and Snell's R^2 = .000, Nagelkerke's R^2 = .000. The overall percentage of accuracy in classification was 89.6% (cut-off < 50%). The phonological similarity did not significantly predict language mixing errors in compounds in Dutch (L1 non-dominant). Full details of the analysis can be found in Appendix C.

German. The most commonly occurring errors in the participant's L2 German were 'no responses' (no responses: 25.00%, language mixing errors: 19.45%, constituent errors 11.11%, phonological errors: 8.33%, semantic errors: 2.78%).

BwA1 produced eight *language mixing errors* in her dominant L2 German (seven in the category 'Within 10 seconds', one in the category 'Further' – see Table 6 and Table 7): Five errors of language mixing in the first constituent (three errors of type a and two errors of type b), two errors of language mixing in the second constituent (one error of type a and one error of type b), one error of literal translation of non-target to the target language (type a). Thus, the distribution of language mixing errors across the constituents showed a higher occurrence of language mixing errors in the modifier constituent: In five cases, the German modifier constituent was named in Dutch (L1 non-dominant), whereas in two cases, the German head constituent was named in Dutch.

The results of the binomial logistic regression analysis investigating the impact of phonological similarity on language mixing errors in compounds was found to be statistically significant: χ^2 (df = 1) = 6.84, p = .009, Cox and Snell's R^2 = .144, Nagelkerke's R^2 = .262, with 86.4% of accuracy in classification (cut-off < 50%). Phonological similarity (p = .031, OR = 1.029, 95%-CI[1.00, 1.057) significantly predicted language mixing errors in German (L2, dominant). Full details of the analysis can be found in Appendix C.

Data on Accuracy and Language Mixing Errors in Compounds in BwA2

Accuracy in Compounds in Polish (L1) and German (L2) – BwA2

BwA2 exhibited an accuracy of 48.72% (n = 19/39) for the Polish compounds item set and 15.79% (n = 12/76) for the German compounds item set, according to the accuracy data presented in Table 4. Accuracy varied significantly between the two languages (Fisher's Exact Test, two-tailed: p < .001).

The accuracy within languages was higher for simple words than that for compound words in Polish. The same accuracy analysis within German (L2) showed significantly higher accuracy for simple words compared to compound words (Fisher's Exact test two-tailed: p < .001).

Error Types/Language Mixing Errors in Compounds in Polish (L1) and German (L2) – BwA2

Polish. The most common error type observed in the participant's L1 Polish was the 'constituent error' (constituent errors: 35%, semantic errors: 30%, no responses: 10%, phonological errors: 0%, language mixing errors: 0%).

BwA2 presented no language mixing errors in his L1 (see Table 6 and Table 7).

German. The most prevalent error types observed in the participant's L2 German were 'constituent errors' (constituent errors: 25%, no responses: 17.19%, semantic errors: 12.5%, phonological errors: 9.38%, language mixing errors: 0%).

BwA2 produced no language mixing errors in his L2 German (see Table 6 and Table 7).

Data on Accuracy and Language Mixing Errors in Compounds in BwA3

Accuracy in Compounds in Dutch (L1) and German (L2) – BwA3

Table 4 presents the accuracy in compound picture naming for BwA3, with 44.26% (n=27/61) for the Dutch and 50.85% (n=30/59) for the German compounds item set. There was no significant difference in compound accuracy across languages.

The accuracy in compound words was higher than that of simple words in the participant's L1 Dutch. Conversely, compound accuracy versus simple word accuracy analysis showed higher accuracy for simple words in the participant's L2 German.

Error Types/Language Mixing Errors in Compounds in Dutch (L1) and German (L2) – BwA3

Dutch. 'Semantic errors' and 'language mixing errors' were the most commonly occurring error types in the compound production of participant's L1 (Dutch) (semantic errors: 16.13%, language mixing errors: 16.13%, constituent errors: 12.90%, no responses: 6.45%, phonological errors: 3.23%).

When naming compounds in his non-dominant L1 Dutch, BwA3 made a total of 11 language mixing errors, with five falling under the category 'Within 10 seconds' and six under the category 'Further' (see Table 6 and Table 7). Among these errors, four were observed in the first constituent (three errors of type a, one error of type c), while four were observed in the second constituent (three errors of type a, one error of type c). Furthermore, three errors were attributed to the literal translation of non-target to target language, all classified as error type a. Hence, the number of language mixing errors was found to be the same for both the modifier and head constituent.

The binomial logistic regression analysis examining the impact of phonological similarity on language mixing errors in compounds was not statistically significant, χ^2 (df = 1) = 0.01, p = .916, Cox and Snell's R^2 = .000, Nagelkerke's R^2 = .000. The overall percentage of accuracy in classification was 85.1% (cut-off < 50%). The phonological similarity did not significantly predict language mixing errors in compounds in Dutch (non-dominant L1). Appendix E shows all details of the analysis.

German. The most commonly occurring errors within the compound set in the participant's L2 German were 'phonological errors' (phonological errors: 31.03%, constituent errors: 17.24%, language mixing errors: 13.79%, semantic errors: 6.90%, no responses: 6.90%).

BwA3 made four language mixing errors when naming German compounds, with all four errors falling under the category 'Within 10 seconds' – see Table 6 and Table 7). Among these errors, two were observed in the first constituent (one error of type a and one error of type c), while the remaining two were observed in the second constituent (two errors of type a). Consequently, an equal number of language mixing errors was observed for both the modifier and head constituent.

The result of the binomial logistic regression analysis investigating the impact of phonological similarity on language mixing errors in compounds was not statistically significant, χ^2 (df = 1) = 0.05, p = .832, Cox and Snell's $R^2 = .001$, Nagelkerke's $R^2 = .003$, 93.2% of accuracy in classification (cut-off < 50%). Therefore, the findings suggest that phonological similarity did not significantly predict language mixing errors in compounds in German (dominant L2). Appendix E presents all details of the analysis.

Data on Accuracy and Language Mixing Errors in Compounds in BwA4

Accuracy in Compounds in English (L1) and German (L2) – BwA4

Table 4 displays that BwA4 achieved an accuracy of 55.26% (n = 21/38) for the English compound item set and 40.00% (n = 22/55) for the German compound item set. The two languages had no significant difference in the compounds' accuracy.

When comparing the accuracy of simple and compound words within each language, results showed that accuracy was significantly higher for simple words compared to compound words for English (Fisher Exact test two-tailed: p = .025). This pattern was consistent across both of the participant's languages: Simple word accuracy was higher than compound word accuracy in the participant's L2 German.

Error Types/Language Mixing Errors in Compounds in English (L1) and German (L2) – BwA4

English. In the participant's L1 English, 'semantic errors' stood out as the most frequent error type (semantic errors: 29.41%, no responses: 23.53%, constituent errors: 5.88%, phonological errors: 0%, language mixing errors: 0%).

BwA4 exhibited no language mixing errors in her dominant L1 English (see Table 6 and Table 7).

German. The most prevalent errors observed in the participant's L2 German were 'no responses' and 'constituent errors' (no responses: 15.15%, constituent errors: 15.15%, phonological errors: 9.09%, semantic errors: 6.06%, language mixing errors: 6.06%).

BwA4 committed two language mixing errors while naming German compounds in her non-dominant L2 language (both under the category 'Within 10 seconds' – see Table 6 and Table 7). Both errors were literal translation of non-target to the target language (type a).

Since BwA4 made only literal translation errors, there was no analysis performed on the modifier and head constituent.

The binomial logistic regression model examining the effect of phonological similarity on language mixing errors in compounds was not statistically significant, χ^2 (df = 1) = 0.35, p = .552, Cox and Snell's R^2 = .009, Nagelkerke's R^2 = .027, 94.7% of accuracy in classification (cut-off < 50%). The phonological similarity did not significantly predict language mixing errors in compounds in German (non-dominant L2). Full details of the analysis can be found in Appendix F.

Data on Accuracy and Language Mixing Errors in Compounds in BwA5

Accuracy in Compounds in English (L1) and Italian (L1) – BwA5

Table 4 above shows the accuracy in compound picture naming in BwA5 with 5.00% (n = 2/40) for the English compounds item set and 0% (n = 0/22) for the Italian compounds item set. There was no significant difference in the compounds' accuracy across the participant's languages.

Within English, accuracy was higher for simple words compared to compound words. There was no difference in accuracy for Italian between simple words and compound words.

Error Types/Language Mixing Errors in Compounds in English (L1) and Italian (L1) – BwA5

English. 'No responses' were the most commonly occurring error type in the participant's L1 English (no responses: 34.21%, semantic errors: 18.42%, constituent errors: 7.89%, phonological errors: 0%, language mixing errors: 0%).

BwA5 did not make any language mixing errors in his dominant L1 English (see Table 6 and Table 7).

Italian. The most commonly occurring errors in the participant's L1 Italian were 'no responses' (no responses: 40.91%, phonological errors: 0%, semantic errors: 0%, constituent errors: 0%, language mixing errors: 0%).

BwA5 produced no language mixing errors in his non-dominant L1 Italian (see Table 6 and Table 7).

Data on Accuracy and Language Mixing Errors in Compounds in BwA6

Accuracy in Compounds in English (L1) and French (L2) – BwA6

Table 4 summarizes the accuracy data and shows an accuracy of 76.74% (n = 33/43) for the English compounds item set and 29.41% (n = 5/17) for the French compounds item set for BwA6. There was a significant difference in the compounds' accuracy across languages in BwA6 (Fisher's Exact Test, two-tailed: p = .001).

Unsurprisingly, the within language analysis showed a significantly higher accuracy for simple words than that of compound words for the participant's L1 English (Fisher's Exact Test, two-tailed: p = .030). The same pattern was observed for the participant's L2 French, with higher accuracy for simple words than compound words.

Error Types/Language Mixing Errors in Compounds in English (L1) and French (L2) – BwA6

English. In the participant's L1 English, 'constituent errors' presented as the most frequent error types (constituent errors: 50%, semantic errors: 10%, no responses: 10%, phonological errors: 0%, language mixing errors: 0%).

BwA6 made no language mixing errors in her dominant L1 English (see Table 6 and Table 7).

French. The most prevalent error type observed in the participant's L2 French were 'constituent errors' (constituent errors: 25%, semantic errors: 16.67%, no responses: 16.67%, phonological errors: 0%, language mixing errors: 0%).

During picture naming in her non-dominant L2 French, BwA6 made four language mixing errors (one error in the category 'Within 10 seconds', and three errors in the category 'Further' – see Table 6 and Table 7). The four errors were all classified as literal translation of non-target to the target language errors consisting of one error of type a and three errors of type b. Since BwA6 made only literal translation language mixing errors, no specific analysis on the modifier and head constituent was performed

The binomial logistic regression model investigating the effect of phonological similarity on language mixing errors in compound naming was not statistically significant, χ^2 (df = 1) = 0.37, p = .543, Cox and Snell's R^2 = .023, Nagelkerke's R^2 = .043 and had 87.5% of accuracy in classification (cut-off < 50%). The phonological similarity did not significantly predict language mixing errors in compounds in French (non-dominant L2). Full details of the analysis can be found in Appendix H.

Data on Accuracy and Language Mixing Errors in Compounds in BwA7

Accuracy in Compounds in French (L1) and English (L2) – BwA7

Table 4 above demonstrates that BwA7 showed accuracy of 52.94% (n = 9/17) for the French compounds item set and 51.16% (n = 22/43) for the English compounds item set during compound picture naming. There was no significant difference in the compounds' accuracy across his two languages.

The analysis within languages showed higher accuracy for simple words than that of compound words for his L1 French. The same analysis within the participant's L2 English showed significantly higher accuracy for simple words compared to compound words (Fisher Exact test, two-tailed: English, p = .007).

Error Types/Language Mixing Errors in Compounds in French (L1) and English (L2) – BwA7

French. 'Semantic errors', 'constituent errors', and 'no responses' were the most commonly occurring in the participant's L1 Dutch (semantic errors: 12.50%, no responses: 12.50%, constituent errors: 12.50%, phonological errors: 0%, language mixing errors: 0%).

BwA7 produced three language mixing errors in her non-dominant L1 French, with all three errors made in the category 'Further' (see Table 6 and Table 7). The three committed errors were literal translation of non-target to the target language errors (type b). As BwA7 exclusively made literal translation errors, no specific analyses on the modifier and head constituent were performed.

The binomial logistic regression analysis exploring the impact of phonological similarity on language mixing errors in compound naming was not statistically significant, χ^2 (df = 1) = 0.23, p = .631, Cox and Snell's R^2 = .014, Nagelkerke's R^2 = .027. The model's accuracy in classification was 87.5% of (cut-off < 50%). The phonological similarity did not significantly predict language mixing errors in compounds in French (non-dominant L1). Refer to Appendix I for the analysis details.

English. The most commonly occurring errors in the participant's L2 English were 'no responses' (no responses: 28.57%, constituent errors: 23.81%, semantic errors: 4.76%, phonological errors: 0%, language mixing errors: 0%).

BwA7 made no language mixing errors in her dominant L2 English (see Table 6 and Table 7).

Data on Accuracy and Language Mixing Errors in Compounds in BwA8

Accuracy in Compounds in French (L1) and English (L2) – BwA8

Table 4 above displays that BwA8 showed an accuracy of 35.29% (n = 6/17) for the French compounds item set and 74.42% (n = 32/43) for the English compounds item set. A significant difference was observed in the compounds' accuracy between languages (Fisher's Exact Test, two-tailed: p = .007).

As observed for the previous participants in the within language analysis, accuracy for simple words was higher compared to compound words in both of the participant's languages.

Error Types/Language Mixing Errors in Compounds in French (L1) and English (L2) – BwA8

French. In the participant's L1 French, 'no responses' stood out as the most frequent error type (no responses: 36.36%, constituent errors: 18.18%, semantic errors: 9.09%, phonological errors: 0%, language mixing errors: 9%).

BwA8 made three language mixing errors in her non-dominant L1 French (all three in the category 'Further' – see Table 6 and Table 7). In all instances, these errors were literal translations of non-target to the target language errors (one error of type a, two errors of type b). As BwA8 only presented literal translation errors, no specific modifier and head constituent analysis was conducted.

The binomial logistic regression model examining the effect of phonological similarity on language mixing errors in compounds naming was not statistically significant, χ^2 (df = 1) = 0.07, p = .790, Cox and Snell's $R^2 = .005$, Nagelkerke's $R^2 = .012$. The accuracy in classification was 93.3% of (cut-off < 50%). The phonological similarity did not significantly predict language mixing errors in compounds in French (non-dominant L1). For details on the analysis outcome, see Appendix J.

English. The most frequent error type observed in the participant's L2 English were 'constituent errors' (constituent errors: 27.27%, no responses: 18.18%, semantic errors: 9.09%, phonological errors: 0%, language mixing errors: 0%).

BwA8 made no language mixing errors in her dominant L2 English (see Table 6 and Table 7).

For a list of the distribution of all error types among all participants in both of their languages, see Appendix C to Appendix J.

Discussion

This study investigated spoken compound word naming in eight bilingual speakers with aphasia, all presenting with word finding difficulties ranging from severe to moderate. This study was only the second study conducting compound picture naming in bilingual speakers with aphasia, with similar findings for accuracy compared to Jarema et al. (2010): Higher accuracy across languages was observed for the dominant language.

In our study compound naming accuracy across languages was investigated and compared to accuracy in simple word naming within and across languages for each participant. In addition, associated error types were documented and categorised using a step-by-step guide to describe language mixing errors in compound words. This guide was developed during the course of this project.

The results obtained from the accuracy and language mixing errors analyses revealed an influence of the bilingual profile on the individual's spoken word retrieval performance: Language dominance was a key factor. Naming accuracy analyses revealed a difference in compound naming across languages, with higher accuracy in the dominant language for six participants, regardless of whether the dominant language was the L1 or L2. Similarly, the language mixing error analyses indicated six participants with mixing errors in either both or one of their languages spoken. These mixing errors across participants consistently manifested in their non-dominant language, regardless of whether the non-dominant language was their L1 or L2. Hence, the accuracy and the error analyses are complementary in their pattern.

Language Dominance as a Driver for Accuracy and Error Patterns in Bilingual Speakers with Aphasia

Accuracy Pattern

While seven participants (BwA1, BwA2, BwA3, BwA4, BwA5, BwA6, BwA8; significant for BwA2, BwA6 and BwA8) showed higher accuracy for their dominant language, one participant posed an exception to this 'rule' as the accuracy pattern was higher in the non-dominant language (BwA7). The results highlight the influence of language dominance on accuracy, which has also been found in a project on compound word processing including three French-English speakers with a language impairment (Jarema et al., 2010). Two of the three included participants showed higher accuracy in their dominant language English, while the third participant exhibited a balanced accuracy pattern across languages; however, this third participant was also classified as a balanced bilingual speaker. This pattern of balanced accuracy in compound naming across languages, within a balanced bilingual speaker, has been also found in our study. BwA7 exhibited higher compound word accuracy in his non-dominant language French (L1). However, it needs to be acknowledged that the percentage of accuracy across languages had a difference of less than 2% (Fisher's Exact Test, two-tailed: p = 1) suggesting a balanced level of accuracy across the participant's languages. Additionally, the participant's self-report and the project's dominance assessment pictured BwA7 as a nearly balanced bilingual speaker, with English (L2) only slightly being his dominant language. This was further supported by the background assessment performance, revealing a similar language impairment across the available languages.

Consequently, the results suggested that compound words are easier to name in the dominant language of a bilingual speaker with aphasia, regardless of whether the dominant language is the L1 or L2, since the dominant language is the 'stronger' language, which might be less vulnerable to language impairment. These findings are in alignment with research that emphasized that language dominance is a more reliable factor for lexical access in bilingual speakers with a language disorder than the age of acquisition of the available languages (e.g., Kiran & Tuchtenhagen, 2005).

Error Pattern (Language Mixing Errors)

The important role of language dominance in word processing was also supported by the language mixing errors presented by six participants in this study in either both (BwA1 and BwA3) or one (BwA4, BwA6, BwA7 and BwA8) of their available languages, always in their non-dominant language regardless of whether the non-dominant language was their L1 or L2. The dominant language was the stronger language in all cases and according to Green (1986, 1998) the stronger and dominant languages requires greater ongoing inhibition processes within the bilingual language system. Due to (partly) impaired inhibition processes, caused by the stroke, inhibition problems may occur more often in the dominant and stronger language. Therefore, more language mixing errors occur in the non-dominant language due to unsuccessful inhibition of the dominant language.

Among the bilingual participants, two individuals (BwA2, BwA5) did not exhibit language mixing errors. BwA5, an English-Italian participant, presented with a severe language impairment with reduced naming abilities with minimal responses (5% correct) in English and no responses in Italian. The functional impairment, therefore, explains the absence of these error types in BwA5. BwA2, another participant without the demonstration of language mixing errors, was a Polish-German bilingual speaker. German and Polish are languages from different language families (German: Germanic language, Polish: Slavic language) that are characterized by significant differences in their morphological structure and different ways of compounding. These differences might lead to less interference and, therefore, fewer language mixing errors compared to people that speak languages that share greater morphological characteristics across languages.

Accuracy and Error Types in the Framework of Psycholinguistic Models

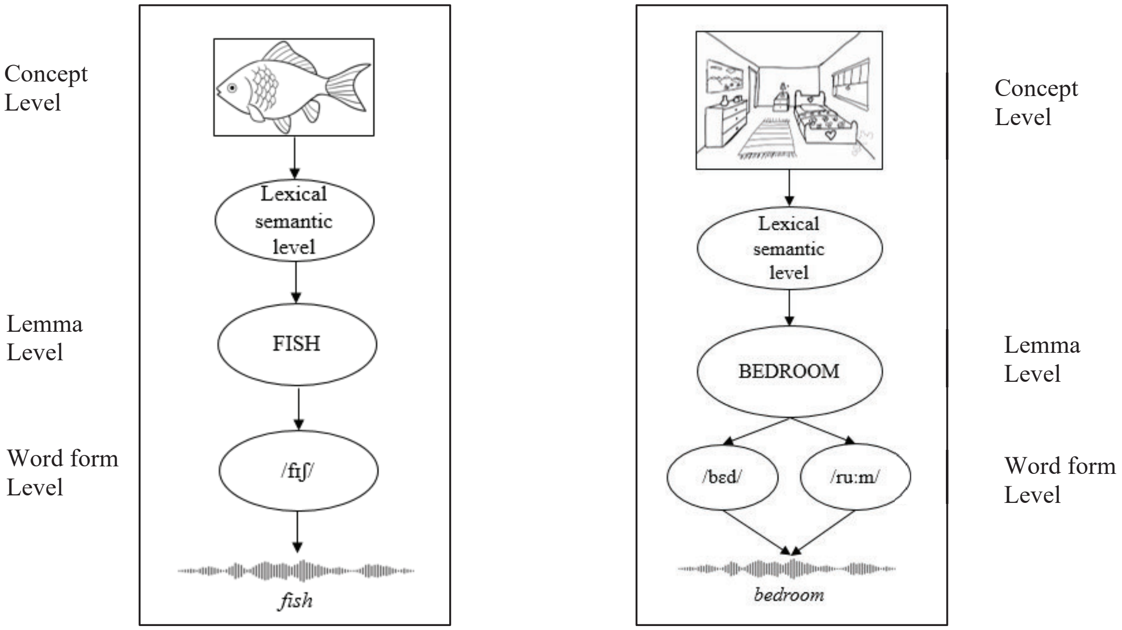
Accuracy

The findings of the accuracy analysis within languages (comparing compound word accuracy to simple word accuracy [matched list for word length and word form frequency] in each language) matched with the project's predictions of higher accuracy in simple words than compound words. Seventy-five percent of the analyses (12 out of 16 analyses, four analyses with a significant difference) presented a consistent pattern of higher naming accuracy in simple words compared to compound words. These findings align with the findings of different research groups, that argue for a more complex retrieval process for compound words (e.g., bedroom) over the retrieval process for simple words (e.g., fish) (e.g., Badecker, 2001; Blanken, 2000; Lorenz et al., 2014; Lorenz & Zwitserlood, 2014), which makes the retrieval for compound word more vulnerable as the retrieval of simple words.

These findings can also be understood within the framework of the Two-Stage Model (e.g., Levelt et al.,1999), which proposes two word form entries for a compound word and one word form entry for a simple word (see Figure 4). Due to this more complex representation of compounds at the phonological word form level, more processing steps are involved in accessing the phonological word form of compound words in comparison to simple words, that in contrast need to activate, select and access only one phonological word form.

Figure 4

Levelt et al.'s (1999) Monolingual Two-Stage Assumption for Word Processing of a Simple Word (Fish) and a Compound Word (Bedroom)



BwA1 and BwA3 were participants in this study, that did not consistently exhibit this accuracy pattern across simple words and compound words. The bilingual language profile of these two participants might account for their differing patterns of lower accuracy in simple words compared to compound words (BwA1 L1 Dutch and BwA3 L1 Dutch) or equal distribution of accuracy between simple and compound words (BwA1 L2 German). Both of the participants were Dutch-German bilingual speakers. Dutch and German are both languages that are known for their rich morphology, not only in compound words. It is, therefore, a reasonable consideration that there was no difference in accuracy between compound and simple word naming or higher accuracy for compound than simple word naming, given that simple words can have morphological complex word structures across these languages. Additionally, BwA5 an English-Italian speaker, presented no difference in naming accuracy across the compound and simple words in Italian. This pattern can be attributed to the participant's functional impairment, as his naming abilities in Italian have not recovered after the stroke, which resulted in an accuracy of 0% for both word types.

Error Types (Language Mixing Errors)

The language mixing errors by six participants align with reported non-selective activation of both languages/both lexical forms in bilingual healthy speakers (e.g., Moon & Jiang, 2012; Green, 1986, 1998) and in bilingual speakers with language impairments (e.g., Siyambalapitiya et al., 2013; Gray & Kira, 2013). Language mixing errors that, for example, are a blending of constituents from both languages (e.g., schlafroom: Language mixing error of Schlafzimmer [German word for bedroom] and bedroom), can only be explained by parallel language activation when a bilingual speaker speaks (see Figure 5).

In addition, these findings support research on the representation of monolingual compound word representation in the mental lexicon. Evidence for a representation of compound words, with two phonological word forms at the word form level ('single-lemma-multiple-word form account') was found by multiple projects across healthy speakers (Lüttman et al., 2011, Lorenz et al., 2018; Lorenz & Zwitserlood, 2016) and speakers with aphasia (e.g., Semenza et al., 1997; Badecker, 2001). Returning to the example of 'schlafroom' (language mixing error of Schlafzimmer [German for bedroom] and the English word bedroom): Only with a separate representation of the compound constituents at word form level this language mixing error can arise (see Figure 5).

However, the question of why these language mixing errors occur remains. A possible explanation may lie in impaired inhibition processes: Due to the non-selective activation of both languages when a bilingual speaker speaks, there are ongoing concurrent activation and inhibition processes, which have been explained in the Inhibitory Control model by Green (1986, 1998). According to Green (1986, 1998) ongoing inhibition processes (via Language Task Schemas, see Figure 5) at the lemma level are needed to suppress the non-target language. It is assumed that inhibition processes might be (partly) impaired as a result of the stroke that caused the

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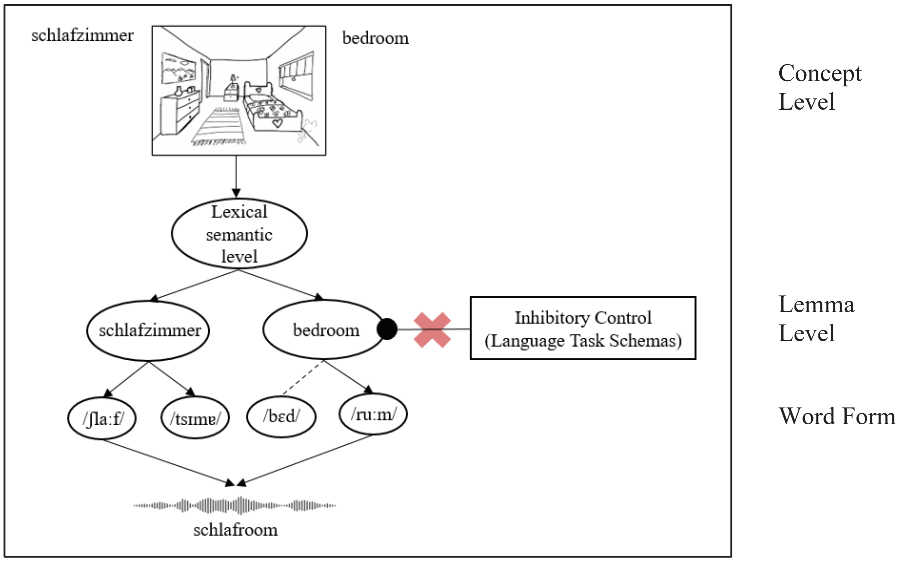
Figure 5

Word Processing of a Compound Word That Results in a Language Mixing Error



Note. Word processing of a compound word in a Two-Stage Model (Levelt et al., 1999) in a German-English bilingual speaker, resulting in a language mixing error. The Model supports the non-selective activation of lexical forms in bilingual speakers (e.g., Siyambalapitiya et al., 2013) with separate representations of the compound constituents at the word form level (e.g., Badecker, 2001). Based on (partly) impaired inhibition processes (language task schemas; Green, 1986, 1998) a language mixing error occurs.

Influence of Phonological Similarity on Language Mixing Errors

The presented language mixing errors were further investigated to examine the influence of phonological similarity across item pairs (phonological similarity of target and non-target language translation equivalent). Only BwA1 (Dutch-German) showed a significant phonological similarity effect on language mixing errors in her dominant L2, while we initially predicted phonological similarity effects on language mixing errors across participants. This prediction was based on previous research in bilingual speakers, that reported a higher occurrence of language mixing errors in languages with shared structural similarities; similar words/cognates between two languages can contribute to interference and might lead to mixing errors (e.g., Abutablebi et al., 2009; Kurland & Falcon, 2011). We acknowledge, that the different language mixing error types, included in the analyses to test for the phonological similarity effect, might have influenced the analysis outcome. As reported, 41 errors were incorporated in the analysis, of which 18 errors were literal translation language mixing errors[42]. These literal translation errors might be specifically characterized by morphology processes and less by phonology. Literal translation errors support the reported compound effect found in previous research: People with aphasia often maintain the knowledge of the structure of compound words (morphosyntactic information at lemma-level) and how to build compounds, however, they have difficulties in retrieving the complete phonological form (e.g., Semenza, 2011, Chiarelli et al., 2007; Semenza et al., 1997). Therefore, a majority of the language mixing errors included in the regression analyses, to test for phonological similarity effects, were most likely less influenced by phonology but more influenced by morphology, potentially reducing the predicted phonological similarity effect. The question, of whether phonological similarity across item pairs influences language mixing errors in bilingual speakers with aphasia, can only be answered by upcoming research that incorporates a greater number of first constituent and second constituent language mixing errors (see method section for a further explanation of these error types).

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[42] Example: The target word is a simple word, the non-target equivalent word is a compound word, the response is a compound (literal translation of the non-target language compound word into the target language), e.g., méduse ^{target} (French word for jellyfish) → poisson de gellée ^{response} (literal translation of the non-target language compound word jellyfish into the target language French).

Conclusion

The current study has demonstrated the benefit of the investigation of compound word naming in bilingual speakers with aphasia to gain a deeper understanding of the bilingual language system, which is still under-specified (for a recent attempt see, e.g., Dijkstra et al., 2019; however, noun compounds are not a focus of Dijkstra's framework). Language dominance influenced compound naming accuracy and the occurrence of language mixing errors, highlighting the importance of considering a bilingual speakers' language profile in (compound) word processing in bilingual speakers with aphasia. The investigation of language mixing errors has given further insight into the bilingual language system and underlying mechanisms: The project's findings support (a) the non-selective activation of both languages in bilingual speakers during lexical processing with related (partly) impaired inhibition processes to supress the non-target language, and (b) the separate representation of compound words constituents at word form level within the mental lexicon.

Moreover, the conducted project has developed a novel guide to define and code language mixing errors in compound words in bilingual speakers with aphasia. Since the current study is only the second study that investigated compound word processing in bilingual speakers in aphasia and additionally the first study that examined language mixing errors, there was no guide available to classify and code theses errors in bilingual speakers with a language impairment. The developed guide holds the potential to get applied in future research in bilingual speakers with aphasia and/or as assessment tool in clinical practice by speech pathologists.

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Appendices

Appendix A

Compound Item List for all Included Language Combinations

Table A1

Compounds Item List for The Language Combination Dutch-German (Including Number of Phonemes and Resemblance Score)

Picture	Language	Session	Name	Phonemes	Resemblance
PICTURE_214	Dutch	1a-5	slaapkamer	9	184
PICTURE_121	Dutch	1a-13	doolhof	6	65
PICTURE_93	Dutch	1a-23	skateboard	8	195
PICTURE_79	Dutch	1a-25	toetsenbord	10	135
PICTURE_151	Dutch	1a-35	dienblad	7	147
PICTURE_724	Dutch	1a-40	walvis	6	53
PICTURE_299	Dutch	1a-43	struisvogel	11	
PICTURE_652	Dutch	1a-45	reuzenrad	8	197
PICTURE_163	Dutch	1a-48	kokosnoot	8	207
PICTURE_373	Dutch	1a-50	bloemkool	7	205
PICTURE_46	Dutch	1b-13	schroevendraaier	13	211
PICTURE_119	Dutch	1b-32	walnoot	6	125
PICTURE_297	Dutch	1b-51	vliegtuig	8	
PICTURE_185	Dutch	1c-1	voetbal	6	140
PICTURE_586	Dutch	1c-5	strijkijzer	11	114
PICTURE_729	Dutch	1c-7	vrijheidsbeeld	13	
PICTURE_212	Dutch	1c-9	weegschaal	7	48
PICTURE_57	Dutch	1c-11	postzegel	9	117
PICTURE_531	Dutch	1c-18	schildpad	8	179
PICTURE_425	Dutch	1c-22	doedelzak	8	
PICTURE_101	Dutch	1c-24	drumstel	8	95
PICTURE_160	Dutch	1c-28	kruiwagen	8	
PICTURE_617	Dutch	1c-30	vliegveld	8	140
PICTURE_12	Dutch	1c-33	zeemeermin	8	
PICTURE_207	Dutch	1c-36	litteken	7	49
PICTURE_591	Dutch	1c-37	handdoek	6	150
PICTURE_181	Dutch	1c-44	driehoek	6	125
PICTURE_702	Dutch	1c-46	brandblusser	11	
PICTURE_381	Dutch	1c-50	aardbei	5	100

PICTURE_56	Dutch	1c-52	elleboog	6	115
PICTURE_262	Dutch	1c-55	zaklamp	7	169
PICTURE_695	Dutch	1c-57	sinaasappel	9	71
PICTURE_305	Dutch	2a-37	brievenbus	9	129
PICTURE_29	Dutch	2a-44	cowboy	6	
PICTURE_698	Dutch	2a-47	oorbel	5	36
PICTURE_562	Dutch	2a-50	broodrooster	10	132
PICTURE_493	Dutch	2a-52	stinkdier	8	191
PICTURE_48	Dutch	2a-54	brandweerman	11	140
PICTURE_246	Dutch	2a-57	tandarts	8	177
PICTURE_308	Dutch	2b-1	dobbelsteen	9	
PICTURE_258	Dutch	2b-11	stokbrood	8	99
PICTURE_161	Dutch	2b-13	stropdas	8	128
PICTURE_260	Dutch	2b-14	eiland	6	65
PICTURE_516	Dutch	2b-18	rekenmachine	10	
PICTURE_731	Dutch	2b-20	graafmachine	10	68
PICTURE_540	Dutch	2b-23	vuurtoren	8	
PICTURE_14	Dutch	2b-26	badjas	6	120
PICTURE_547	Dutch	2b-31	vleermuis	8	
PICTURE_282	Dutch	2b-34	neushoorn	9	
PICTURE_141	Dutch	2b-41	zonnebloem	8	217
PICTURE_249	Dutch	2b-43	aardappel	7	138
PICTURE_711	Dutch	2b-49	grasmaaier	9	135
PICTURE_576	Dutch	2b-54	handschoen	8	170
PICTURE_115	Dutch	2b-56	nijlpaard	8	170
PICTURE_138	Dutch	2c-21	koelkast	7	139
PICTURE_387	Dutch	2c-26	nietmachine	9	82
PICTURE_89	Dutch	2c-31	stopcontact	11	158
PICTURE_743	Dutch	2c-33	vogelverschrikker	14	
PICTURE_734	Dutch	2c-35	wasmachine	9	199
PICTURE_589	Dutch	2c-48	slaapkamer	9	184
PICTURE_537	Dutch	2c-57	vingerafdruk	11	
PICTURE_171	German	1a-1	torwart	7	65
PICTURE_684	German	1a-3	erdnuss	6	79
PICTURE_214	German	1a-5	schlafzimmer	9	184
PICTURE_93	German	1a-23	skateboard	8	195
PICTURE_652	German	1a-45	riesenrad	7	197
PICTURE_163	German	1a-48	kokosnuss	8	207
PICTURE_373	German	1a-50	blumenkohl	9	205
PICTURE_398	German	1a-52	lenkrad	7	65

PICTURE_46	German	1b-13	schraubenzieher	11	211
PICTURE_119	German	1b-32	walnuss	6	125
PICTURE_297	German	1b-51	flugzeug	9	
PICTURE_185	German	1c-1	fussball	6	140
PICTURE_586	German	1c-5	buegeleisen	8	114
PICTURE_729	German	1c-7	freiheitsstatue	14	
PICTURE_57	German	1c-11	briefmarke	9	117
PICTURE_531	German	1c-18	schildkroete	9	179
PICTURE_558	German	1c-20	feuerzeug	9	
PICTURE_425	German	1c-22	dudelsack	7	
PICTURE_101	German	1c-24	schlagzeug	9	95
PICTURE_223	German	1c-26	reissverschluss	11	110
PICTURE_160	German	1c-28	schubkarre	7	
PICTURE_617	German	1c-30	flughafen	8	140
PICTURE_12	German	1c-33	meerjungfrau	10	
PICTURE_591	German	1c-37	handtuch	7	150
PICTURE_140	German	1c-39	wasserhahn	7	65
PICTURE_181	German	1c-44	dreieck	6	125
PICTURE_702	German	1c-46	feuerloescher	8	
PICTURE_381	German	1c-50	erdbeere	7	100
PICTURE_56	German	1c-52	ellenbogen	7	115
PICTURE_262	German	1c-55	taschenlampe	9	169
PICTURE_126	German	2a-1	fallschirm	7	105
PICTURE_331	German	2a-5	buestenhalter	10	93
PICTURE_305	German	2a-37	briefkasten	9	129
PICTURE_649	German	2a-42	krankenwagen	10	87
PICTURE_29	German	2a-44	cowboy	6	
PICTURE_698	German	2a-47	ohrring	5	36
PICTURE_493	German	2a-52	stinktier	8	191
PICTURE_48	German	2a-54	feuerwehrmann	10	140
PICTURE_246	German	2a-57	zahnarzt	9	177
PICTURE_516	German	2b-18	taschenrechner	9	
PICTURE_540	German	2b-23	leuchtturm	9	
PICTURE_14	German	2b-26	bademantel	9	120
PICTURE_547	German	2b-31	fledermaus	9	
PICTURE_282	German	2b-34	nashorn	7	
PICTURE_464	German	2b-36	radiergummi	9	60
PICTURE_141	German	2b-41	sonnenblume	10	217
PICTURE_711	German	2b-49	rasenmaeher	7	135
PICTURE_576	German	2b-54	handschuh	6	170

PICTURE_115	German	2b-56	nilpferd	8	170
PICTURE_138	German	2c-21	kuehlschrank	8	139
PICTURE_671	German	2c-29	hosentraeger	9	69
PICTURE_89	German	2c-31	steckdose	8	158
PICTURE_743	German	2c-33	vogelscheuche	9	
PICTURE_734	German	2c-35	waschmaschine	9	199
PICTURE_106	German	2c-38	gewaechshaus	10	85
PICTURE_23	German	2c-41	fahrrad	6	77
PICTURE_484	German	2c-43	eichhoernchen	10	
PICTURE_589	German	2c-48	schlafzimmer	9	184
PICTURE_537	German	2c-57	fingerabdruck	10	

Table A2

Compounds Item List for the Language Combination Polish-German (Including Number of Phonemes and Resemblance Score)

Picture	Language	Session	Name	Phonemes	Resemblance
PICTURE_652	Polish	1a-8	diabelskie koło, diabelskiej	16	95
PICTURE_145	Polish	1a-12	kosz na śmieci	12	
PICTURE_358	Polish	1a-13	samochód	7	65
PICTURE_79	Polish	1a-14	klawiatura komputera	20	171
PICTURE_539	Polish	1a-15	astronauta	10	199
PICTURE_540	Polish	1a-52	latarnia morska	14	
PICTURE_273	Polish	1a-67	autobus	7	85
PICTURE_185	Polish	1a-71	piłka nożna	11	91
PICTURE_126	Polish	1b-6	spadochron	9	116
PICTURE_333	Polish	1b-26	babeczka (ciastko)	7	74
PICTURE_514	Polish	1b-28	okręt podwodny, łódź podwodna	14	
PICTURE_464	Polish	1b-30	gumka [do mazania]	5	93
PICTURE_281	Polish	1b-34	jabłko granatowe	15	190
PICTURE_729	Polish	1c-4	Statua Wolności	15	
PICTURE_344	Polish	1c-21	pompa wodna	10	119
PICTURE_331	Polish	1c-26	biustonosz	10	176
PICTURE_431	Polish	1c-40	rękawica	10	104
PICTURE_14	Polish	1c-54	szlafrok, płaszcz kąpielowy	7	64
PICTURE_282	Polish	1c-67	nosorożec	9	134
PICTURE_617	Polish	2a-8	lotnisko, lotnisko, aeroport	8	116
PICTURE_325	Polish	2a-11	telewizor	10	97
PICTURE_57	Polish	2a-37	znaczek pocztowy	13	116
PICTURE_297	Polish	2a-43	samolot	7	
PICTURE_305	Polish	2a-47	skrzynka na listy	15	171
PICTURE_223	Polish	2a-49	zamek błyskawiczny	17	154
PICTURE_537	Polish	2b-4	odcisk palca	12	
PICTURE_181	Polish	2b-31	trójkąt	8	107
PICTURE_308	Polish	2b-34	kostka do gry	11	64
PICTURE_46	Polish	2b-38	śrubokręt	10	
PICTURE_40	Polish	2b-44	liść koniczyny	13	92
PICTURE_711	Polish	2b-58	kosiarka do trawy	14	
PICTURE_724	Polish	2b-60	wieloryb	9	80
PICTURE_577	Polish	2c-25	góra lodowa (lodowiec)[a]	10	75
PICTURE_735	Polish	2c-43	kostka lodu	10	
PICTURE_684	Polish	2c-45	orzech ziemny	10	
PICTURE_262	Polish	2c-47	latarka kieszonkowa	16	142
PICTURE_93	Polish	2c-56	deskorolka	10	115
PICTURE_649	Polish	2c-58	karetka pogotowia	17	188
PICTURE_119	Polish	2c-70	orzech włoski	12	

PICTURE_652	German	1a-8	riesenrad	7	95
PICTURE_145	German	1a-12	muelleimer	7	
PICTURE_558	German	1a-24	feuerzeug	9	
PICTURE_89	German	1a-46	steckdose	8	116
PICTURE_540	German	1a-52	leuchtturm	9	
PICTURE_101	German	1a-60	schlagzeug	9	113
PICTURE_493	German	1a-65	stinktier	8	156
PICTURE_484	German	1a-68	eichhoernchen	10	
PICTURE_185	German	1a-71	fussball	6	91
PICTURE_661	German	1b-1	schublade	7	170
PICTURE_126	German	1b-6	fallschirm	7	116
PICTURE_48	German	1b-12	feuerwehrmann	10	
PICTURE_398	German	1b-14	lenkrad	7	
PICTURE_734	German	1b-22	waschmaschine	9	63
PICTURE_106	German	1b-25	gewaechshaus	10	77
PICTURE_514	German	1b-28	u-boot	4	
PICTURE_464	German	1b-30	radiergummi	9	93
PICTURE_381	German	1b-32	erdbeere	7	82
PICTURE_281	German	1b-34	granatapfel	10	190
PICTURE_23	German	1b-53	fahrrad	6	70
PICTURE_160	German	1b-55	schubkarre	7	88
PICTURE_115	German	1b-61	nilpferd	8	113
PICTURE_334	German	1b-64	schachbrett	7	
PICTURE_729	German	1c-4	freiheitsstatue	14	
PICTURE_425	German	1c-9	dudelsack	7	95
PICTURE_702	German	1c-13	feuerloescher	8	
PICTURE_635	German	1c-22	wildschwein	9	76
PICTURE_737	German	1c-24	unterhose	8	82
PICTURE_331	German	1c-26	buestenhalter	10	176
PICTURE_138	German	1c-28	kuehlschrank	8	97
PICTURE_339	German	1c-30	rucksack	6	107
PICTURE_431	German	1c-40	handschuh	6	104
PICTURE_12	German	1c-42	meerjungfrau	10	
PICTURE_603	German	1c-50	friedhof	7	115
PICTURE_14	German	1c-54	bademantel	9	64
PICTURE_671	German	1c-65	hosentraeger	9	69
PICTURE_282	German	1c-67	nashorn	7	134
PICTURE_617	German	2a-8	flughafen	8	116
PICTURE_576	German	2a-10	handschuh	6	104
PICTURE_747	German	2a-13	badewanne	8	97
PICTURE_56	German	2a-18	ellenbogen	7	45
PICTURE_743	German	2a-22	vogelscheuche	9	115
PICTURE_163	German	2a-28	kokosnuss	8	135
PICTURE_57	German	2a-37	briefmarke	9	116

PICTURE_297	German	2a-43	flugzeug	9	
PICTURE_305	German	2a-47	briefkasten	9	171
PICTURE_223	German	2a-49	reissverschluss	11	154
PICTURE_591	German	2a-51	handtuch	7	105
PICTURE_698	German	2a-57	ohrring	5	61
PICTURE_547	German	2a-64	fledermaus	9	101
PICTURE_171	German	2a-65	torwart	7	83
PICTURE_537	German	2b-4	fingerabdruck	10	
PICTURE_244	German	2b-18	gluehbirne	8	78
PICTURE_181	German	2b-31	dreieck	6	107
PICTURE_46	German	2b-38	schraubenzieher	11	
PICTURE_29	German	2b-40	cowboy	6	
PICTURE_40	German	2b-44	kleeblatt	7	92
PICTURE_586	German	2b-46	buegeleisen	8	102
PICTURE_246	German	2b-48	zahnarzt	9	175
PICTURE_711	German	2b-58	rasenmaeher	7	
PICTURE_373	German	2b-61	blumenkohl	9	96
PICTURE_516	German	2b-66	taschenrechner	9	
PICTURE_531	German	2c-7	schildkroete	9	58
PICTURE_140	German	2c-18	wasserhahn	7	65
PICTURE_214	German	2c-21	schlafzimmer	9	129
PICTURE_577	German	2c-25	eisberg	7	75
PICTURE_580	German	2c-27	krankenschwester	12	
PICTURE_141	German	2c-39	sonnenblume	10	133
PICTURE_735	German	2c-43	eiswuerfel	8	
PICTURE_684	German	2c-45	erdnuss	6	
PICTURE_589	German	2c-52	schlafzimmer	9	129
PICTURE_262	German	2c-47	taschenlampe	9	142
PICTURE_478	German	2c-54	waschbecken	7	
PICTURE_93	German	2c-56	skateboard	8	115
PICTURE_649	German	2c-58	krankenwagen	10	188
PICTURE_119	German	2c-70	walnuss	6	

[a] = The words in the brackets are the translation of Duñabeitia et al. (2022). For further information, see method chapter ‘Materials’.

Table A3

Compounds Item List for The Language Combination English-German (Including Number of Phonemes and Resemblance Score)

Picture	Language	Session	Name	Phonemes	Resemblance
PICTURE_244	English	1a-22	lightbulb	8	114
PICTURE_711	English	1a-26	lawnmower	8	
PICTURE_79	English	1a-29	keyboard	6	81
PICTURE_171	English	1a-31	goalkeeper	9	85
PICTURE_56	English	1a-35	elbow	5	100
PICTURE_689	English	1b-20	fish tank	7	80
PICTURE_95	English	1b-24	suitcase	7	71
PICTURE_698	English	1b-36	earring	5	72
PICTURE_163	English	1b-46	coconut	8	157
PICTURE_589	English	1b-54	bedroom	6	83
PICTURE_542	English	1c-2	fireplace	10	61
PICTURE_309	English	1c-5	ice cream	7	62
PICTURE_540	English	1c-7	lighthouse	8	
PICTURE_214	English	1c-20	bedroom	6	83
PICTURE_46	English	1c-32	screwdriver	11	
PICTURE_185	English	1c-44	football	6	150
PICTURE_537	English	1c-53	fingerprint	11	
PICTURE_101	English	2a-8	drum kit	7	111
PICTURE_106	English	2a-26	greenhouse	8	159
PICTURE_381	English	2a-36	strawberry	8	100
PICTURE_734	English	2a-48	washing machine	10	185
PICTURE_425	English	2b-4	bagpipes	8	97
PICTURE_141	English	2b-7	sunflower	9	153
PICTURE_48	English	2b-9	fireman	8	159
PICTURE_617	English	2b-12	airport	7	61
PICTURE_702	English	2b-15	fire extinguisher	17	
PICTURE_603	English	2b-27	graveyard	9	67
PICTURE_193	English	2b-39	jellyfish	8	97
PICTURE_729	English	2b-44	statue of liberty	15	
PICTURE_365	English	2b-51	hedgehog	7	48
PICTURE_351	English	2b-53	butterfly	9	135
PICTURE_29	English	2c-2	cowboy	6	
PICTURE_442	English	2c-5	pineapple	8	90
PICTURE_202	English	2c-27	fishing rod	8	
PICTURE_743	English	2c-29	scarecrow	9	

PICTURE_93	English	2c-38	skateboard	9	195
PICTURE_160	English	2c-41	wheelbarrow	9	78
PICTURE_37	English	2c-49	doughnut	6	132
PICTURE_140	German	GER-1a-10	wasserhahn	7	
PICTURE_246	German	GER-1a-16	zahnarzt	9	175
PICTURE_649	German	GER-1a-20	krankenwagen	10	112
PICTURE_244	German	GER-1a-22	gluehbirne	8	114
PICTURE_711	German	GER-1a-26	rasenmaeher	7	
PICTURE_171	German	GER-1a-31	torwart	7	85
PICTURE_56	German	GER-1a-35	ellenbogen	7	100
PICTURE_698	German	GER-1b-36	ohrring	5	72
PICTURE_547	German	GER-1b-38	fledermaus	9	
PICTURE_40	German	GER-1b-40	kleeblatt	7	118
PICTURE_163	German	GER-1b-46	kokosnuss	8	157
PICTURE_516	German	GER-1b-49	taschenrechner	9	
PICTURE_589	German	GER-1b-54	schlafzimmer	9	83
PICTURE_540	German	GER-1c-7	leuchtturm	9	
PICTURE_126	German	GER-1c-14	fallschirm	7	97
PICTURE_138	German	GER-1c-17	kuehlschrank	8	93
PICTURE_214	German	GER-1c-20	schlafzimmer	9	83
PICTURE_57	German	GER-1c-27	briefmarke	9	
PICTURE_46	German	GER-1c-32	schraubenzieher	11	
PICTURE_514	German	GER-1c-34	u-boot	4	60
PICTURE_661	German	GER-1c-40	schublade	7	43
PICTURE_185	German	GER-1c-44	fussball	6	150
PICTURE_484	German	GER-1c-50	eichhoernchen	10	
PICTURE_537	German	GER-1c-53	fingerabdruck	10	
PICTURE_115	German	GER-1c-55	nilpferd	8	70
PICTURE_101	German	GER-2a-8	schlagzeug	9	111
PICTURE_558	German	GER-2a-12	feuerzeug	9	
PICTURE_586	German	GER-2a-22	buegeleisen	8	83
PICTURE_106	German	GER-2a-26	gewaechshaus	10	159
PICTURE_12	German	GER-2a-29	meerjungfrau	10	
PICTURE_381	German	GER-2a-36	erdbeere	7	100
PICTURE_734	German	GER-2a-48	waschmaschine	9	185
PICTURE_145	German	GER-2a-54	muelleimer	7	69
PICTURE_425	German	GER-2b-4	dudelsack	7	97
PICTURE_141	German	GER-2b-7	sonnenblume	10	153
PICTURE_48	German	GER-2b-9	feuerwehrmann	10	159
PICTURE_617	German	GER-2b-12	flughafen	8	61

PICTURE_702	German	GER-2b-15	feuerloescher	8	
PICTURE_576	German	GER-2b-22	handschuh	6	32
PICTURE_603	German	GER-2b-27	friedhof	7	67
PICTURE_281	German	GER-2b-30	granatapfel	10	165
PICTURE_729	German	GER-2b-44	freiheitsstatue	14	
PICTURE_262	German	GER-2b-48	taschenlampe	9	82
PICTURE_29	German	GER-2c-2	cowboy	6	
PICTURE_23	German	GER-2c-9	fahrrad	6	60
PICTURE_478	German	GER-2c-14	waschbecken	7	
PICTURE_580	German	GER-2c-17	krankenschwester	12	
PICTURE_493	German	GER-2c-19	stinktier	8	136
PICTURE_223	German	GER-2c-24	reissverschluss	11	59
PICTURE_743	German	GER-2c-29	vogelscheuche	9	
PICTURE_181	German	GER-2c-33	dreieck	6	125
PICTURE_93	German	GER-2c-38	skateboard	8	195
PICTURE_160	German	GER-2c-41	schubkarre	7	78
PICTURE_331	German	GER-2c-46	buestenhalter	10	63
PICTURE_282	German	GER-2c-55	nashorn	7	60

Table A4

Compounds Item List for The Language Combination English-Italian (Including Number of Phonemes and Resemblance Score)

Picture	Language	Session	Name	Phonemes	Resemblance
PICTURE_37	English	1a-4	doughnut	6	
PICTURE_609	English	1a-10	pencil case	10	106
PICTURE_93	English	1a-16	skateboard	9	250
PICTURE_163	English	1a-25	coconut	8	110
PICTURE_206	English	1a-48	paint roller	11	98
PICTURE_537	English	1a-54	fingerprint	11	176
PICTURE_79	English	1b-7	keyboard	6	91
PICTURE_48	English	1b-20	fireman	8	98
PICTURE_689	English	1b-27	fish tank	7	67
PICTURE_106	English	1b-49	greenhouse	8	55
PICTURE_734	English	1b-51	washing machine	10	
PICTURE_512	English	1c-9	eye patch	6	63
PICTURE_542	English	1c-12	fireplace	10	61
PICTURE_617	English	1c-14	airport	7	177
PICTURE_12	English	1c-18	mermaid	7	89
PICTURE_603	English	1c-20	graveyard	9	95
PICTURE_425	English	1c-27	bagpipes	8	89
PICTURE_56	English	1c-30	elbow	5	52
PICTURE_698	English	1c-32	earring	5	82
PICTURE_351	English	1c-36	butterfly	9	153
PICTURE_702	English	2a-9	fire extinguisher	17	194
PICTURE_160	English	2a-12	wheelbarrow	9	78
PICTURE_743	English	2a-14	scarecrow	9	151
PICTURE_442	English	2a-18	pineapple	8	90
PICTURE_242	English	2a-25	postman	8	165
PICTURE_711	English	2a-27	lawnmower	8	
PICTURE_540	English	2a-43	lighthouse	8	49
PICTURE_381	English	2a-49	strawberry	8	118
PICTURE_244	English	2a-55	lightbulb	8	137
PICTURE_171	English	2b-10	goalkeeper	9	119
PICTURE_185	English	2b-35	football	6	69
PICTURE_392	English	2b-56	teapot	5	67
PICTURE_141	English	2c-3	sunflower	9	112
PICTURE_46	English	2c-5	screwdriver	11	
PICTURE_719	English	2c-9	bathroom	6	73

PICTURE_560	English	2c-24	watermelon	10	80
PICTURE_202	English	2c-26	fishing rod	8	
PICTURE_675	English	2c-30	windmill	7	75
PICTURE_101	English	2c-41	drum kit	7	101
PICTURE_193	English	2c-50	jellyfish	8	76
PICTURE_562	Italian	1a-9	tostapane	9	132
PICTURE_93	Italian	1a-16	skateboard	9	250
PICTURE_57	Italian	1a-27	francobollo	11	
PICTURE_586	Italian	1b-13	ferro da stiro	12	80
PICTURE_721	Italian	1b-53	macchina fotografica	18	135
PICTURE_281	Italian	1c-2	melograno	9	172
PICTURE_617	Italian	1c-14	aeroporto	9	177
PICTURE_425	Italian	1c-27	cornamusa	9	89
PICTURE_126	Italian	1c-57	paracadute	10	164
PICTURE_181	Italian	2a-2	triangolo	9	200
PICTURE_743	Italian	2a-14	spaventapasseri	15	151
PICTURE_711	Italian	2a-27	tagliaerba	9	
PICTURE_382	Italian	2b-8	portafoglio	10	58
PICTURE_172	Italian	2b-27	pappagallo	10	80
PICTURE_141	Italian	2c-3	girasole	8	112
PICTURE_46	Italian	2c-5	cacciavite	9	
PICTURE_331	Italian	2c-11	reggiseno	9	52
PICTURE_40	Italian	2c-21	trifoglio	8	91
PICTURE_202	Italian	2c-26	canna da pesca	12	
PICTURE_621	Italian	2c-28	carro armato	11	82
PICTURE_218	Italian	2c-42	pannolino	9	
PICTURE_626	Italian	2c-51	pianoforte	10	115

Table A5

Compounds Item List for The Language Combination French-English (Including Number of Phonemes and Resemblance Score)

Picture	Language	Session	Name	Phonemes	Resemblance
PICTURE_46	French	1a-12	tournevis	8	130
PICTURE_720	French	1a-31	cerf-volant	7	43
PICTURE_562	French	1a-41	grille-pain	6	71
PICTURE_331	French	1a-50	soutien-gorge	9	32
PICTURE_163	French	1b-10	noix-de-coco	9	98
PICTURE_698	French	1b-12	boucle d'oreille	9	37
PICTURE_425	French	1c-36	cornemuse	8	103
PICTURE_547	French	1c-48	chauve-souris	7	
PICTURE_586	French	1c-54	fer à repasser	10	74
PICTURE_141	French	2a-1	tournesol	8	131
PICTURE_734	French	2a-7	machine-à-laver	10	136
PICTURE_382	French	2a-36	portefeuille	8	
PICTURE_29	French	2a-43	cow-boy	5	107
PICTURE_721	French	2b-29	appareil photo	6	59
PICTURE_202	French	2b-44	canne à pêche	7	
PICTURE_719	French	2b-48	salle de bain	7	75
PICTURE_729	French	2c-55	statue de la liberté	16	304
PICTURE_46	English	1a-12	screwdriver	11	130
PICTURE_442	English	1a-32	pineapple	8	90
PICTURE_392	English	1a-34	teapot	5	67
PICTURE_48	English	1a-36	fireman	8	58
PICTURE_702	English	1a-54	fire extinguisher	17	
PICTURE_540	English	1a-60	lighthouse	8	51
PICTURE_598	English	1b-4	dart board	8	73
PICTURE_163	English	1b-10	coconut	8	98
PICTURE_698	English	1b-12	earring	5	37
PICTURE_244	English	1b-14	lightbulb	8	84
PICTURE_56	English	1b-19	elbow	5	31
PICTURE_309	English	1b-21	ice cream	7	50
PICTURE_214	English	1b-33	bedroom	6	
PICTURE_689	English	1b-42	fish tank	7	64
PICTURE_537	English	1c-3	fingerprint	11	102
PICTURE_609	English	1c-16	pencil case	10	84
PICTURE_542	English	1c-18	fireplace	10	67
PICTURE_617	English	1c-27	airport	7	86

PICTURE_351	English	1c-34	butterfly	9	86
PICTURE_425	English	1c-36	bagpipes	8	103
PICTURE_141	English	2a-1	sunflower	9	131
PICTURE_734	English	2a-7	washing machine	10	136
PICTURE_675	English	2a-14	windmill	7	75
PICTURE_95	English	2a-24	suitcase	7	71
PICTURE_589	English	2a-29	bedroom	6	
PICTURE_711	English	2a-33	lawnmower	8	
PICTURE_29	English	2a-43	cowboy	6	107
PICTURE_12	English	2a-47	mermaid	7	59
PICTURE_365	English	2b-5	hedgehog	7	56
PICTURE_160	English	2b-10	wheelbarrow	9	57
PICTURE_79	English	2b-42	keyboard	6	70
PICTURE_202	English	2b-44	fishing rod	8	
PICTURE_719	English	2b-48	bathroom	6	75
PICTURE_603	English	2b-57	graveyard	9	73
PICTURE_193	English	2b-59	jellyfish	8	76
PICTURE_106	English	2c-2	greenhouse	8	35
PICTURE_743	English	2c-6	scarecrow	9	76
PICTURE_242	English	2c-14	postman	8	
PICTURE_101	English	2c-19	drum kit	7	81
PICTURE_381	English	2c-31	strawberry	8	65
PICTURE_560	English	2c-38	watermelon	10	73
PICTURE_250	English	2c-51	chainsaw	7	
PICTURE_729	English	2c-55	statue of liberty	15	304

Appendix B

Matching List for all Included Language Combinations

Matching List for the Dutch-German Language Combination

Table B1

Matching List for Dutch (Simple Words and Compound Words Matched for Word Lengths and Word Form Frequency)

Simple words					Compound words				
Picture	Session	Name	Frequency	Phonemes	Picture	Session	Name	Frequency	Phonemes
PICTURE_192	1a-55	thermometer	1.76	10	PICTURE_93	1a-23	skateboard	1.91	8
PICTURE_208	1a-57	microfoon	2.66	8	PICTURE_151	1a-35	dienblad	1.74	7
PICTURE_579	1a-6	olifant	2.72	7	PICTURE_724	1a-40	walvis	2.51	6
PICTURE_189	1b-1	krokodil	2.33	8	PICTURE_652	1a-45	reuzenrad	1.81	8
PICTURE_175	1b-30	schilder	2.66	7	PICTURE_163	1a-48	kokosnoot	1.88	8
PICTURE_204	1b-33	printer	1.60	7	PICTURE_373	1a-50	bloemkool	1.40	7
PICTURE_107	1b-53	saxofoon	1.64	8	PICTURE_119	1b-32	walnoot	1.51	6
PICTURE_200	1b-8	trompet	2.07	7	PICTURE_297	1b-51	vliegtuig	3.59	8
PICTURE_682	1b-9	pinguin	1.00	7	PICTURE_185	1c-1	voetbal	2.75	6
PICTURE_581	1c-13	asperge	0.90	7	PICTURE_531	1c-18	schildpad	2.28	8
PICTURE_28	1c-14	microscoop	1.93	9	PICTURE_425	1c-22	doedelzak	1.40	8
PICTURE_539	1c-16	astronaut	2.30	9	PICTURE_101	1c-24	drumstel	1.83	8
PICTURE_558	1c-20	aansteker	2.40	8	PICTURE_160	1c-28	kruiwagen	1.75	8
PICTURE_370	1c-47	schorpioen	2.13	9	PICTURE_617	1c-30	vliegveld	3.15	8
PICTURE_153	1c-8	sigaret	3.09	7	PICTURE_12	1c-33	zeemeermin	2.09	8

PICTURE_126	2a-1	parachute	2.36	7	PICTURE_207	1c-36	litteken	2.63	7
PICTURE_479	2a-15	kangoeroe	1.84	7	PICTURE_591	1c-37	handdoek	2.66	6
PICTURE_245	2a-2	wortels	2.40	7	PICTURE_181	1c-44	driehoek	2.03	6
PICTURE_108	2a-31	kalender	2.17	8	PICTURE_702	1c-46	brandblusser	1.86	11
PICTURE_363	2a-32	ventilator	2.05	10	PICTURE_56	1c-52	elleboog	2.16	6
PICTURE_209	2a-33	boemerang	1.20	7	PICTURE_262	1c-55	zaklamp	2.35	7
PICTURE_649	2a-42	ambulance	3.04	9	PICTURE_212	1c-9	weegschaal	1.91	7
PICTURE_172	2a-9	papegaai	2.16	7	PICTURE_29	2a-44	cowboy	2.83	6
PICTURE_361	2b-12	dolfijn	1.92	7	PICTURE_493	2a-52	stinkdier	1.97	8
PICTURE_573	2b-19	aubergine	1.49	8	PICTURE_260	2b-14	eiland	3.35	6
PICTURE_283	2b-45	limousine	2.33	9	PICTURE_14	2b-26	badjas	2.00	6
PICTURE_269	2b-46	kameleon	1.72	9	PICTURE_249	2b-43	aardappel	2.17	7
PICTURE_351	2b-6	vlinder	2.43	7	PICTURE_138	2c-21	koelkast	2.81	7
PICTURE_689	2c-23	aquarium	2.10	9	PICTURE_89	2c-31	stopcontact	1.76	11
PICTURE_196	2c-8	computer	3.32	9	PICTURE_537	2c-57	vingerafdruk	2.28	11

Table B2

Matching List for German (Simple Words and Compound Words Matched for Word Lengths and Word Form Frequency)

Simple words					Compound words				
Picture	Session	Name	Frequency	Phonemes	Picture	Session	Name	Frequency	Phonemes
PICTURE_121	1a-13	labyrinth	2.05	8	PICTURE_171	1a-1	torwart	1.45	7
PICTURE_79	1a-25	tastatur	1.59	8	PICTURE_93	1a-23	skateboard	1.58	8
PICTURE_61	1a-41	zeitung	3.06	7	PICTURE_684	1a-3	erdnuss	1.58	6
PICTURE_192	1a-55	thermometer	1.60	9	PICTURE_652	1a-45	riesenrad	1.58	7
PICTURE_208	1a-57	mikrofon	2.05	8	PICTURE_163	1a-48	kokosnuss	1.76	8
PICTURE_579	1a-6	elefant	2.27	7	PICTURE_214	1a-5	schlafzimmer	2.79	9
PICTURE_189	1b-1	krokodil	1.79	8	PICTURE_398	1a-52	lenkrad	2.01	7
PICTURE_70	1b-21	orchester	2.02	7	PICTURE_119	1b-32	walnuss	1.40	6
PICTURE_657	1b-37	medaille	2.01	7	PICTURE_425	1c-22	dudelsack	1.15	7
PICTURE_107	1b-53	saxophon	1.71	8	PICTURE_160	1c-28	schubkarre	1.42	7
PICTURE_200	1b-8	trompete	1.76	8	PICTURE_617	1c-30	flughafen	2.97	8
PICTURE_682	1b-9	pinguin	1.78	7	PICTURE_591	1c-37	handtuch	2.56	7
PICTURE_28	1c-14	mikroskop	1.54	9	PICTURE_140	1c-39	wasserhahn	1.40	7
PICTURE_539	1c-16	astronaut	1.92	9	PICTURE_181	1c-44	dreieck	1.86	6
PICTURE_370	1c-47	skorpion	2.02	8	PICTURE_702	1c-46	feuerloescher	1.83	8
PICTURE_74	1c-53	traktor	1.71	7	PICTURE_586	1c-5	buegeleisen	1.08	8
PICTURE_153	1c-8	zigarette	2.73	9	PICTURE_381	1c-50	erdbeere	1.32	7
PICTURE_479	2a-15	kaenguru	1.48	8	PICTURE_56	1c-52	ellenbogen	1.43	7
PICTURE_245	2a-2	wurzeln	2.25	7	PICTURE_126	2a-1	fallschirm	2.09	7
PICTURE_173	2a-24	apotheke	2.12	7	PICTURE_649	2a-42	krankenwagen	2.75	10
PICTURE_108	2a-31	kalender	2.29	7	PICTURE_493	2a-52	stinktier	1.67	8

PICTURE_363	2a-32	ventilator	1.88	10	PICTURE_282	2b-34	nashorn	1.78	7
PICTURE_172	2a-9	papagei	2.00	7	PICTURE_141	2b-41	sonnenblume	1.11	10
PICTURE_573	2b-19	aubergine	0.95	8	PICTURE_711	2b-49	rasenmaeher	1.81	7
PICTURE_283	2b-45	limousine	2.11	8	PICTURE_576	2b-54	handschuh	2.29	6
PICTURE_269	2b-46	chamaeleon	1.11	8	PICTURE_115	2b-56	nilpferd	1.43	8
PICTURE_351	2b-6	schmetterling	2.10	8	PICTURE_138	2c-21	kuehlschrank	2.67	8
PICTURE_689	2c-23	aquarium	1.93	8	PICTURE_89	2c-31	steckdose	1.48	8
PICTURE_129	2c-46	zitrone	2.05	8	PICTURE_23	2c-41	fahrrad	2.54	6
PICTURE_196	2c-8	computer	3.27	8	PICTURE_589	2c-48	schlafzimmer	2.79	9

Matching List for the Polish-German Language Combination

Table B3

Matching List for Polish (Simple Words and Compound Words Matched for Word Lengths and Word Form Frequency)

Simple words					Compound words				
Picture	Session	Name	Frequency	Phonemes	Picture	Session	Name	Frequency	Phonemes
PICTURE_558	1a-24	zapalniczka	2.34	10	PICTURE_145	1a-12	kosz na śmieci	2.82	12
PICTURE_199	1a-28	spódnica	2.20	9	PICTURE_358	1a-13	samochód	4.38	7
PICTURE_77	1a-33	wielbłąd	2.13	10	PICTURE_79	1a-14	klawiatura komputera	1.71	20
PICTURE_682	1a-37	pingwin	2.42	9	PICTURE_539	1a-15	astronauta	2.24	10
PICTURE_434	1a-63	nauczyciel	3.32	9	PICTURE_540	1a-52	latarnia morska	2.48	14
PICTURE_484	1a-68	wiewiórka	2.54	11	PICTURE_273	1a-67	autobus	3.52	7
PICTURE_131	1b-10	piosenkarz(-rka)	2.20	10	PICTURE_185	1a-71	piłka nożna	3.39	11
PICTURE_398	1b-14	kierownica	2.12	10	PICTURE_333	1b-26	babeczka (ciastko)	2.12	7
PICTURE_695	1b-15	pomarańcz	1.74	9	PICTURE_514	1b-28	okręt podwodny, łódź podwodna	3.38	14
PICTURE_208	1b-21	mikrofon	2.93	9	PICTURE_464	1b-30	gumka [do mazania]	1.92	5
PICTURE_115	1b-61	hipopotam	1.98	10	PICTURE_281	1b-34	jabłko granatowe	3.07	15
PICTURE_334	1b-64	szachownica	1.64	10	PICTURE_126	1b-6	spadochron	2.57	9
PICTURE_70	1c-11	orkiestra	2.58	9	PICTURE_344	1c-21	pompa wodna	2.34	10
PICTURE_192	1c-33	termometr	2.10	9	PICTURE_331	1c-26	biustonosz	2.28	10
PICTURE_594	1c-37	strzykawka	2.04	9	PICTURE_431	1c-40	rękawica	2.20	10
PICTURE_431	1c-40	rękawica	2.20	10	PICTURE_14	1c-54	szlafrok, płaszcz kąpielowy	2.66	7
PICTURE_153	1c-60	papieros	2.49	9	PICTURE_282	1c-67	nosorożec	2.03	9

PICTURE_744	1c-66	pierścionek	3.35	12	PICTURE_325	2a-11	telewizor	3.34	10
PICTURE_130	1c-8	kamizelka	2.42	10	PICTURE_57	2a-37	znaczek pocztowy	2.49	13
PICTURE_694	2a-1	przytulić	2.83	9	PICTURE_297	2a-43	samolot	3.86	7
PICTURE_576	2a-10	rękawica	2.20	10	PICTURE_305	2a-47	skrzynka na listy	2.71	15
PICTURE_135	2a-14	garnitur	3.35	9	PICTURE_223	2a-49	zamek błyskawiczny	3.44	17
PICTURE_184	2a-17	czarownica	2.67	10	PICTURE_617	2a-8	lotnisko, lotnisko, aeroport	3.43	8
PICTURE_28	2a-20	mikroskop	2.08	10	PICTURE_181	2b-31	trójkąt	2.68	8
PICTURE_743	2a-22	czupiradło	0.85	9	PICTURE_308	2b-34	kostka do gry	2.70	11
PICTURE_457	2a-39	piramida	2.29	10	PICTURE_46	2b-38	śrubokręt	2.39	10
PICTURE_121	2a-61	labirynt	2.52	9	PICTURE_537	2b-4	odcisk palca	3.11	12
PICTURE_51	2b-13	szubienica	1.61	10	PICTURE_40	2b-44	liść koniczyny	2.46	13
PICTURE_582	2b-57	laboratorium	3.77	13	PICTURE_711	2b-58	kosiarka do trawy	1.82	14
PICTURE_213	2b-62	policjant(ka)	3.34	11	PICTURE_724	2b-60	wieloryb	2.46	9
PICTURE_516	2b-66	kalkulator	1.93	10	PICTURE_735	2c-43	kostka lodu	2.70	10
PICTURE_214	2c-21	sypialnia	2.87	10	PICTURE_684	2c-45	orzech ziemny	2.47	10
PICTURE_580	2c-27	pielęgniarka	3.08	14	PICTURE_262	2c-47	latarka kieszonkowa	2.40	16
PICTURE_141	2c-39	słonecznik	1.81	10	PICTURE_93	2c-56	deskorolka	1.51	10
PICTURE_303	2c-49	pantomima	1.20	10	PICTURE_649	2c-58	karetka pogotowia	2.82	17
PICTURE_498	2c-68	filiżanka	2.42	11	PICTURE_119	2c-70	orzech włoski	2.47	12

Table B4

Matching List for Polish (Simple Words and Compound Words Matched for Word Lengths and Word Form Frequency)

Simple words					Compound words				
Picture	Session	Name	Frequency	Phonemes	Picture	Session	Name	Frequency	Phonemes
PICTURE_161	1a-10	krawatte	2.44	7	PICTURE_145	1a-12	muelleimer	1.93	7
PICTURE_79	1a-14	tastatur	1.59	8	PICTURE_558	1a-24	feuerzeug	2.18	9
PICTURE_539	1a-15	astronaut	1.92	9	PICTURE_89	1a-46	steckdose	1.48	8
PICTURE_510	1a-16	gesicht	3.70	6	PICTURE_540	1a-52	leuchtturm	1.79	9
PICTURE_85	1a-18	diamant	2.16	7	PICTURE_101	1a-60	schlagzeug	1.60	9
PICTURE_164	1a-2	strasse	3.50	6	PICTURE_493	1a-65	stinktier	1.67	8
PICTURE_148	1a-20	pfeife	2.41	6	PICTURE_185	1a-71	fussball	2.63	6
PICTURE_741	1a-26	bonbon	1.86	6	PICTURE_652	1a-8	riesenrad	1.58	7
PICTURE_597	1a-27	fenster	3.33	6	PICTURE_661	1b-1	schublade	2.42	7
PICTURE_20	1a-3	skelett	1.91	6	PICTURE_398	1b-14	lenkrad	2.01	7
PICTURE_681	1a-34	rakete	2.61	6	PICTURE_734	1b-22	waschmaschine	1.86	9
PICTURE_682	1a-37	pinguin	1.78	7	PICTURE_514	1b-28	u-boot	2.54	4
PICTURE_662	1a-42	pelikan	1.30	7	PICTURE_464	1b-30	radiergummi	1.15	9
PICTURE_607	1a-45	pullover	2.13	6	PICTURE_381	1b-32	erdbeere	1.32	7
PICTURE_247	1a-48	gehirn	3.14	6	PICTURE_23	1b-53	fahrrad	2.54	6
PICTURE_107	1a-56	saxophon	1.71	8	PICTURE_160	1b-55	schubkarre	1.42	7
PICTURE_74	1a-58	traktor	1.71	7	PICTURE_126	1b-6	fallschirm	2.09	7
PICTURE_200	1a-6	trompete	1.76	8	PICTURE_115	1b-61	nilpferd	1.43	8
PICTURE_245	1a-64	wurzeln	2.25	7	PICTURE_334	1b-64	schachbrett	1.18	7
PICTURE_418	1a-69	vorhang	2.22	6	PICTURE_702	1c-13	feuerloescher	1.83	8
PICTURE_68	1a-7	kerze	2.24	6	PICTURE_635	1c-22	wildschwein	1.86	9

PICTURE_695	1b-15	orange	2.40	6	PICTURE_737	1c-24	unterhose	2.20	8
PICTURE_277	1b-17	peruecke	0.48	6	PICTURE_138	1c-28	kuehlschrank	2.67	8
PICTURE_363	1b-19	ventilator	1.88	10	PICTURE_339	1c-30	rucksack	2.25	6
PICTURE_622	1b-2	kreide	2.05	6	PICTURE_431	1c-40	handschuh	2.08	6
PICTURE_208	1b-21	mikrofon	2.05	8	PICTURE_603	1c-50	friedhof	2.55	7
PICTURE_108	1b-24	kalender	2.29	7	PICTURE_14	1c-54	bademantel	1.88	9
PICTURE_614	1b-27	koenigin	2.95	7	PICTURE_671	1c-65	hosentraeger	1.36	9
PICTURE_283	1b-37	limousine	2.11	8	PICTURE_282	1c-67	nashorn	1.78	7
PICTURE_76	1b-50	brokkoli	1.23	7	PICTURE_425	1c-9	dudelsack	1.15	7
PICTURE_173	1b-52	apotheke	2.12	7	PICTURE_576	2a-10	handschuh	2.29	6
PICTURE_477	1b-56	avocado	0.90	7	PICTURE_747	2a-13	badewanne	2.31	8
PICTURE_579	1c-10	elefant	2.27	7	PICTURE_56	2a-18	ellenbogen	1.43	7
PICTURE_70	1c-11	orchester	2.02	7	PICTURE_743	2a-22	vogelscheuche	1.60	9
PICTURE_479	1c-25	kaenguru	1.48	8	PICTURE_163	2a-28	kokosnuss	1.76	8
PICTURE_192	1c-33	thermometer	1.60	9	PICTURE_57	2a-37	briefmarke	1.40	9
PICTURE_129	1c-34	zitrone	2.05	8	PICTURE_297	2a-43	flugzeug	3.34	9
PICTURE_594	1c-37	spritze	2.45	7	PICTURE_305	2a-47	briefkasten	2.05	9
PICTURE_61	1c-43	zeitung	3.06	7	PICTURE_591	2a-51	handtuch	2.56	7
PICTURE_153	1c-60	zigarette	2.73	9	PICTURE_698	2a-57	ohrring	1.99	5
PICTURE_694	2a-1	umarmung	2.16	7	PICTURE_547	2a-64	fledermaus	1.94	9
PICTURE_325	2a-11	fernseher	2.91	7	PICTURE_171	2a-65	torwart	1.45	7
PICTURE_351	2a-16	schmetterling	2.10	8	PICTURE_617	2a-8	flughafen	2.97	8
PICTURE_28	2a-20	mikroskop	1.54	9	PICTURE_244	2b-18	gluehbirne	1.64	8
PICTURE_457	2a-39	pyramide	1.91	8	PICTURE_181	2b-31	dreieck	1.86	6
PICTURE_189	2a-42	krokodil	1.79	8	PICTURE_29	2b-40	cowboy	2.53	6
PICTURE_573	2a-52	aubergine	0.95	8	PICTURE_40	2b-44	kleeblatt	1.57	7

PICTURE_348	2a-6	paprika	1.48	7	PICTURE_586	2b-46	buegeleisen	1.08	8
PICTURE_121	2a-61	labyrinth	2.05	8	PICTURE_246	2b-48	zahnarzt	2.36	9
PICTURE_509	2b-15	telefon	3.57	7	PICTURE_711	2b-58	rasenmaeher	1.81	7
PICTURE_249	2b-32	kartoffel	1.96	7	PICTURE_373	2b-61	blumenkohl	1.15	9
PICTURE_370	2b-36	skorpion	2.02	8	PICTURE_516	2b-66	taschenrechner	1.46	9
PICTURE_593	2b-5	schokolade	2.71	8	PICTURE_140	2c-18	wasserhahn	1.40	7
PICTURE_269	2b-54	chamaeleon	1.11	8	PICTURE_214	2c-21	schlafzimmer	2.79	9
PICTURE_213	2b-62	polizist	3.09	9	PICTURE_577	2c-25	eisberg	1.58	7
PICTURE_209	2b-67	bumerang	0.95	7	PICTURE_735	2c-43	eiswuerfel	1.57	8
PICTURE_657	2b-69	medaille	2.01	7	PICTURE_684	2c-45	erdnuss	1.58	6
PICTURE_572	2b-9	jongleur	0.48	7	PICTURE_262	2c-47	taschenlampe	2.10	9
PICTURE_172	2c-1	papagei	2.00	7	PICTURE_589	2c-52	schlafzimmer	2.79	9
PICTURE_196	2c-3	computer	3.27	8	PICTURE_478	2c-54	waschbecken	1.81	7
PICTURE_689	2c-35	aquarium	1.93	8	PICTURE_93	2c-56	skateboard	1.58	8
PICTURE_443	2c-4	lehrerin	2.63	7	PICTURE_531	2c-7	schildkroete	2.53	9
PICTURE_303	2c-49	pantomime	1.42	9	PICTURE_119	2c-70	walnuss	1.40	6

Matching List for the English-German Language Combination

Table B5

Matching List for English (Simple Words and Compound Words Matched for Word Lengths and Word Form Frequency)

Simple words					Compound words				
Picture	Session	Name	Frequency	Phonemes	Picture	Session	Name	Frequency	Phonemes
PICTURE_246	1a-16	dentist	3.76	7	PICTURE_244	1a-22	lightbulb	2.68	8
PICTURE_649	1a-20	ambulance	4.47	9	PICTURE_711	1a-26	lawnmower	3.11	8
PICTURE_659	1a-30	radio	4.82	7	PICTURE_79	1a-29	keyboard	3.64	6
PICTURE_249	1a-34	potato	4.44	8	PICTURE_171	1a-31	goalkeeper	4.13	9
PICTURE_208	1a-39	microphone	3.80	10	PICTURE_56	1a-35	elbow	3.85	5
PICTURE_607	1a-41	jumper	3.84	7	PICTURE_689	1b-20	fish tank		7
PICTURE_370	1a-42	scorpion	3.81	7	PICTURE_95	1b-24	suitcase	3.78	7
PICTURE_196	1a-49	computer	4.64	9	PICTURE_698	1b-36	earring	3.07	5
PICTURE_407	1a-51	mountain	4.64	7	PICTURE_163	1b-46	coconut	4.08	8
PICTURE_682	1a-53	penguin	3.88	7	PICTURE_589	1b-54	bedroom	5.00	6
PICTURE_74	1a-8	tractor	3.84	7	PICTURE_214	1c-20	fireplace	4.21	10
PICTURE_581	1b-19	asparagus	3.88	9	PICTURE_542	1c-2	ice cream	1.65	7
PICTURE_572	1b-22	juggler	2.75	7	PICTURE_309	1c-5	lighthouse	3.77	8
PICTURE_457	1b-23	pyramid	3.71	7	PICTURE_540	1c-7	bedroom	5.00	6
PICTURE_314	1b-31	perfume	3.94	7	PICTURE_46	1c-32	screwdriver	3.34	11
PICTURE_477	1b-35	avocado	3.52	8	PICTURE_185	1c-44	football	5.12	6
PICTURE_40	1b-40	clover	3.23	7	PICTURE_537	1c-53	fingerprint	3.21	11
PICTURE_516	1b-49	calculator	3.28	10	PICTURE_101	2a-8	drum kit	4.33	7
PICTURE_718	1b-7	trousers	4.24	8	PICTURE_106	2a-26	greenhouse	3.76	8

PICTURE_209	1c-11	boomerang	3.04	7	PICTURE_381	2a-36	strawberry	3.99	8
PICTURE_126	1c-14	parachute	3.71	7	PICTURE_734	2a-48	washing machine		10
PICTURE_317	1c-18	soldier	4.62	8	PICTURE_425	2b-4	bagpipes	3.16	8
PICTURE_561	1c-23	caterpillar	3.66	8	PICTURE_141	2b-7	sunflower	3.55	9
PICTURE_514	1c-34	submarine	3.77	8	PICTURE_48	2b-9	fireman	3.48	8
PICTURE_173	1c-38	pharmacy	3.44	7	PICTURE_617	2b-12	airport	4.54	7
PICTURE_28	1c-48	microscope	3.56	11	PICTURE_702	2b-15	fire extinguisher		17
PICTURE_387	1c-54	stapler	2.58	8	PICTURE_603	2b-27	graveyard	3.48	9
PICTURE_20	1c-6	skeleton	3.78	8	PICTURE_193	2b-39	jellyfish	3.56	8
PICTURE_325	2a-1	television	4.87	9	PICTURE_729	2b-44	statue of liberty		15
PICTURE_539	2a-38	astronaut	3.48	8	PICTURE_365	2b-51	hedgehog	3.72	7
PICTURE_85	2b-18	diamond	4.39	8	PICTURE_351	2b-53	butterfly	4.03	9
PICTURE_559	2b-21	cucumber	3.77	9	PICTURE_29	2c-2	cowboy	4.06	6
PICTURE_281	2b-30	pomegranate	3.24	10	PICTURE_442	2c-5	pineapple	3.84	8
PICTURE_108	2b-36	calendar	1.39	8	PICTURE_202	2c-27	fishing rod		8
PICTURE_439	2c-18	volcano	3.91	9	PICTURE_743	2c-29	scarecrow	3.35	9
PICTURE_509	2c-28	telephone	4.32	8	PICTURE_93	2c-38	skateboard	3.39	9
PICTURE_181	2c-33	triangle	3.93	9	PICTURE_160	2c-41	wheelbarrow	3.39	9
PICTURE_192	2c-7	thermometer	3.30	10	PICTURE_37	2c-49	doughnut	3.50	6

Table B6

Matching List for German (Simple Words and Compound Words Matched for Word Lengths and Word Form Frequency)

Simple words					Compound words				
Picture	Session	Name	Frequency	Phonemes	Picture	Session	Name	Frequency	Phonemes
PICTURE_69	1a-11	banane	2.08	6	PICTURE_140	1a-10	wasserhahn	1.40	7
PICTURE_79	1a-29	tastatur	1.59	8	PICTURE_244	1a-22	gluehbirne	1.64	8
PICTURE_151	1a-3	tablett	1.92	6	PICTURE_711	1a-26	rasenmaeher	1.81	7
PICTURE_249	1a-34	kartoffel	1.96	7	PICTURE_171	1a-31	torwart	1.45	7
PICTURE_208	1a-39	mikrofon	2.05	8	PICTURE_56	1a-35	ellenbogen	1.43	7
PICTURE_585	1a-40	ameise	1.68	6	PICTURE_698	1b-36	ohrring	1.99	5
PICTURE_370	1a-42	skorpion	2.02	8	PICTURE_40	1b-40	kleeblatt	1.57	7
PICTURE_121	1a-44	labyrinth	2.05	8	PICTURE_163	1b-46	kokosnuss	1.76	8
PICTURE_682	1a-53	pinguin	1.78	7	PICTURE_126	1c-14	fallschirm	2.09	7
PICTURE_74	1a-8	traktor	1.71	7	PICTURE_138	1c-17	kuehlschrank	2.67	8
PICTURE_303	1b-14	pantomime	1.42	9	PICTURE_661	1c-40	schublade	2.42	7
PICTURE_581	1b-19	spargel	1.43	6	PICTURE_185	1c-44	fussball	2.63	6
PICTURE_689	1b-20	aquarium	1.93	8	PICTURE_115	1c-55	nilpferd	1.43	8
PICTURE_457	1b-23	pyramide	1.91	8	PICTURE_586	2a-22	buegeleisen	1.08	8
PICTURE_477	1b-35	avocado	0.90	7	PICTURE_381	2a-36	erdbeere	1.32	7
PICTURE_209	1c-11	bumerang	0.95	7	PICTURE_145	2a-54	muelleimer	1.93	7
PICTURE_633	1c-12	trichter	1.32	6	PICTURE_617	2b-12	flughafen	2.97	8
PICTURE_28	1c-48	mikroskop	1.54	9	PICTURE_702	2b-15	feuerloescher	1.83	8
PICTURE_20	1c-6	skelett	1.91	6	PICTURE_576	2b-22	handschuh	2.08	6
PICTURE_348	2a-28	paprika	1.48	7	PICTURE_603	2b-27	friedhof	2.55	7
PICTURE_539	2a-38	astronaut	1.92	9	PICTURE_425	2b-4	dudelsack	1.15	7

PICTURE_657	2a-41	medaille	2.01	7	PICTURE_141	2b-7	sonnenblume	1.11	10
PICTURE_479	2a-7	kaenguru	1.48	8	PICTURE_478	2c-14	waschbecken	1.81	7
PICTURE_129	2b-19	zitrone	2.05	8	PICTURE_493	2c-19	stinktier	1.67	8
PICTURE_76	2b-23	brokkoli	1.23	7	PICTURE_29	2c-2	cowboy	2.53	6
PICTURE_363	2b-24	ventilator	1.88	10	PICTURE_181	2c-33	dreieck	1.86	6
PICTURE_200	2b-35	trompete	1.76	8	PICTURE_93	2c-38	skateboard	1.58	8
PICTURE_153	2b-46	zigarette	2.73	9	PICTURE_160	2c-41	schubkarre	1.42	7
PICTURE_172	2c-10	papagei	2.00	7	PICTURE_282	2c-55	nashorn	1.78	7
PICTURE_192	2c-7	thermometer	1.60	9	PICTURE_23	2c-9	fahrrad	2.54	6

Matching List for the English-Italian Language Combination

Table B7

Matching List for English (Simple Words and Compound Words Matched for Word Lengths and Word Form Frequency)

Simple words					Compound words				
Picture	Session	Name	Frequency	Phonemes	Picture	Session	Name	Frequency	Phonemes
PICTURE_439	1a-11	volcano	3.91	9	PICTURE_609	1a-10	pencil case		10
PICTURE_561	1a-14	caterpillar	3.66	8	PICTURE_93	1a-16	skateboard	3.39	9
PICTURE_299	1a-23	ostrich	3.52	7	PICTURE_163	1a-25	coconut	4.08	8
PICTURE_407	1a-46	mountain	4.64	7	PICTURE_37	1a-4	doughnut	3.50	6
PICTURE_516	1a-50	calculator	3.28	10	PICTURE_206	1a-48	paint roller		11
PICTURE_45	1a-51	tambourine	3.13	8	PICTURE_537	1a-54	fingerprint	3.21	11
PICTURE_153	1a-52	cigarette	4.11	7	PICTURE_48	1b-20	fireman	3.48	8
PICTURE_559	1a-57	cucumber	3.77	9	PICTURE_689	1b-27	fish tank		7
PICTURE_246	1a-7	dentist	3.76	7	PICTURE_106	1b-49	greenhouse	3.76	8
PICTURE_562	1a-9	toaster	3.29	7	PICTURE_734	1b-51	washing machine		10
PICTURE_326	1b-10	tomato	4.27	7	PICTURE_79	1b-7	keyboard	3.64	6
PICTURE_325	1b-14	television	4.87	9	PICTURE_542	1c-12	fireplace	4.21	10
PICTURE_80	1b-25	helicopter	4.38	10	PICTURE_617	1c-14	airport	4.54	7
PICTURE_209	1b-30	boomerang	3.04	7	PICTURE_12	1c-18	mermaid	3.41	7
PICTURE_108	1b-43	calendar	1.39	8	PICTURE_603	1c-20	graveyard	3.48	9
PICTURE_682	1b-52	penguin	3.88	7	PICTURE_425	1c-27	bagpipes	3.16	8
PICTURE_192	1b-57	thermometer	3.30	10	PICTURE_56	1c-30	elbow	3.85	5
PICTURE_699	1c-17	telescope	3.98	9	PICTURE_698	1c-32	earring	3.07	5
PICTURE_281	1c-2	pomegranate	3.24	10	PICTURE_351	1c-36	butterfly	4.03	9

PICTURE_649	1c-25	ambulance	4.47	9	PICTURE_512	1c-9	eye patch	1.65	6
PICTURE_85	1c-40	diamond	4.39	8	PICTURE_160	2a-12	wheelbarrow	3.39	9
PICTURE_593	1c-41	chocolate	4.77	7	PICTURE_743	2a-14	scarecrow	3.35	9
PICTURE_249	1c-49	potato	4.44	8	PICTURE_442	2a-18	pineapple	3.84	8
PICTURE_196	1c-5	computer	4.64	9	PICTURE_242	2a-25	postman	4.02	8
PICTURE_20	1c-50	skeleton	3.78	8	PICTURE_711	2a-27	lawnmower	3.11	8
PICTURE_572	1c-52	juggler	2.75	7	PICTURE_540	2a-43	lighthouse	3.77	8
PICTURE_126	1c-57	parachute	3.71	7	PICTURE_381	2a-49	strawberry	3.99	8
PICTURE_200	2a-17	trumpet	3.82	7	PICTURE_244	2a-55	lightbulb	2.68	8
PICTURE_181	2a-2	triangle	3.93	9	PICTURE_702	2a-9	fire extinguisher		17
PICTURE_509	2a-21	telephone	4.32	8	PICTURE_171	2b-10	goalkeeper	4.13	9
PICTURE_581	2a-38	asparagus	3.88	9	PICTURE_185	2b-35	football	5.12	6
PICTURE_74	2a-47	tractor	3.84	7	PICTURE_392	2b-56	teapot	3.78	5
PICTURE_204	2a-51	printer	3.35	7	PICTURE_560	2c-24	watermelon	3.13	10
PICTURE_208	2a-58	microphone	3.80	10	PICTURE_202	2c-26	fishing rod		8
PICTURE_370	2a-7	scorpion	3.81	7	PICTURE_141	2c-3	sunflower	3.55	9
PICTURE_718	2b-1	trousers	4.24	8	PICTURE_675	2c-30	windmill	3.51	7
PICTURE_154	2b-16	dominoes	3.11	8	PICTURE_101	2c-41	drum kit		7
PICTURE_28	2b-39	microscope	3.56	11	PICTURE_46	2c-5	screwdriver	3.34	11
PICTURE_293	2c-22	dinosaur	3.98	8	PICTURE_193	2c-50	jellyfish	3.56	8
PICTURE_539	2c-8	astronaut	3.48	8	PICTURE_719	2c-9	bathroom	4.81	6

Table B8

Matching List for Italian (Simple Words and Compound Words Matched for Word Lengths and Word Form Frequency)

Simple words					Compound words				
Picture	Session	Name	Frequency	Phonemes	Picture	Session	Name	Frequency	Phonemes
PICTURE_516	1a-50	calcolatrice	2.07	12	PICTURE_562	1a-9	tostapane	2.54	9
PICTURE_547	1a-45	pipistrello	2.57	11	PICTURE_93	1a-16	skateboard	2.44	9
PICTURE_582	1b-3	laboratorio	3.75	11	PICTURE_57	1a-27	francobollo	2.16	11
PICTURE_363	1b-41	ventilatore	2.25	11	PICTURE_586	1b-13	ferro da stiro		12
PICTURE_282	2a-26	rinoceronte	2.30	11	PICTURE_721	1b-53	macchina fotografica	0.48	18
PICTURE_28	2b-39	microscopio	2.39	11	PICTURE_281	1c-2	melograno	1.79	9
PICTURE_138	2b-42	frigorifero	2.81	11	PICTURE_617	1c-14	aeroporto	3.53	9
PICTURE_587	1b-47	pannocchia	1.72	9	PICTURE_425	1c-27	cornamusa	1.68	9
PICTURE_45	1a-51	tamburello	1.86	10	PICTURE_126	1c-57	paracadute	2.68	10
PICTURE_433	1b-11	campanello	2.94	10	PICTURE_181	2a-2	triangolo	2.68	9
PICTURE_325	1b-14	televisore	2.64	10	PICTURE_743	2a-14	spaventapasseri	2.35	15
PICTURE_80	1b-25	elicottero	3.36	10	PICTURE_711	2a-27	tagliaerba	1.76	9
PICTURE_108	1b-43	calendario	2.88	10	PICTURE_382	2b-8	portafoglio	3.18	10
PICTURE_192	1b-57	termometro	2.19	10	PICTURE_172	2b-27	pappagallo	2.67	10
PICTURE_699	1c-17	telescopio	2.53	10	PICTURE_141	2c-3	girasole	1.99	8
PICTURE_88	1b-19	stampella	1.78	9	PICTURE_46	2c-5	cacciavite	2.49	9
PICTURE_75	1c-38	palloncino	2.59	10	PICTURE_331	2c-11	reggiseno	2.92	9
PICTURE_484	2b-14	scoiattolo	2.66	10	PICTURE_40	2c-21	trifoglio	1.72	8
PICTURE_115	2b-25	ippopotamo	2.15	10	PICTURE_202	2c-26	canna da pesca		12
PICTURE_155	2c-2	proiettile	3.49	10	PICTURE_621	2c-28	carro armato	0.70	11
PICTURE_539	2c-8	astronauta	2.77	10	PICTURE_218	2c-42	pannolino	2.60	9

PICTURE_23	2c-16	bicicletta	3.11	10	PICTURE_626	2c-51	pianoforte	2.89	10

Matching List for the French-English Language Combination

Table B9

Matching List for French (Simple Words and Compound Words Matched for Word Lengths and Word Form Frequency)

Simple words					Compound words				
Picture	Session	Name	Frequency	Phonemes	Picture	Session	Name	Frequency	Phonemes
PICTURE_192	1a-19	thermomètre	4.29	9	PICTURE_46	1a-12	tournevis	3.90	8
PICTURE_702	1a-54	extincteur		9	PICTURE_720	1a-31	cerf-volant		7
PICTURE_207	1b-39	cicatrice		8	PICTURE_562	1a-41	grille-pain	4.27	6
PICTURE_689	1b-42	aquarium		8	PICTURE_331	1a-50	soutien-gorge		9
PICTURE_28	1b-6	microscope	3.56	9	PICTURE_163	1b-10	noix-de-coco		9
PICTURE_80	1b-9	hélicoptère		9	PICTURE_698	1b-12	boucle d'oreille		9
PICTURE_580	1c-19	infirmière		8	PICTURE_425	1c-36	cornemuse	1.69	8
PICTURE_196	1c-4	ordinateur	6.42	9	PICTURE_547	1c-48	chauve-souris	2.91	7
PICTURE_270	2b-35	flèche	3.91	9	PICTURE_586	1c-54	fer à repasser		10
PICTURE_121	2b-8	labyrinthe	3	14	PICTURE_141	2a-1	tournesol	3.66	8
PICTURE_653	2c-16	parapluie	4.54	8	PICTURE_382	2a-36	portefeuille		8
PICTURE_699	2c-25	télescope	3.36	8	PICTURE_29	2a-43	cow-boy		5
PICTURE_282	2c-39	rhinocéros	2.38	9	PICTURE_734	2a-7	machine-à-laver		10
PICTURE_115	2c-43	hippopotame	2.66	8	PICTURE_721	2b-29	appareil photo		6
PICTURE_250	2c-51	tronçonneuse		8	PICTURE_202	2b-44	canne à pêche		7
PICTURE_743	2c-6	épouvantail	2.97	8	PICTURE_719	2b-48	salle de bain		7
PICTURE_607	2c-7	pull		8	PICTURE_729	2c-55	statue de la liberté		16

Table B10

Matching List for English (Simple Words and Compound Words Matched for Word Lengths and Word Form Frequency)

Simple words					Compound words				
Picture	Session	Name	Frequency	Phonemes	Picture	Session	Name	Frequency	Phonemes
PICTURE_204	1a-10	printer	3.35	7	PICTURE_46	1a-12	screwdriver	3.34	11
PICTURE_192	1a-19	thermometer	3.30	10	PICTURE_442	1a-32	pineapple	3.84	8
PICTURE_293	1a-23	dinosaur	3.98	8	PICTURE_392	1a-34	teapot	3.78	5
PICTURE_338	1a-24	present	4.90	7	PICTURE_48	1a-36	fireman	3.48	8
PICTURE_38	1a-30	spider	4.24	7	PICTURE_702	1a-54	fire extinguisher		17
PICTURE_562	1a-41	toaster	3.29	7	PICTURE_540	1a-60	lighthouse	3.77	8
PICTURE_649	1a-43	ambulance	4.47	9	PICTURE_163	1b-10	coconut	4.08	8
PICTURE_561	1a-56	caterpillar	3.66	8	PICTURE_698	1b-12	earring	3.07	5
PICTURE_566	1b-16	violin	3.82	7	PICTURE_244	1b-14	lightbulb	2.68	8
PICTURE_299	1b-2	ostrich	3.52	7	PICTURE_56	1b-19	elbow	3.85	5
PICTURE_173	1b-22	pharmacy	3.44	7	PICTURE_309	1b-21	ice cream	1.65	7
PICTURE_326	1b-34	tomato	4.27	7	PICTURE_214	1b-33	bedroom	5.00	6
PICTURE_479	1b-44	kangaroo	3.62	7	PICTURE_598	1b-4	dart board		8
PICTURE_439	1b-48	volcano	3.91	9	PICTURE_689	1b-42	fish tank		7
PICTURE_153	1b-49	cigarette	4.11	7	PICTURE_609	1c-16	pencil case		10
PICTURE_559	1b-51	cucumber	3.77	9	PICTURE_542	1c-18	fireplace	4.21	10
PICTURE_209	1b-52	boomerang	3.04	7	PICTURE_617	1c-27	airport	4.54	7
PICTURE_581	1b-57	asparagus	3.88	9	PICTURE_537	1c-3	fingerprint	3.21	11
PICTURE_181	1b-59	triangle	3.93	9	PICTURE_351	1c-34	butterfly	4.03	9
PICTURE_28	1b-6	microscope	3.56	11	PICTURE_425	1c-36	bagpipes	3.16	8
PICTURE_484	1b-60	squirrel	3.94	7	PICTURE_141	2a-1	sunflower	3.55	9

PICTURE_80	1b-9	helicopter	4.38	10	PICTURE_675	2a-14	windmill	3.51	7
PICTURE_154	1c-15	dominoes	3.11	8	PICTURE_95	2a-24	suitcase	3.78	7
PICTURE_659	1c-21	radio	4.82	7	PICTURE_589	2a-29	bedroom	5.00	6
PICTURE_407	1c-25	mountain	4.64	7	PICTURE_711	2a-33	lawnmower	3.11	8
PICTURE_477	1c-30	avocado	3.52	8	PICTURE_29	2a-43	cowboy	4.06	6
PICTURE_593	1c-32	chocolate	4.77	7	PICTURE_12	2a-47	mermaid	3.41	7
PICTURE_579	1c-39	elephant	4.34	7	PICTURE_734	2a-7	washing machine		10
PICTURE_196	1c-4	computer	4.64	9	PICTURE_160	2b-10	wheelbarrow	3.39	9
PICTURE_40	1c-57	clover	3.23	7	PICTURE_79	2b-42	keyboard	3.64	6
PICTURE_314	1c-7	perfume	3.94	7	PICTURE_202	2b-44	fishing rod		8
PICTURE_450	2a-12	magician	3.73	7	PICTURE_719	2b-48	bathroom	4.81	6
PICTURE_370	2a-13	scorpion	3.81	7	PICTURE_365	2b-5	hedgehog	3.72	7
PICTURE_509	2a-35	telephone	4.32	8	PICTURE_603	2b-57	graveyard	3.48	9
PICTURE_514	2a-52	submarine	3.77	8	PICTURE_193	2b-59	jellyfish	3.56	8
PICTURE_718	2b-15	trousers	4.24	8	PICTURE_242	2c-14	postman	4.02	8
PICTURE_85	2c-1	diamond	4.39	8	PICTURE_101	2c-19	drum kit		7
PICTURE_20	2c-20	skeleton	3.78	8	PICTURE_106	2c-2	greenhouse	3.76	8
PICTURE_699	2c-25	telescope	3.98	9	PICTURE_381	2c-31	strawberry	3.99	8
PICTURE_208	2c-36	microphone	3.80	10	PICTURE_560	2c-38	watermelon	3.13	10
PICTURE_588	2c-47	bracelet	3.79	8	PICTURE_250	2c-51	chainsaw	3.21	7
PICTURE_108	2c-60	calendar	1.39	8	PICTURE_729	2c-55	statue of liberty		15
PICTURE_387	2c-8	stapler	2.58	8	PICTURE_743	2c-6	scarecrow	3.35	9

Appendix C

Results of BwA1

Error Types and Language Mixing Errors in BwA1

Table C1

Error Types in Compounds in Dutch (L1) and German (L2) of BwA1

	Dutch (L1) (n = 44/61).		German (L2) (n = 36/59)	
Error type	Number of errors	% of errors	Number of errors	% of errors
Phonological error	1	2.27	3	8.33
Phonological error non-target language	3	6.82	--	--
Phonologically unrelated non-word	--	--	1	2.78
Semantic error	6	13.64	1	2.78
Semantic error non-target language	2	4.55	1	2.78
Semantically unrelated error	1	2.27	--	--
Constituent error	1	2.27	4	11.11
Constituent error non-target language	1	2.27	--	--
Single word circumlocution	1	2.27	1	2.78
Single word circumlocution non-target language	1	2.27	--	--
Multiword circumlocution	--	--	1	2.78
Acceptable semantic alternative	1	2.27	2	5.56
Use-of-language error	1	2.27	--	--
Other error	1	2.27	3	8.33

No response	16	36.36	9	25.00
Correct in non-target language	5	11.36	3	8.33
Language mixing error I	3	6.82	6	16.67
Language mixing error II: Back-translation error	--	--	1	2.78

Correlation Matrix Outcome and Logistic Regression Outcome for BwA1 in Dutch (L1)

Table C2

Binomial Logistic Regression BwA1 Dutch (L1) – Model Fit Measures, Predictive Measures

Model Fit Measures									
						Overall Model Test			Predictive measures –
Model	Deviance	AIC	BIC	R^2_{CS}	R^2_N	χ^2	df	p	Accuracy[a]
1	32.1	36.1	39.8	0.000127	0.000260	0.00608	1	0.938	0.896

[a] The cut-off value is set to 0.5.

Table C3

Binomial Logistic Regression BwA1 Dutch (L1) – Model Coefficients, Collinearity Statistics, Omnibus Likelihood Radio Tests

Model Coefficients - Accuracy								Collinearity Statistics		Omnibus Likelihood Ratio Tests		
						95% CI						
Predictor	Estimate	SE	Z	p	OR	Lower	Upper	VIF	T	χ^2	df	p
Intercept	-2.05	1.37201	-1.4947	0.135	0.129	0.00874	1.89					
Resemblance	-7.61e−4	0.00976	-0.0780	0.938	0.999	0.98031	1.02	1.00	1.00	0.00608	1	0.938

Note. Resemblance = Phonological similarity, CI = Confidence Interval, OR = Odds ratio, T = Tolerance.

Correlation Matrix Outcome and Logistic Regression Outcome for BwA1 in German (L2)

Table C4

Binomial Logistic Regression BwA1 German (L2) – Model Fit Measures, Predictive Measures

Model Fit Measures									
						Overall Model Test			Predictive measures –
Model	Deviance	AIC	BIC	R^2_{CS}	R^2_N	χ^2	df	p	Accuracy[a]
1	28.2	32.2	35.8	0.144	0.262	6.84	1	0.009	0.864

[a] The cut-off value is set to 0.5.

Table C5

Binomial Logistic Regression BwA1 German (L2) – Model Coefficients, Collinearity Statistics, Omnibus Likelihood Radio Tests

Model Coefficients - Accuracy								Collinearity Statistics		Omnibus Likelihood Ratio Tests		
						95% CI						
Predictor	Estimate	SE	Z	p	OR	Lower	Upper	VIF	T	χ^2	df	p
Intercept	-6.3663	2.3809	-2.67	0.007	0.00172	1.62e-5	0.183					
Resemblance	0.0290	0.0135	2.15	0.031	1.02944	1.00	1.057	1.00	1.00	6.84	1	0.009

Note. Resemblance = Phonological similarity, CI = Confidence Interval, OR = Odds ratio, T = Tolerance.

Appendix D

Results of BwA2

Error Types and Language Mixing Errors in BwA2

Table D1

Error Types in Compounds in Polish (L1) and German (L2) of BwA2

	Polish (L1) (n = 20/39).		German (L2) (n = 64/76)	
Error type	Number of errors	% of errors	Number of errors	% of errors
Phonological error	--	--	6	9.38
Phonologically unrelated non-word	--	--	1	1.56
Semantic error	6	30	8	12.5
Semantic-than-phonological error	--	--	2	3.13
Morphological error	--	--	2	3.13
Constituent error	7	35	16	25
Constituent error non-target language	1	5	--	--
Multiword circumlocution	--	--	3	4.69
Single word circumlocution	--	--	2	3.13
Visual error	--	--	3	4.69
Acceptable semantic alternative	4	20	5	7.81
Other error	--	--	1	1.56
No response	2	10	11	17.19
Correct in non-target language	--	--	4	6.25

Appendix E

Results of BwA3

Error Types and Language Mixing Errors in BwA3

Table E1

Error Types in Compounds in Dutch (L1) and German (L2) of BwA3

	Dutch (L1) (n = 23/61)		German (L2) (n = 29/59)	
Error type	Number of errors	% of errors	Number of errors	% of errors
Phonological error	1	3.23	9	31.03
Phonological error non-target language	1	3.23	--	--
Semantic error	5	16.13	2	6.90
Semantic error non-target language	3	9.68	1	3.45
Constituent error	4	12.90	5	17.24
Multiword circumlocution	1	3.23	2	6.90
Single word circumlocution	1	3.23	--	--
Visual error	3	9.68	1	3.45
Acceptable semantic alternative	3	9.68	2	6.90
Other error	1	3.23	1	3.45
No response	2	6.45	2	6.90
Correct in non-target language	4	12.90	--	--
Language mixing error I	3	9.68	4	13.79
Language mixing error II: Back-translation error	2	6.45	--	--

Correlation Matrix Outcome and Logistic Regression Outcome for BwA3 in Dutch (L1)

Table E2

Binomial Logistic Regression BwA3 Dutch (L1) – Model Fit Measures, Predictive Measures

Model Fit Measures									
						Overall Model Test			Predictive measures –
Model	Deviance	AIC	BIC	R^2_{CS}	R^2_N	χ^2	df	p	Accuracy[a]
1	39.5	43.5	47.3	0.000235	0.000412	0.0110	1	0.916	0.851

[a] The cut-off value is set to 0.5.

Table E3

Binomial Logistic Regression BwA3 Dutch (L1) – Model Coefficients, Collinearity Statistics, Omnibus Likelihood Radio Tests

Model Coefficients - Accuracy								Collinearity Statistics		Omnibus Likelihood Ratio Tests		
						95% CI						
Predictor	Estimate	SE	Z	p	OR	Lower	Upper	VIF	T	χ^2	df	p
Intercept	-1.62	1.20253	-1.350	0.177	0.197	0.0187	2.08					
Resemblance	-8.92e–4	0.00848	-0.105	0.916	0.999	0.9826	1.02	1.00	1.00	0.0110	1	0.916

Note. Resemblance = Phonological similarity, CI = Confidence Interval, OR = Odds ratio, T = Tolerance.

Correlation Matrix Outcome and Logistic Regression Outcome for BwA3 in German (L2)

Table E4

Binomial Logistic Regression BwA3 German (L2) – Model Fit Measures, Predictive Measures

Model Fit Measures									
						Overall Model Test			Predictive measures –
Model	Deviance	AIC	BIC	R^2_{CS}	R^2_N	χ^2	df	p	Accuracy[a]
1	21.9	25.9	29.4	0.00102	0.00261	0.0450	1	0.832	0.932

[a] The cut-off value is set to 0.5.

Table E5

Binomial Logistic Regression BwA3 German (L2) – Model Coefficients, Collinearity Statistics, Omnibus Likelihood Radio Tests

Model Coefficients - Accuracy								Collinearity Statistics		Omnibus Likelihood Ratio Tests		
						95% CI						
Predictor	Estimate	SE	Z	p	OR	Lower	Upper	VIF	T	χ^2	df	p
Intercept	-2.97310	1.8257	-1.628	0.103	0.0511	0.00143	1.83					
Resemblance	0.00262	0.0124	0.212	0.832	1.0026	0.97858	1.03	1.00	1.00	0.0450	1	0.832

Note. Resemblance = Phonological similarity, CI = Confidence Interval, OR = Odds ratio, T = Tolerance.

Appendix F

Results of BwA4

Error Types and Language Mixing Errors in BwA4

Table F1

Error Types in Compounds in English (L1) and German (L2) of BwA4

	English (L1) (n = 17/38)		German (L2) (n = 33/55)	
Error type	Number of errors	% of errors	Number of errors	% of errors
Phonological error	--	--	3	9.09
Phonological error non-target language	--	--	1	3.03
Phonologically unrelated non-word	--	--	1	3.03
Semantic error	5	29.41	2	6.06
Semantically unrelated error non-target language	--	--	1	3.03
Semantic-than-phonological error	--	--	1	3.03
Morphological error	1	5.88	1	3.03
Constituent error	1	5.88	5	15.15
Visual error	1	5.88	--	--
Acceptable semantic alternative	4	23.53	3	9.09
Use-of-language error non-target language	--	--	2	6.06
Other error	1	5.88	1	3.03
No response	4	23.53	5	15.15
Correct in non-target language	--	--	5	15.15

Language mixing error II: Back-translation error	--	--	2	6.06

Correlation Matrix Outcome and Logistic Regression Outcome for BwA4 in German (L2)

Table F2

Binomial Logistic Regression BwA4 German (L2) – Model Fit Measures, Predictive Measures

Model Fit Measures									
						Overall Model Test			Predictive measures –
Model	Deviance	AIC	BIC	R^2_{CS}	R^2_N	χ^2	df	p	Accuracy[a]
1	15.3	19.3	22.6	0.00925	0.0274	0.353	1	0.552	0.947

[a] The cut-off value is set to 0.5.

Table F3

Binomial Logistic Regression BwA4 German (L2) – Model Coefficients, Collinearity Statistics, Omnibus Likelihood Radio Tests

Model Coefficients - Accuracy								Collinearity Statistics		Omnibus Likelihood Ratio Tests		
						95% CI						
Predictor	Estimate	SE	Z	p	OR	Lower	Upper	VIF	T	χ^2	df	p
Intercept	-1.8142	1.9211	-0.944	0.345	0.163	0.00377	7.04					
Resemblance	-0.0114	0.0204	-0.558	0.577	0.989	0.95000	1.03	1.00	1.00	0.353	1	0.552

Note. Resemblance = Phonological similarity, CI = Confidence Interval, OR = Odds ratio, T = Tolerance.

Appendix G

Results of BwA5

Error Types and Language Mixing Errors in BwA5

Table G1

Error Types in Compounds in English (L1) and Italian (L1) of BwA5

	English (L1) (n = 38/40)		Italian (L1) (n = 22/22)	
Error type	Number of errors	% of errors	Number of errors	% of errors
Semantic error	7	18.42	--	--
Semantic error non-target language	--	--	2	9.09
Semantically unrelated error	--	--	1	4.55
Constituent error	3	7.89	--	--
Constituent error non-target language	--	--	2	9.09
Multiword circumlocution	3	7.89	--	--
Single word circumlocution	1	2.63	--	--
Acceptable semantic alternative	1	2.63	--	--
Other error	10	26.32	--	--
Other error non-target language	--	--	5	22.73
No response	13	34.21	9	40.91
Correct in non-target language	--	--	3	13.64

Appendix H

Results of BwA6

Error Types and Language Mixing Errors in BwA6

Table H1

Error Types in Compounds in English (L1) and French (L2) of BwA6

	English (L1) (n = 10/43)		French (L2) (n = 12/17)	
Error type	Number of errors	% of errors	Number of errors	% of errors
Semantic error	1	10.00	2	16.67
Semantic error non-target language	--	--	1	8.33
Morphological error non-target language	--	--	1	8.33
Constituent error	5	50.00	3	25.00
Constituent error non-target language	--	--	1	8.33
Multiword circumlocution	--	--	1	8.33
Acceptable semantic alternative	3	30.00	--	--
No response	1	10.00	2	16.67
Correct in non-target language	--	--	1	8.33

Correlation Matrix Outcome and Logistic Regression Outcome for BwA6 in French (L2)

Table H2

Binomial Logistic Regression BwA6 French (L2) – Model Fit Measures, Predictive Measures

Model Fit Measures									
						Overall Model Test			Predictive measures –
Model	Deviance	AIC	BIC	R^2_{CS}	R^2_N	χ^2	df	p	Accuracy[a]
1	11.7	15.7	17.2	0.0228	0.0431	0.369	1	0.543	0.875

[a] The cut-off value is set to 0.5.

Table H3

Binomial Logistic Regression BwA6 French (L2) – Model Coefficients, Collinearity Statistics, Omnibus Likelihood Radio Tests

Model Coefficients - Accuracy								Collinearity Statistics		Omnibus Likelihood Ratio Tests		
						95% CI						
Predictor	Estimate	SE	Z	p	OR	Lower	Upper	VIF	T	χ^2	df	p
Intercept	-1.0553	1.7450	-0.605	0.545	0.348	0.0114	10.64					
Resemblance	-0.0104	0.0204	-0.512	0.608	0.990	0.9509	1.03	1.00	1.00	0.369	1	0.543

Note. Resemblance = Phonological similarity, CI = Confidence Interval, OR = Odds ratio, T = Tolerance.

Appendix I

Results of BwA7

Error Types and Language Mixing Errors in BwA7

Table I1

Error Types in Compounds in French (L1) and English (L2) of BwA7

	French (L1) (n = 8/17)		English (L2) (n = 21/43)	
Error type	Number of errors	% of errors	Number of errors	% of errors
Semantic error	1	12.50	1	4.76
Morphological error	--	--	1	4.76
Constituent error	1	12.50	5	23.81
Multiword circumlocution	--	--	1	4.76
Visual error	--	--	1	4.76
Acceptable semantic alternative	1	12.50	3	14.29
Other error	2	25.00	2	9.52
No response	1	12.50	6	28.57
Correct in non-target language	2	25.00	1	4.76

Correlation Matrix Outcome and Logistic Regression Outcome for BwA7 in French (L1)

Table I2

Binomial Logistic Regression BwA7 French (L1) – Model Fit Measures, Predictive Measures

Model Fit Measures									
						Overall Model Test			Predictive measures –
Model	Deviance	AIC	BIC	R^2_{CS}	R^2_N	χ^2	df	p	Accuracy[a]
1	11.8	15.8	17.4	0.0143	0.0270	0.231	1	0.631	0.875

[a] The cut-off value is set to 0.5.

Table I3

Binomial Logistic Regression BwA7 French (L1) – Model Coefficients, Collinearity Statistics, Omnibus Likelihood Radio Tests

Model Coefficients - Accuracy								Collinearity Statistics		Omnibus Likelihood Ratio Tests		
						95% CI						
Predictor	Estimate	SE	Z	p	OR	Lower	Upper	VIF	T	χ^2	df	p
Intercept	-1.27363	1.6597	-0.767	0.443	0.280	0.0108	7.24					
Resemblance	-0.00760	0.0181	-0.419	0.675	0.992	0.9578	1.03	1.00	1.00	0.231	1	0.631

Note. Resemblance = Phonological similarity, CI = Confidence Interval, OR = Odds ratio, T = Tolerance.

Appendix J

Results of BwA8

Error Types and Language Mixing Errors in BwA8

Table J1

Error Types in Compounds in French (L1) and English (L2) of BwA8

	French (L1) (n = 11/17)		English (L2) (n = 11/43)	
Error type	Number of errors	% of errors	Number of errors	% of errors
Semantic error	1	9.09	1	9.09
Constituent error	2	18.18	3	27.27
Acceptable semantic alternative	2	18.18	5	45.45
Other error	1	9.09	0	0.00
No response	4	36.36	2	18.18
Correct in non-target language	1	9.09	0	0.00

Correlation Matrix Outcome and Logistic Regression Outcome for BwA8 in French (L1)

Table J2

Binomial Logistic Regression BwA8 French (L1) – Model Fit Measures, Predictive Measures

Model Fit Measures									
						Overall Model Test			Predictive measures –
Model	Deviance	AIC	BIC	R^2_{CS}	R^2_N	χ^2	df	p	Accuracy[a]
1	7.28	11.3	12.7	0.00470	0.0121	0.0707	1	0.790	0.933

[a] The cut-off value is set to 0.5.

Table J3

Binomial Logistic Regression BwA8 French (L1) – Model Coefficients, Collinearity Statistics, Omnibus Likelihood Radio Tests

Model Coefficients - Accuracy								Collinearity Statistics		Omnibus Likelihood Ratio Tests		
						95% CI						
Predictor	Estimate	SE	Z	p	OR	Lower	Upper	VIF	T	χ^2	df	p
Intercept	-2.16056	2.1201	-1.019	0.308	0.115	0.00181	7.35					
Resemblance	-0.00525	0.0218	-0.240	0.810	0.995	0.95308	1.04	1.00	1.00	0.0707	1	0.790

Note. Resemblance = Phonological similarity, CI = Confidence Interval, OR = Odds ratio, T = Tolerance.

Appendix K

Detailed Naming Accuracy Data in Compound Words in all Bilingual Speakers with Aphasia

Table K1

Detailed Naming Accuracy Data in Compound Words in all Bilingual Speakers with Aphasia

			Accuracy															
															L1: Simple words vs compounds		L2: Simple words vs compounds	
			All items				Simple words				Compounds				All simple words	Matched list[f]	All simple words	Matched list[f]
ID	Languages		N items	N total correct	% correct	L1 vs L2 p (2-tailed)[c]	N items	N total correct	% correct	L1 vs L2 p (2-tailed)[c]	N items	N total correct	% correct	L1 vs L2 p (2-tailed)[e]	Fisher's Exact Test, 2-tailed		Fisher's Exact Test, 2-tailed	
BwA1	L1	NL	347	142	40.92	**p<.001***	286	125	43.71	**p<.001***	61	17	27.87	p=.274	**p=.033***	p=.252	**p=.001***	p=1
	L2	GE[b]	347	203	58.50		288	180	62.5		59	23	38.98					
BwA2	L1	PL[b]	422	285	67.54	**p<.001***	383	266	69.63	**p<.001***	39	19	48.72	**p<.001***	**p=.014***	p=.479	**p<.001***	**p<.001***
	L2	GE[b]	422	168	39.81		346	156	45.09		76	12	15.79					
BwA3	L1	NL	347	186	53.60	**p=.041***	286	159	55.59	p=.131	61	27	44.26	p=.591	p=.142	p=.797	p=.142	p=.604
	L2	GE[b]	347	209	60.23		288	179	62.15		59	30	50.85					
BwA4	L1	EN[b]	331	265	80.06	**p<.001***	293	244	83.28	**p<.001***	38	21	55.26	p=.218	**p<.001***	**p=.025***	**p=.003***	p=.438
	L2	GE	331	195	58.91		276	173	62.68		55	22	40.00					
BwA5[a]	L1	EN[b]	356	72	20.22	**p<.001*[d]**	316	70	22.15	**p<.001***	40	2	5	p=.535	**p=.020***	p=.432	p=1	p=1
	L1	IT	356	0	0		334	0	0		22	0	0					
BwA6	L1	EN[b]	365	314	86.03	**p<.001***	322	281	87.27	**p<.001***	43	33	76.74	**p=.001***	p=.102	**p=.030***	p=.101	p=1
	L2	FR	365	189	51.78		348	184	52.87		17	5	29.41					
BwA7	L1	FR	365	254	69.59	p=.409	348	245	70.40	p=.268	17	9	52. 94	p=1	p=.209	p=.728	**p=.03***	**p=.007***
	L2	EN[b]	365	262	71.78		322	240	74.53		43	22	51.16					
BwA8	L1	FR	365	240	65.75	**p<.001***	348	234	67.24	**p<.001***	17	6	35.29	**p=.007***	**p=.014***	p=1	p=.411	p=1
	L2	EN[b]	365	293	80.27		322	261	81.06		43	32	74.42					

Note. ID = Participant, NL = Dutch, GE = German, PL = Polish, EN = English, IT = Italian, FR = French. Bold represents significant results.

[a] = Early parallel bilingual speaker, both languages (English and Italian) are L1.

[b] = Dominant language.

[c] = McNemar’s Test, two-tailed.

[d] = BwA5 experienced severe naming difficulties in Italian with naming accuracy of 0% (0/356). One single Italian error response was transferred to correct to obtain an estimated p-value (McNemar’s Test) of naming accuracy across languages.

[e] = Fisher’s Exact Test, two-tailed.

[f] = See method section ’Data analysis’ for matching lists (lists of compound words and simple words that were matched for word lengths [number of phonemes] and spoken word form frequency).

Chapter 5:

General Discussion

The empirical papers presented in this thesis addressed two main questions:

(1) Can spoken word retrieval be influenced differently or similarly across languages within a speaker with aphasia?

(2) To what extend do similar-sounding words influence each other within and across language(s) in speakers with aphasia?

Three studies investigated spoken word production within and across languages in bilingual speakers with aphasia each focusing on slightly different aspects of bilingual word retrieval including speaker- and language-specific factors that may influence the word finding process. A summary of the results is presented below, together with other relevant literature. Findings are then discussed within the current speech production models that were introduced at the start of this thesis (see Dell et al, 2007; Levelt et al., 1999; Dijkstra et al., 2019, Green, 1986; 1998).

What Factors Influence Bilingual Word Retrieval Within and Across Languages Within a Speaker with Aphasia?

We investigated speaker-specific and language-specific factors that might influence a bilingual speaker's word finding process. While each language might present with different word frequencies, word lengths, and age-of-acquisition values (to name just a few) to express the same concepts, each bilingual speaker with aphasia presents unique differences including pre-onset factors such as the age of language acquisition, language proficiency and language dominance, and post-onset factors such as functional language breakdown, recovery patterns, language use and language context. Hence, Chapter 2 (paper 1) addressed these factors to understand whether a bilingual speaker with aphasia can show the same or different accuracy and error patterns across languages within one speaker. Chapter 3 (paper 2) expanded these factors to variables that are not commonly controlled and assessed for in *either* mono- or bilingual speakers with aphasia: these were phonological neighbourhood density and phonological neighbourhood frequency within *and* across languages. The specific aim of this second study was to clarify whether having more phonological similar sounding words to the target (within) but also to the non-target word (across) helps or hinders lexical access.

While most literature stems from the unimpaired bilingual population when investigating phonological neighbourhood density (Hameau et al, 2021a), literature on bilingual aphasia is scarce. Overall, the effects of phonological density and frequency on spoken word findings provide an inconsistent evidence base (e.g., Hameau et al., 2021b; Sadat et al., 2016). Hence, paper 2 added a novel approach by calculating a phonological similarity score across target and non-target translations. The critical measure was simply accuracy. While Chapter 3 (paper 2) expanded the list of lexical variables controlled for compared to Chapter 2 (paper 1), Chapter 4 (paper 3) tried to focus on a special subset of items: ‘compound words’. By comparing simple words with compound words and analysing accuracy and error patterns, three unique error types emerged for compound words: (i) substitution errors concerning the first constituent of the target compound, (ii) substitution errors concerning the second constituent of the target compound and (iii) literal translation errors.

All papers describe the same methodological approach: spoken picture naming within and across languages. Overall, materials consisted of six picture and word sets (n > of 300), that were developed for six languages: English, French, German, Dutch, Polish and Italian. Each language set was controlled for several linguistic variables. All three studies included the same eight bilingual participants with aphasia. Only Chapter 3 (paper 2) included an additional ten monolingual speakers (five English and five German speakers) to be able to compare our findings on monolingual phonological neighbourhood effects to findings in the literature (e.g., Gordon, 2002). However, the monolinguals also served as a control for the within-language analyses for the bilingual German-English speakers.

Interestingly, every study showed accuracy and error patterns that were influenced by language dominance. This was a finding we did not predict. Below, each chapter is summarised in more detail, followed by an overall summary of the results related to current language models. Furthermore, limitations and potential future directions will be given, including implications for the assessment and treatment of bilingual aphasia.

Chapter 2 (Paper 1): Accuracy and Error Pattern in Spoken Picture Naming Across Languages in Bilingual Speakers with Aphasia

This study consisted of an experimental spoken picture naming task using a case-series design to investigate accuracy patterns, error patterns, and error types across languages in bilingual speakers with aphasia. We considered the following factors when analysing naming responses: (i) the bilingual language profile (e.g., language age of acquisition, proficiency per language, dominance, language use and context, the linguistic similarity of language combination spoken for each participant), and (ii) a set of lexical variables with specific manifestation for each language spoken (e.g., word frequency, word age of acquisition, word length, imageability, familiarity etc).

Eight bilingual speakers (all classified as late bilinguals, except for one who was classified as early) with aphasia who spoke different language combinations (Dutch-German, Polish-German, English-German, English-Italian, English-French, French-English) were included. All speakers presented with spoken word finding difficulties. Items for the experimental picture naming task were taken from MultiPic (Duñabeitia et al., 2017) and each picture stimulus had a name agreement of at least 80%. Depending on the language, item lists consisted of approximately 300 to 400 pictures. Linguistic variables were collected for each item in each language. Participants named these items in each of their languages. Testing sessions were counterbalanced over at least four sessions. Responses were coded for accuracy and error type and analysed within and between languages for each participant. A regression analysis was carried out to analyse the influence of linguistic variables on accuracy. The distribution of error types between languages for each participant was calculated by comparing the proportion of a specific error type to the overall error types between languages.

Six participants displayed a significant difference in their naming accuracy across languages; most interestingly, higher naming accuracy was usually observed in their dominant language, regardless of whether the dominant language was their L1 or L2. Only one participant did not show a significant difference in naming accuracy across languages, which may be explained by the speaker's 'balanced bilingual status'. The only linguistic variables influencing naming accuracy significantly were word length, item age of acquisition, and imageability (direction: the shorter the word, the earlier acquired the word and the higher imageability, accuracy increased). Analyses for the non-target language errors resulted in significantly more non-target language naming errors for the non-dominant language in six participants, regardless of whether the non-dominant language was the participant's first language or second language. The error type analysis showed significant differences in error type distribution across languages for seven participants.

Language dominance emerged as a key factor for accuracy patterns, error patterns, and error types for the target language responses. Furthermore, error pattern and error type analyses provided evidence to support the processing principles of non-selective activation of available languages and related inhibition processes that control the target language output in bilingual speakers (e.g., Green, 1998) affecting word production. Furthermore, the importance of developing a comprehensive understanding of the individual language impairment and related symptoms in each language was supported by our findings since the analysis revealed *different* distributions of error types across languages for seven participants.

The findings on semantic errors across the participants, which were often distributed similarly across languages, might suggest that semantic representations are the same/similar across languages within a bilingual language system. Findings on other error types caused interestingly different error patterns across languages (e.g., phonological errors for example did not show a clear and consistent pattern occurs across participants; some participants displayed significantly more phonological errors in their L2, others did not experience a difference in phonological errors across their available languages). These findings illustrate the importance of a fine-tuned assessment of the functional breakdown in both languages and potentially a different treatment focus in each language in the latter event when the error pattern looks different across the language spoken.

Chapter 3 (Paper 2): Spoken Picture Naming Accuracy in Monolingual and Bilingual Speakers with Aphasia: Influence of Phonological Neighbourhood Within and Across Languages

This study investigated the influence of similar-sounding words (phonological neighbours) on accuracy in monolinguals and bilingual speakers with aphasia. As in paper 1, a spoken picture-naming task was carried out, using the same items across the languages spoken. The same eight bilingual speakers from Chapter 2, who presented with different language combinations (Dutch-German, Polish-German, English-German, English-Italian, French-English) and all showed word finding difficulties were included in Chapter 3. In addition, ten monolingual speakers with aphasia (five German speaking, five English speaking) were recruited, who served as controls for the within-language effects for the German-English bilingual speakers, whose responses were also analysed for within-language neighbourhood effects. It also enabled us to understand whether monolingual phonological neighbourhood density effects could be replicated that were reported in the monolingual aphasia literature (e.g., Gordon, 2002). Materials used were the same as for Chapter 2 (Paper 1) with the exception that each item was now also controlled for its phonological neighbourhood density and neighbourhood frequency (see below). For all included items phonological neighbourhood variables were collected via CLEARPOND (Marian et al., 2012), including within-language phonological neighbours for the monolingual and bilingual and additionally across-language phonological neighbours for only the bilingual speakers with aphasia. Responses were coded for accuracy. In addition, a phonological similarity score was calculated between the target word and non-target language translation equivalent word.

A regression analysis was carried out to analyse the influence of within and across phonological neighbours on accuracy.

For the ten monolingual speakers with aphasia, nine participants showed no effects of phonological neighbourhood density and frequency within language on accuracy, and only one participant showed increased accuracy when phonological neighbourhood density and frequency were high. For the eight bilingual speakers with aphasia, five participants showed increased picture naming accuracy when targets had a higher phonological neighbourhood frequency/phonological similarity in the within-language analyses. The effect was only evident in the participants' non-dominant/weaker language for five participants. For the across-language analyses, only minimal non-significant effects were observed: Only one participant showed an increased accuracy when the phonological similarity between languages was high, again this was observed for the non-dominant language. This finding stands in contrast to Chapter 2 (paper 1) where accuracy was usually higher for the dominant language of a speaker, however, the effects of the phonological neighbourhood seem subtle, so are best picked up in the weaker or non-dominant language. The findings help us to better understand the bilingual language network: Bilingual speakers seem to benefit from the activation of phonological neighbours *within* their languages when speaking in the non-dominant/weaker language. As such, there is a compelling rationale for considering these factors when enhancing picture naming accuracy and diagnosing and treating bilingual speakers with aphasia in speech pathology. Materials for assessment and/or treatment in the bilingual speakers' non-dominant/weaker language can therefore be carefully chosen, (e.g., controlling for phonological neighbourhood features that may facilitate naming accuracy within a language).

Additionally, given that across-phonological neighbourhood showed hardly an effect in our study (only one participant benefitted in our study), it is probably unnecessary to control for this variable when considering treatment transfer effects. Our study also gives inspiration for future studies, whether the target language is only activated at this late stage since across-language neighbourhood effects seem almost absent.

Chapter 4 (Paper 3): Accuracy Pattern and Language Mixing Errors in Compound Word Picture Naming in Bilingual Speakers with Aphasia

In Chapter 4, the third study of this thesis was presented. The study investigated compound picture naming in bilingual speakers with aphasia, including accuracy analysis across languages and within languages. Analyses contrasted compound word accuracy versus simple word accuracy, including a language mixing error analysis. As for studies 1 and 2, speaker-specific factors and language-specific variables were considered.

The same spoken picture naming task as for study 1 and study 2 was conducted including the same eight bilingual speakers with aphasia. From the item sets presented to participants in study 1 and 2, a subset of compound words and simple words was extracted; these lists contained between 17 to 76 compound words per language (matched to a subset of simple words controlled for frequency and word length). For each compound item, values for word length, spoken word form frequency, and their phonological similarity were collected. Participants named the subsets in each of their available languages, counterbalanced over at least four sessions. Responses were coded for accuracy and error type. Compound naming accuracy across languages was investigated and compared to accuracy in simple word naming within languages for each participant. In addition, language mixing errors in compound words were explored. A regression analysis was conducted to examine the influence of phonological similarity between the target and the non-target translation word on the occurrence of language mixing errors.

Naming accuracy analyses revealed three observed main error types: A difference in compound naming across languages with higher accuracy in the dominant language for six participants, regardless of whether the dominant language was the L1 or L2. Accuracy within-language analysis presented higher accuracy in simple words than in compound words. The language mixing error analyses indicated six participants with mixing errors in either both or one of their languages spoken. These mixing errors across participants consistently manifested in their non-dominant language, regardless of whether the non-dominant language was their L1 or L2. Phonological similarity had an effect on the occurrence of language mixing errors in only one participant. Overall, three main error types which could be categorised under ‘language mixing errors’ could be identified for compound words: (i) substitution errors concerning the first constituent of the target compound, (ii) substitution errors concerning the second constituent of the target compound, and (iii) literal translation errors. Given that not enough language mixing errors were made per participant, these error-type patterns remain of descriptive nature at this stage.

To sum up, the main findings for paper 3, language dominance influenced compound naming accuracy and the occurrence of language mixing errors, highlighting the importance of considering a bilingual speaker’s language profile in (compound) word processing in aphasia. The investigation of language mixing errors has given further insight into the organisation of the bilingual language system and its underlying mechanisms: The project’s findings may give an indication for non-selective activation (Green, 1998; 1989) of both languages in bilingual speakers during lexical processing since the first two error types (substitution of the first or second constituent) indicates a partly impaired inhibition process that is not able to suppress the non-target language.

Overall, all three studies contributed to a comprehensive error coding categorisation guide (see General Appendix F) that includes guidelines on how to define and code language mixing errors in simple and compound words in bilingual speakers with aphasia. This bilingual error coding system can hopefully be of use in future research into bilingual aphasia. The developed materials that span five language combinations will be made available as open-access resources so that they can be used as assessment tools in clinical practice by speech pathologists, that are looking for specific language combinations.

Overall Summary of Findings

The present thesis has demonstrated the complex nature of word processing and word production in bilingual speakers with aphasia. A comprehensive analysis of the included studies made it evident that accuracy patterns, error patterns, and error types can differ across languages in bilingual speakers with aphasia. Key factors that cause these different patterns across languages are the heterogenous bilingual language profiles, the level of breakdown each individual brings and the lexical variables that need to be considered for each language separately. Language dominance was observed to be a key factor in the spoken word retrieval process for people with bilingual aphasia for study 1 and 3. This accumulated evidence highlights the importance of acquiring a comprehensive understating of the language impairment across the languages in bilingual aphasia. In addition, study 3 was able to add some evidence in favour of non-selective language activation, indicating that both languages were active at least in some cases when a compound word was named. The different types of mixing errors observed pointed in the direction of an inhibitory control problem indicating the important role of inhibitory control mechanisms during bilingual word form access.

Even though our findings indicate a greater complexity for bilingual word processes compared to monolingual speakers with aphasia, it needs to be emphasised again that bilingual speakers do not merely process two languages within their bilingual language system (see Grosjean, 1989). As this thesis demonstrates across three studies, bilingual speakers with aphasia exhibit distinct language profiles that can vary to a great extent. As pointed out, it is not only the language combination that adds complexity, but factors such as language age of acquisition (whether someone is, for example, an early or late bilingual speaker), and language dominance.

How to Understand Findings in Existing Monolingual and Bilingual Word Processing Frameworks?

We drew from monolingual frameworks on word processing and word production (Dell et al., 2007; Levelt et al., 1999) as well as bilingual language frameworks (Dijkstra et al., 2019, Green, 1998) were utilised to explain and discuss each study's results.

The findings of study 1 can be best described within Green's model, explaining the same and different error patterns across languages (for example, the occurrence of non-target language errors such as semantic errors and phonological errors in the non-target language: e.g., target is 'desk', response is 'Stuhl' [German for 'chair'], or target is 'desk', response is 'Pisch' [German for desk (Tisch) with a phonological error]). According to Green (1998) a bilingual language network is characterised by parallel/non-selective activation of both languages/both lexical forms during word processing and this non-selective activation is accompanied by consistent inhibition processes to suppress the non-target language. However, in the context of a stroke, inhibition processes might be (partly) impaired, leading to non-target language responses across languages as we observed in Study 1.

The findings of study 2 showed an increase in picture naming accuracy with higher phonological neighbourhood frequency. However, this increase in accuracy was observed for the within-analysis of five participants. Only one participant showed a significant increase in accuracy for the across-analysis for phonological similarity. We interpreted the consistent increase in accuracy for the within-analysis as compatible with a bidirectional activation between phonemes and lemmas as outlined in Dell's Interaction Activation Model of spoken language production (Dell et al., 2007). Since we found an influence of the phonological neighbours on the target, parallel activation at the lemma and word form level is necessary to influence the target word retrieval. Since we found the strongest effect of neighbourhood influence in five speakers for their non-dominant languages, we speculate that the non-dominant language target (which was mostly the weaker language for the five speakers, who showed a facilitatory neighbourhood effect) can benefit more strongly from the activation of its phonological neighbour since it has more room to inherit activation. Since the processing pathways between the different lexical retrieval levels are more robust for the dominant language compared to those in the non-dominant language (less prone to be influenced by other lexical factors); a stronger influence of phonological neighbourhood can occur in the latter. In our case, neighbourhood influence manifested in higher accuracy when accessing a target word in their non-dominant language. Since the non-dominant language has less established lexical pathways, there is a higher need for more activation (help) to be selected as a target. This observation 'more benefit for the weaker language' was also mentioned by Ansaldo and Saidi (2014) in the context of cross-linguistic therapy effects.

In addition, we used the Two-Stage model (Levelt et al., 1999) and its monolingual assumption around compound word representation to interpret bilingual compound representations. While Levelt et al. (1999) assumes one lemma entry (with some exceptions to consider) and separate word form representations for a monolingual compound word, we used his framework to explain language mixing errors for bilingual speakers. However, this required a mechanism that can suppress and inhibit the non-target language. Language mixing errors (as we observed in study 3) are evidence that such a language control mechanism is needed but weakened in people with bilingual aphasia. We, therefore, combined Levelt et al.'s theory with Green's (1998) 'Inhibitory Control Model'. This model includes a mechanism that navigates the activation of both languages. Green called this 'parallel activation/non-selective activation' of available languages and proposed an associated inhibition process (by assigning a 'language tag') to suppress the non-target language within a bilingual language network. The notion of a weakened or impaired control mechanism is useful when trying to understand the error patterns and error types we observed in study 3.

As discussed above, language mixing errors that consist of a constituent from each available language (e.g., schlafroom: Language mixing error of Schlafzimmer [German word for bedroom] and bedroom), can only present when having separate entries at word form level within the mental lexicon. Due to inhibition control mechanisms that are (partly) impaired as a result of the stroke, these language mixing errors occur since the non-target language compound word is not successfully suppressed during the word production of a bilingual speaker with aphasia.

Lastly, the MULTILINK model (Dijkstra et al., 2019), which is characterized by its lexical network and associated bidirectional activation, served as a framework to understand and discuss the interplay and dynamic interaction of multiple languages within a bilingual language network. Within the phonological neighbourhood study (study 2), high phonological similarity across the target word and the non-target language equivalent word increased picture naming accuracy in five participants. The MULTILINK model (Dijkstra et al., 2019) offered an additional explanation for the increased accuracy of target words through the activation of semantic and phonological word forms of non-target language words since a key aspect of the MULTILINK model is bidirectional activation that operates between the different linguistic levels and *between available languages* during word processing. With the model's proposed bidirectional activation between languages in the bilingual language network, an explanation is given why the activation of semantic and phonological word forms from the non-target language can enhance the activation of the target word.

Despite the valuable contribution made by the current bilingual models, it is important to acknowledge their limitations as well. The current models are not yet able to fully capture the influence of additional bilingual factors on word processing and word production in bilingual speakers with aphasia, such as the influence of languages age of acquisition, or language dominance. Additionally, it needs to be noted, that these bilingual models are not tailored to outline the nuances of word processing and word production at specific levels within the bilingual mental lexicon, such as the storage and access of information at the lemma level and/or phonological word form level.

Hence, the above interpretation and combination of different models is merely an attempt to start a discussion between monolingual and bilingual language researchers as both disciplines can complement each other with different aspects of the word production processes.

Limitations and Potential Futural Directions

Lack of Diverse Language Combinations

This thesis included bilingual participants with aphasia with different language combinations: Dutch-German, Polish-German, English-German, English-Italian, and French-English. It is therefore important to note that all included participants only showcased Indo-Germanic language combinations (for an overview across all language families, see Fromkin et al., 2018). Consequently, the thesis did not address accuracy and error patterns across different scripts (e.g., English vs Mandarin). Hence, materials to assess bilingual aphasia for language within the Sino-Tibetan branch or Austronesian languages (e.g., Australian Indigenous languages) are still very scarce. Therefore, our findings cannot be generalised to speaker groups outside our five Indo-Germanic language combinations explored. We would like to reassure the reader that participants, who spoke languages outside the Indo-Germanic family branches were not deliberately excluded from this research; rather no potential participants presented to us during our recruitment process.

Hence, one of the urgent future research areas would entail designing picture and word materials that can capture accuracy patterns, error patterns and error types in bilingual speakers with aphasia outside the Indo-Germanic language families. This would be particularly relevant when considering the context of Australia, where Mandarin represents the second biggest language group after English (Australian Bureau of Statistics, 2017). Consequently, bilingual individuals with aphasia, who are Mandarin (L1) and English (L2) speakers are most likely to seek speech pathology services for age-related language impairments such as aphasia in the Australian context.

Uneven Distribution of Compound Words Within the Language Combinations Used

Within the scope of the third study, which focussed on compound word production in bilingual speakers with aphasia, there is a notable difference in the distribution of the number of compound words included across the different languages. Languages like English and German included a substantial number of compound words, while languages like Italian and French had a comparatively smaller pool of compound items available for testing in our set. In future research, it would be worthwhile to aim for a more balanced distribution of testing materials that include a matched number of compound words across languages. Replicating our findings with a larger pool of items would give valuable insight into the stability of the observed effects reported in study 3.

Furthermore, compound words can vary regarding their transparency, they can be semantically transparent (e.g., *bedroom)*, opaque (e.g., *hotdog*), or semi-transparent (e.g., *sunflower*) in meaning. It would be of interest to examine how accuracy and error patterns/error types manifest when transparency/opaqueness is also controlled for across languages.

Conclusions

The research in this thesis explored word production within and across languages in bilingual speakers with aphasia. Having considered several speaker-specific and language-specific factors, a small piece to the puzzle was added to the expansion of bilingual language theories.

Even a small advancement in bilingual theory can facilitate bilingual assessment and treatment planning. For example, understanding that the inhibitory control process may be weakened in bilingual aphasia (as was observed in study 3) or that phonological neighbours across languages have hardly any effect, while phonological neighbours within a language seem to have an influence on word retrieval in bilingual speakers, but only in their weaker language (study 2). Lastly, bilingual speakers with aphasia can show the same and different error patterns across languages (study 1), which informs our material design, assessment and treatment planning considering always all languages spoken by a person with aphasia.

This project made a small start by contributing a comprehensive picture and word material battery that controls for several lexical variables across five languages. In addition, all three studies contribute to an extensive error coding guide for bilingual word finding errors. Definitions for different error types across languages are provided which can help to streamline the bilingual error classification process. It is hoped that the developed picture and word materials together with the error code guide can serve future research projects that want to explore unimpaired and impaired bilingual word retrieval processes in more depth.

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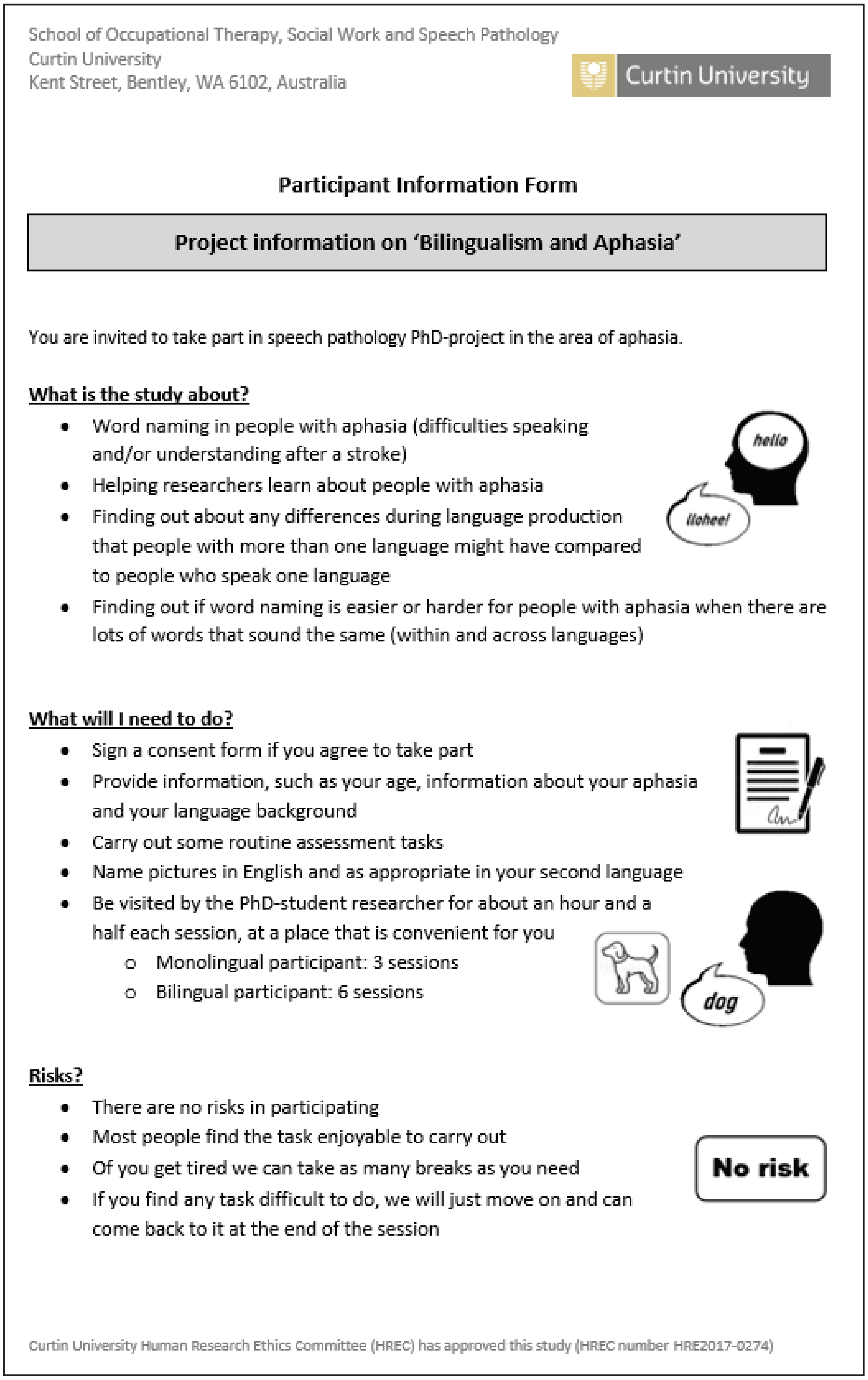
General Appendices

General Appendix A

Participant Information Form



School of Occupational Therapy, Social Work and Speech Pathology
Curtin University
Kent Street, Bentley, WA 6102, Australia

Curtin University

Participant Information Form

Project information on 'Bilingualism and Aphasia'

You are invited to take part in speech pathology PhD-project in the area of aphasia.

What is the study about?

- Word naming in people with aphasia (difficulties speaking and/or understanding after a stroke)
- Helping researchers learn about people with aphasia
- Finding out about any differences during language production that people with more than one language might have compared to people who speak one language
- Finding out if word naming is easier or harder for people with aphasia when there are lots of words that sound the same (within and across languages)

What will I need to do?

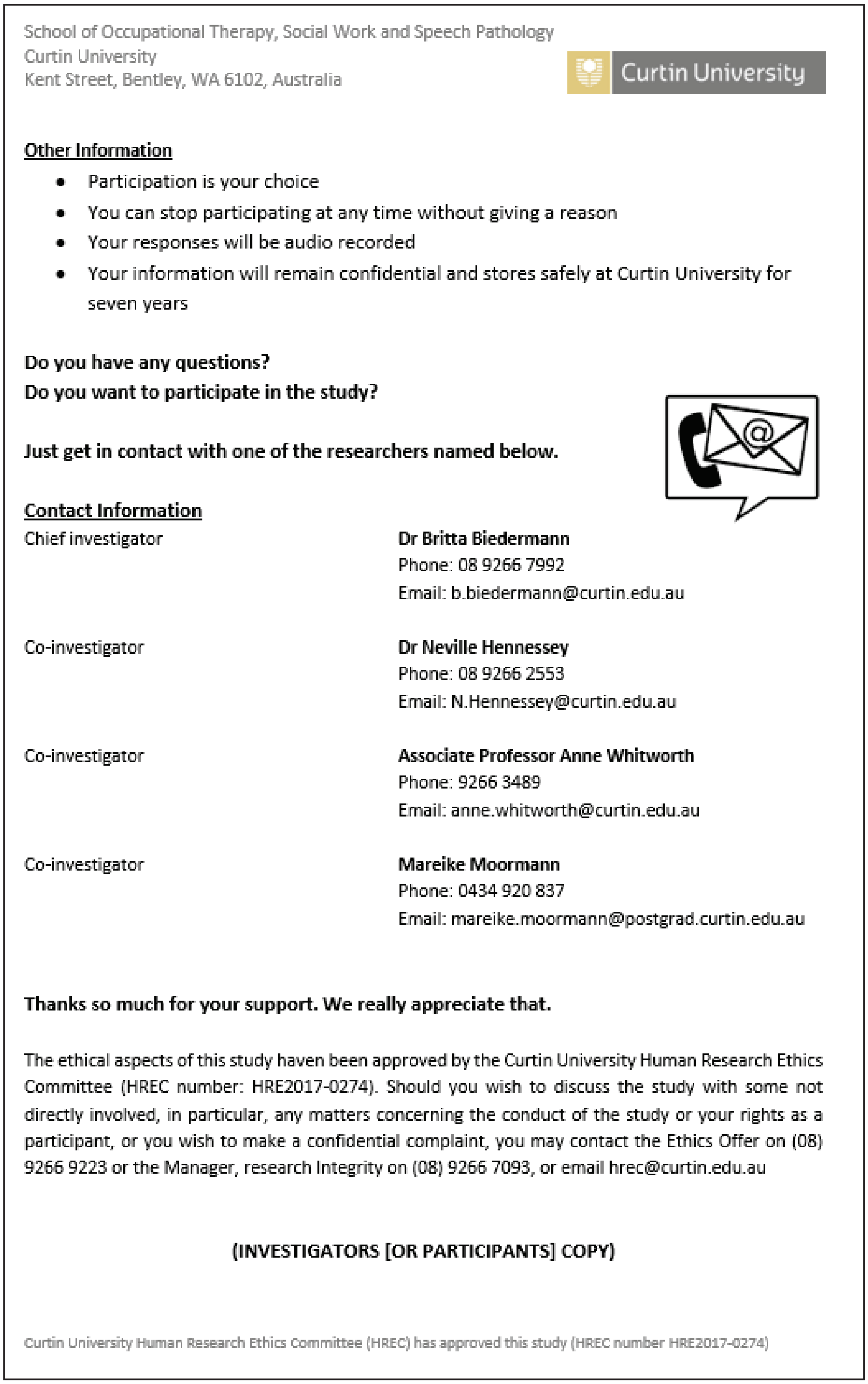
- Sign a consent form if you agree to take part
- Provide information, such as your age, information about your aphasia and your language background
- Carry out some routine assessment tasks
- Name pictures in English and as appropriate in your second language
- Be visited by the PhD-student researcher for about an hour and a half each session, at a place that is convenient for you
    - Monolingual participant: 3 sessions
    - Bilingual participant: 6 sessions

Risks?

- There are no risks in participating
- Most people find the task enjoyable to carry out
- Of you get tired we can take as many breaks as you need
- If you find any task difficult to do, we will just move on and can come back to it at the end of the session

No risk

Curtin University Human Research Ethics Committee (HREC) has approved this study (HREC number HRE2017-0274)



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Curtin University
Kent Street, Bentley, WA 6102, Australia

Curtin University

Other Information

- Participation is your choice
- You can stop participating at any time without giving a reason
- Your responses will be audio recorded
- Your information will remain confidential and stores safely at Curtin University for seven years

Do you have any questions?
Do you want to participate in the study?

Just get in contact with one of the researchers named below.

Contact Information

Chief investigator	**Dr Britta Biedermann** Phone: 08 9266 7992 Email: b.biedermann@curtin.edu.au
Co-investigator	**Dr Neville Hennessey** Phone: 08 9266 2553 Email: N.Hennessey@curtin.edu.au
Co-investigator	**Associate Professor Anne Whitworth** Phone: 9266 3489 Email: anne.whitworth@curtin.edu.au
Co-investigator	**Mareike Moormann** Phone: 0434 920 837 Email: mareike.moormann@postgrad.curtin.edu.au

Thanks so much for your support. We really appreciate that.

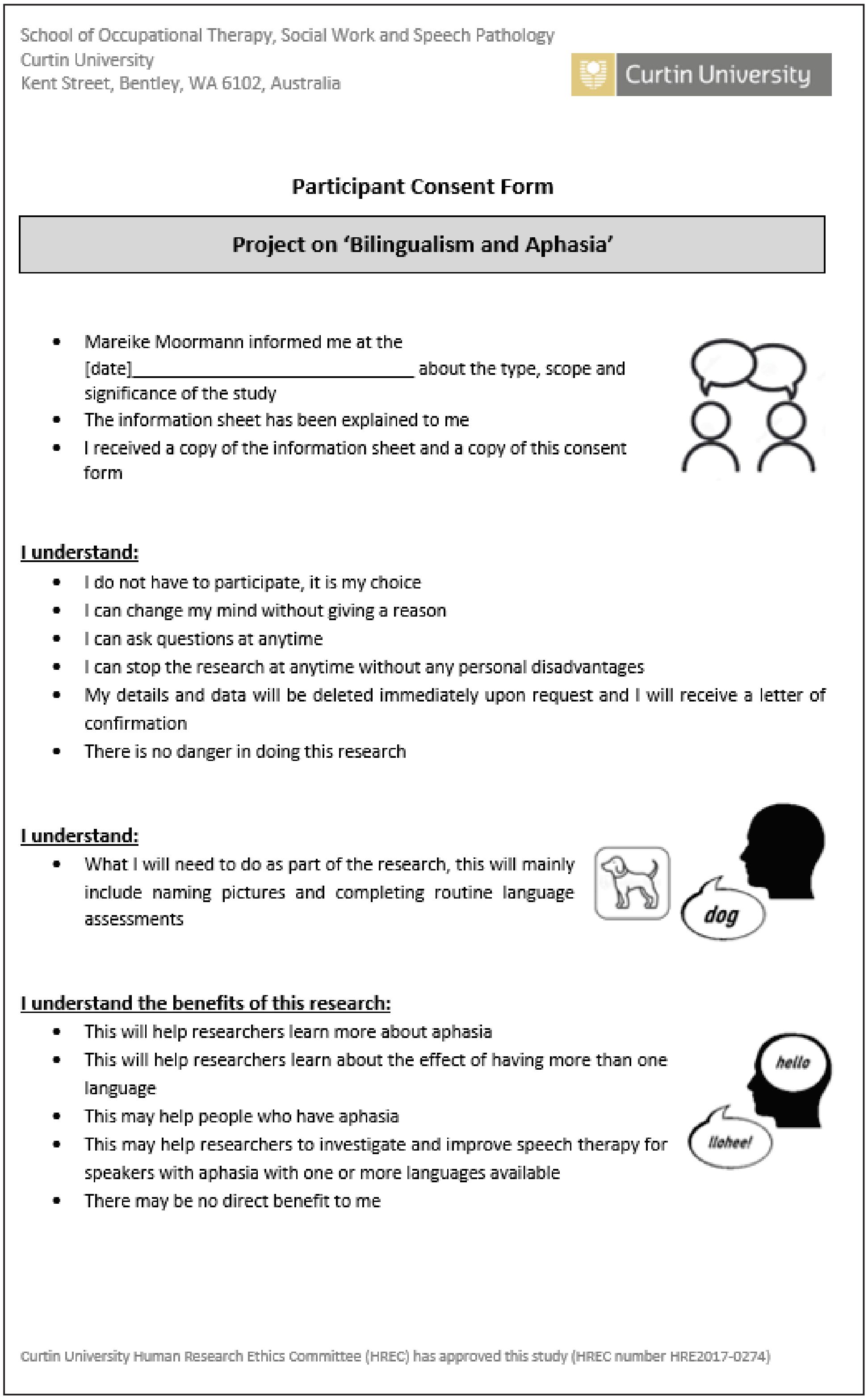
The ethical aspects of this study haven been approved by the Curtin University Human Research Ethics Committee (HREC number: HRE2017-0274). Should you wish to discuss the study with some not directly involved, in particular, any matters concerning the conduct of the study or your rights as a participant, or you wish to make a confidential complaint, you may contact the Ethics Offer on (08) 9266 9223 or the Manager, research Integrity on (08) 9266 7093, or email hrec@curtin.edu.au

(INVESTIGATORS [OR PARTICIPANTS] COPY)

Curtin University Human Research Ethics Committee (HREC) has approved this study (HREC number HRE2017-0274)

General Appendix B

Participant Consent Form



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Curtin University
Kent Street, Bentley, WA 6102, Australia

Curtin University

Participant Consent Form

Project on 'Bilingualism and Aphasia'

- Mareike Moormann informed me at the [date]______________________________ about the type, scope and significance of the study
- The information sheet has been explained to me
- I received a copy of the information sheet and a copy of this consent form

I understand:

- I do not have to participate, it is my choice
- I can change my mind without giving a reason
- I can ask questions at anytime
- I can stop the research at anytime without any personal disadvantages
- My details and data will be deleted immediately upon request and I will receive a letter of confirmation
- There is no danger in doing this research

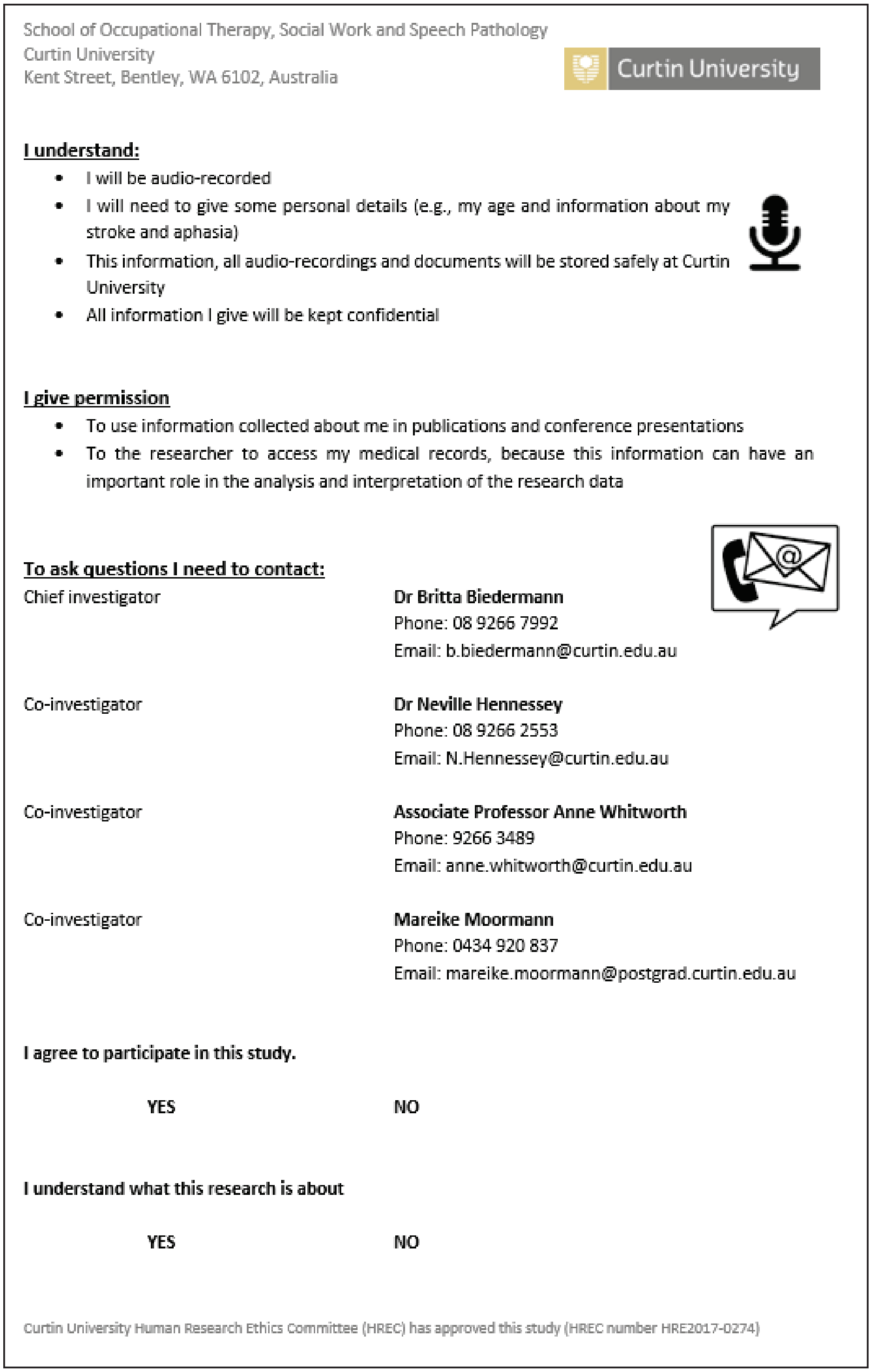
I understand:

- What I will need to do as part of the research, this will mainly include naming pictures and completing routine language assessments

I understand the benefits of this research:

- This will help researchers learn more about aphasia
- This will help researchers learn about the effect of having more than one language
- This may help people who have aphasia
- This may help researchers to investigate and improve speech therapy for speakers with aphasia with one or more languages available
- There may be no direct benefit to me

Curtin University Human Research Ethics Committee (HREC) has approved this study (HREC number HRE2017-0274)



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Curtin University
Kent Street, Bentley, WA 6102, Australia

I understand:

- I will be audio-recorded
- I will need to give some personal details (e.g., my age and information about my stroke and aphasia)
- This information, all audio-recordings and documents will be stored safely at Curtin University
- All information I give will be kept confidential

I give permission

- To use information collected about me in publications and conference presentations
- To the researcher to access my medical records, because this information can have an important role in the analysis and interpretation of the research data

To ask questions I need to contact:

Chief investigator	**Dr Britta Biedermann** Phone: 08 9266 7992 Email: b.biedermann@curtin.edu.au
Co-investigator	**Dr Neville Hennessey** Phone: 08 9266 2553 Email: N.Hennessey@curtin.edu.au
Co-investigator	**Associate Professor Anne Whitworth** Phone: 9266 3489 Email: anne.whitworth@curtin.edu.au
Co-investigator	**Mareike Moormann** Phone: 0434 920 837 Email: mareike.moormann@postgrad.curtin.edu.au

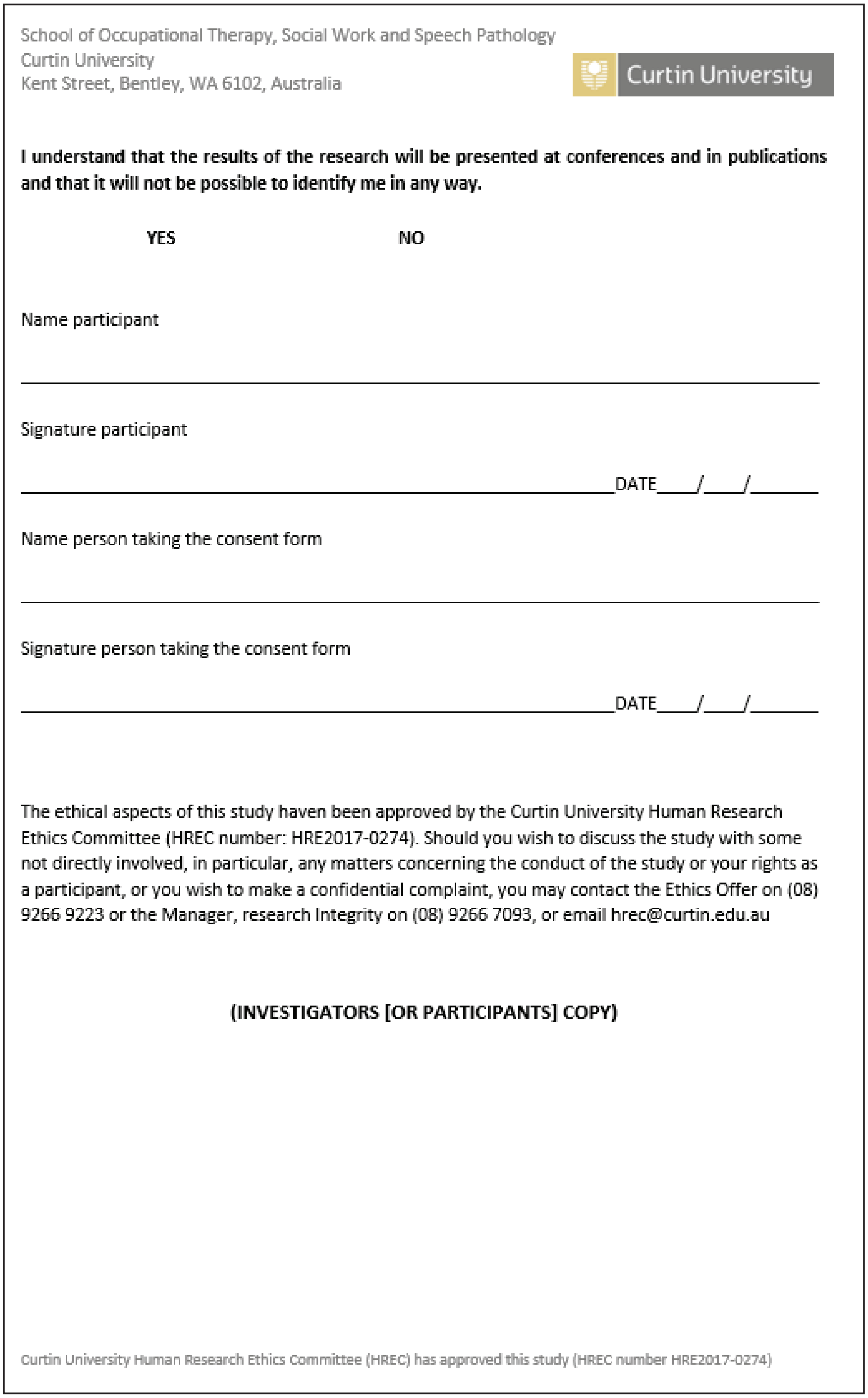
I agree to participate in this study.

YES **NO**

I understand what this research is about

YES **NO**

Curtin University Human Research Ethics Committee (HREC) has approved this study (HREC number HRE2017-0274)



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Curtin University
Kent Street, Bentley, WA 6102, Australia

Curtin University

I understand that the results of the research will be presented at conferences and in publications and that it will not be possible to identify me in any way.

YES **NO**

Name participant

____

Signature participant

____DATE____/____/_______

Name person taking the consent form

____

Signature person taking the consent form

____DATE____/____/_______

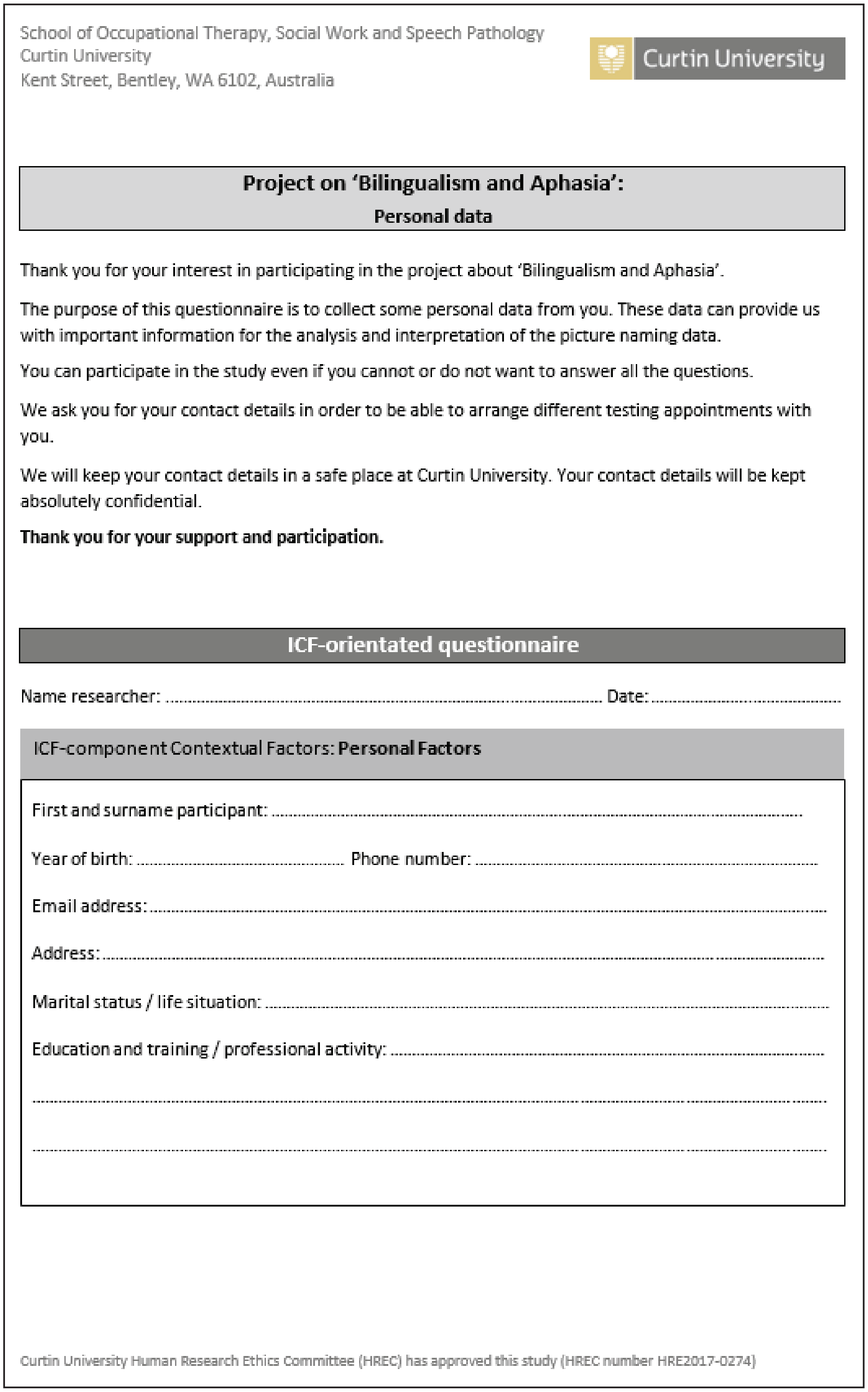
The ethical aspects of this study haven been approved by the Curtin University Human Research Ethics Committee (HREC number: HRE2017-0274). Should you wish to discuss the study with some not directly involved, in particular, any matters concerning the conduct of the study or your rights as a participant, or you wish to make a confidential complaint, you may contact the Ethics Offer on (08) 9266 9223 or the Manager, research Integrity on (08) 9266 7093, or email hrec@curtin.edu.au

(INVESTIGATORS [OR PARTICIPANTS] COPY)

Curtin University Human Research Ethics Committee (HREC) has approved this study (HREC number HRE2017-0274)

General Appendix C

Data Form



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Curtin University
Kent Street, Bentley, WA 6102, Australia

Curtin University

Project on 'Bilingualism and Aphasia':

Personal data

Thank you for your interest in participating in the project about 'Bilingualism and Aphasia'.

The purpose of this questionnaire is to collect some personal data from you. These data can provide us with important information for the analysis and interpretation of the picture naming data.

You can participate in the study even if you cannot or do not want to answer all the questions.

We ask you for your contact details in order to be able to arrange different testing appointments with you.

We will keep your contact details in a safe place at Curtin University. Your contact details will be kept absolutely confidential.

Thank you for your support and participation.

ICF-orientated questionnaire

Name researcher: .... Date: ....

ICF-component Contextual Factors: **Personal Factors**

First and surname participant: ....

Year of birth: .... Phone number: ....

Email address: ....

Address: ....

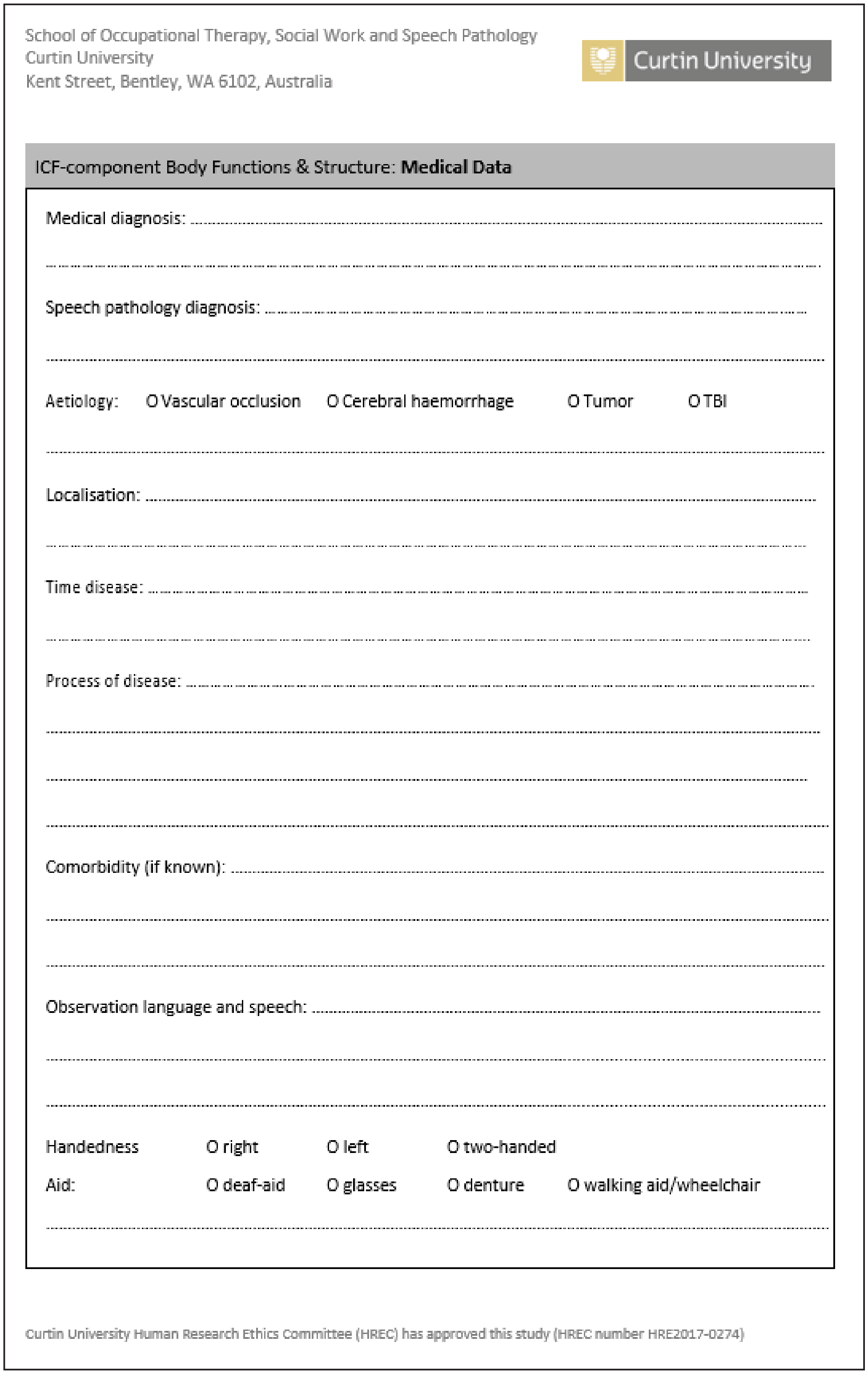
Marital status / life situation: ....

Education and training / professional activity: ....

....

....

Curtin University Human Research Ethics Committee (HREC) has approved this study (HREC number HRE2017-0274)



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Curtin University
Kent Street, Bentley, WA 6102, Australia

Curtin University

ICF-component Body Functions & Structure: **Medical Data**

Medical diagnosis: ....

....

Speech pathology diagnosis: ....

....

Aetiology: ○ Vascular occlusion ○ Cerebral haemorrhage ○ Tumor ○ TBI

....

Localisation: ....

....

Time disease: ....

....

Process of disease: ....

....

....

....

Comorbidity (if known): ....

....

....

Observation language and speech: ....

....

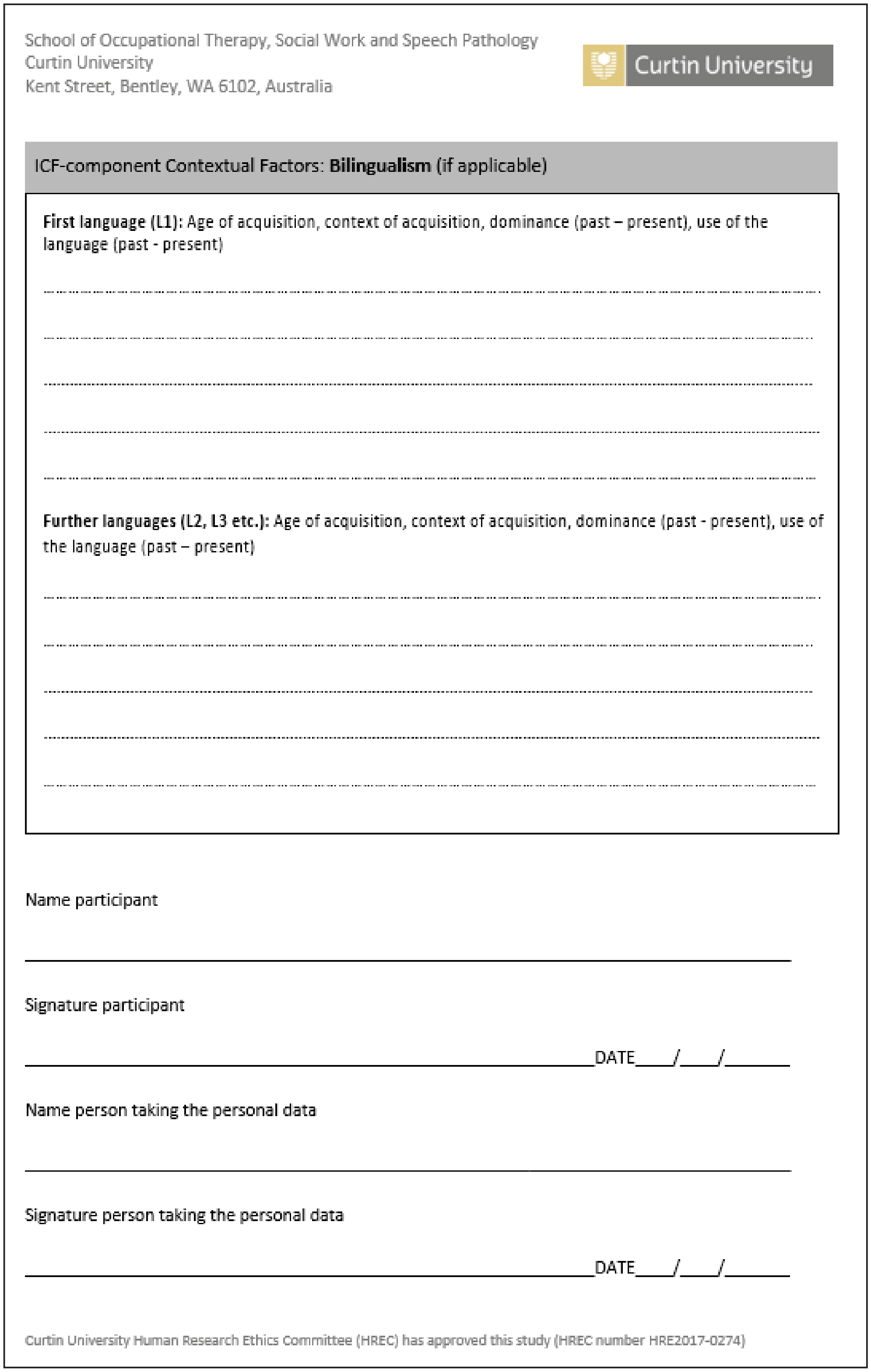
....

Handedness ○ right ○ left ○ two-handed

Aid: ○ deaf-aid ○ glasses ○ denture ○ walking aid/wheelchair

....

Curtin University Human Research Ethics Committee (HREC) has approved this study (HREC number HRE2017-0274)



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ICF-component Contextual Factors: **Bilingualism** (if applicable)

First language (L1): Age of acquisition, context of acquisition, dominance (past – present), use of the language (past - present)

……

……

……

……

……

Further languages (L2, L3 etc.): Age of acquisition, context of acquisition, dominance (past - present), use of the language (past – present)

……

……

……

……

……

Name participant

____

Signature participant

____DATE____/____/_______

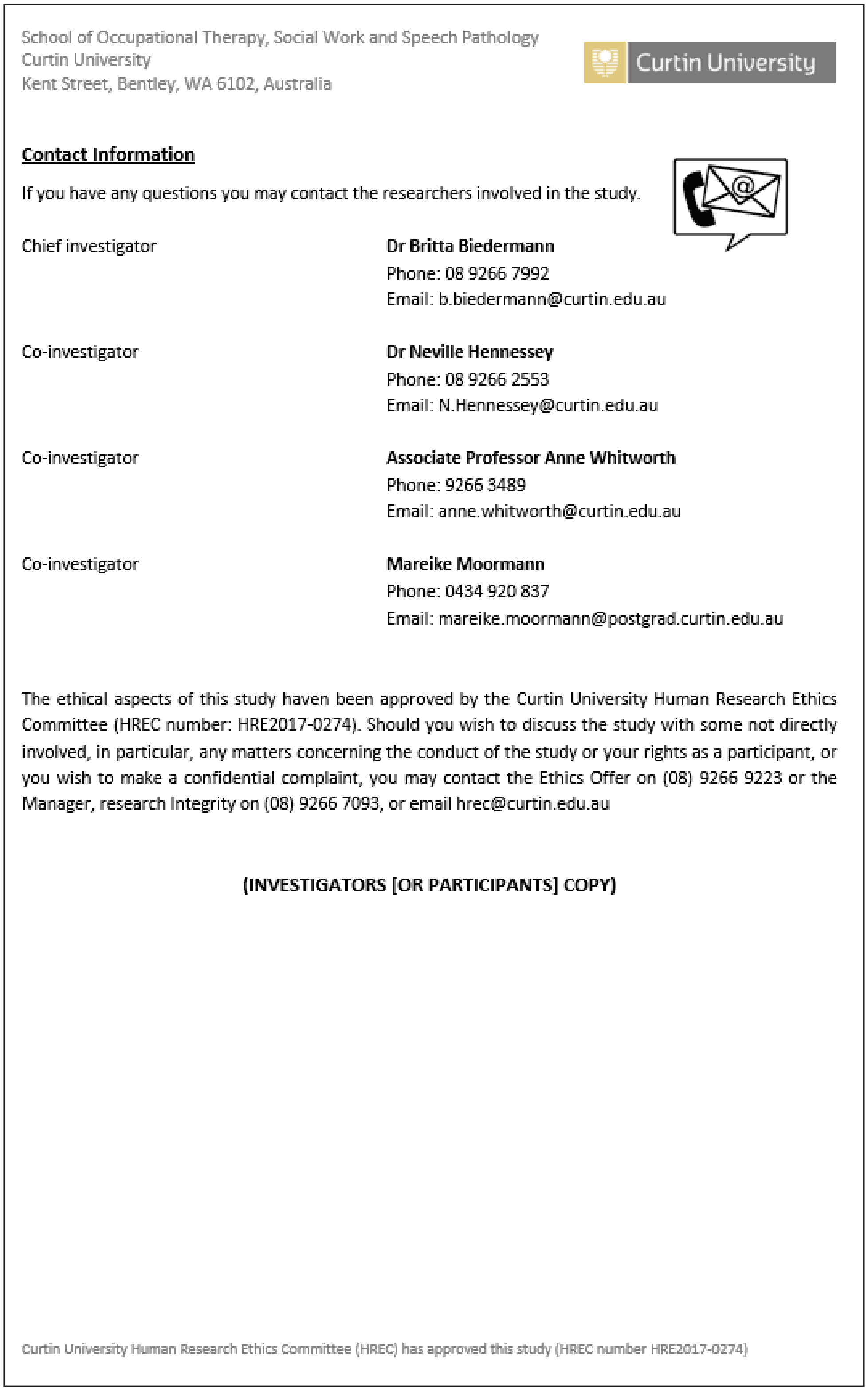
Name person taking the personal data

____

Signature person taking the personal data

____DATE____/____/_______

Curtin University Human Research Ethics Committee (HREC) has approved this study (HREC number HRE2017-0274)



School of Occupational Therapy, Social Work and Speech Pathology
Curtin University
Kent Street, Bentley, WA 6102, Australia

Curtin University

Contact Information

If you have any questions you may contact the researchers involved in the study.

Chief investigator	**Dr Britta Biedermann** Phone: 08 9266 7992 Email: b.biedermann@curtin.edu.au
Co-investigator	**Dr Neville Hennessey** Phone: 08 9266 2553 Email: N.Hennessey@curtin.edu.au
Co-investigator	**Associate Professor Anne Whitworth** Phone: 9266 3489 Email: anne.whitworth@curtin.edu.au
Co-investigator	**Mareike Moormann** Phone: 0434 920 837 Email: mareike.moormann@postgrad.curtin.edu.au

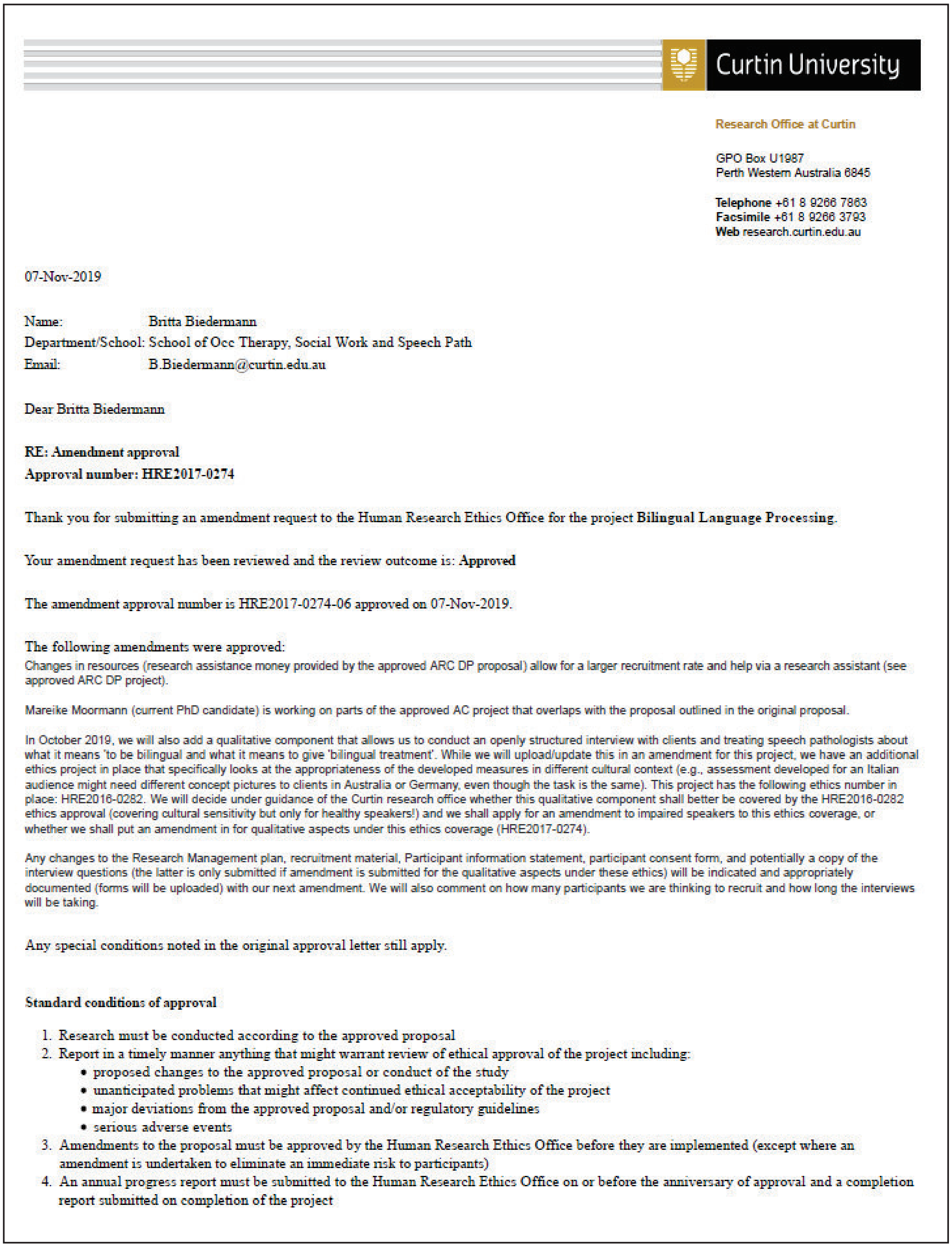
The ethical aspects of this study haven been approved by the Curtin University Human Research Ethics Committee (HREC number: HRE2017-0274). Should you wish to discuss the study with some not directly involved, in particular, any matters concerning the conduct of the study or your rights as a participant, or you wish to make a confidential complaint, you may contact the Ethics Offer on (08) 9266 9223 or the Manager, research Integrity on (08) 9266 7093, or email hrec@curtin.edu.au

(INVESTIGATORS [OR PARTICIPANTS] COPY)

General Appendix D

Ethics Approval

Ethics Approval Curtin University



Curtin University

Research Office at Curtin

GPO Box U1987
Perth Western Australia 6845

Telephone +61 8 9266 7863
Facsimile +61 8 9266 3793
Web research.curtin.edu.au

07-Nov-2019

Name: Britta Biedermann
Department/School: School of Occ Therapy, Social Work and Speech Path
Email: B.Biedermann@curtin.edu.au

Dear Britta Biedermann

RE: Amendment approval
Approval number: HRE2017-0274

Thank you for submitting an amendment request to the Human Research Ethics Office for the project **Bilingual Language Processing**.

Your amendment request has been reviewed and the review outcome is: **Approved**

The amendment approval number is HRE2017-0274-06 approved on 07-Nov-2019.

The following amendments were approved:
Changes in resources (research assistance money provided by the approved ARC DP proposal) allow for a larger recruitment rate and help via a research assistant (see approved ARC DP project).

Mareike Moormann (current PhD candidate) is working on parts of the approved AC project that overlaps with the proposal outlined in the original proposal.

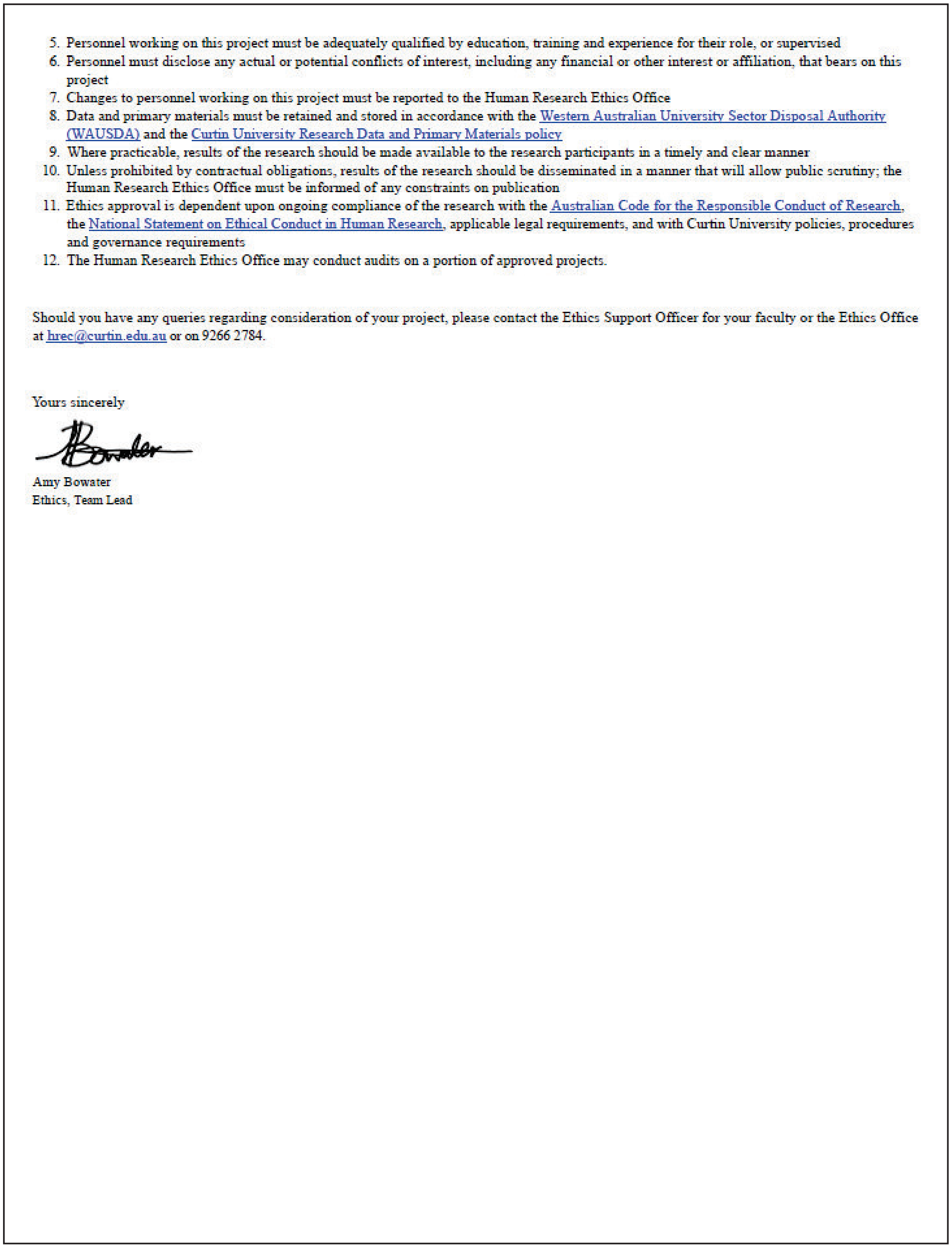
In October 2019, we will also add a qualitative component that allows us to conduct an openly structured interview with clients and treating speech pathologists about what it means 'to be bilingual and what it means to give 'bilingual treatment'. While we will upload/update this in an amendment for this project, we have an additional ethics project in place that specifically looks at the appropriateness of the developed measures in different cultural context (e.g., assessment developed for an Italian audience might need different concept pictures to clients in Australia or Germany, even though the task is the same). This project has the following ethics number in place: HRE2016-0282. We will decide under guidance of the Curtin research office whether this qualitative component shall better be covered by the HRE2016-0282 ethics approval (covering cultural sensitivity but only for healthy speakers!) and we shall apply for an amendment to impaired speakers to this ethics coverage, or whether we shall put an amendment in for qualitative aspects under this ethics coverage (HRE2017-0274).

Any changes to the Research Management plan, recruitment material, Participant information statement, participant consent form, and potentially a copy of the interview questions (the latter is only submitted if amendment is submitted for the qualitative aspects under these ethics) will be indicated and appropriately documented (forms will be uploaded) with our next amendment. We will also comment on how many participants we are thinking to recruit and how long the interviews will be taking.

Any special conditions noted in the original approval letter still apply.

Standard conditions of approval

1. Research must be conducted according to the approved proposal
2. Report in a timely manner anything that might warrant review of ethical approval of the project including:
   - proposed changes to the approved proposal or conduct of the study
   - unanticipated problems that might affect continued ethical acceptability of the project
   - major deviations from the approved proposal and/or regulatory guidelines
   - serious adverse events
3. Amendments to the proposal must be approved by the Human Research Ethics Office before they are implemented (except where an amendment is undertaken to eliminate an immediate risk to participants)
4. An annual progress report must be submitted to the Human Research Ethics Office on or before the anniversary of approval and a completion report submitted on completion of the project



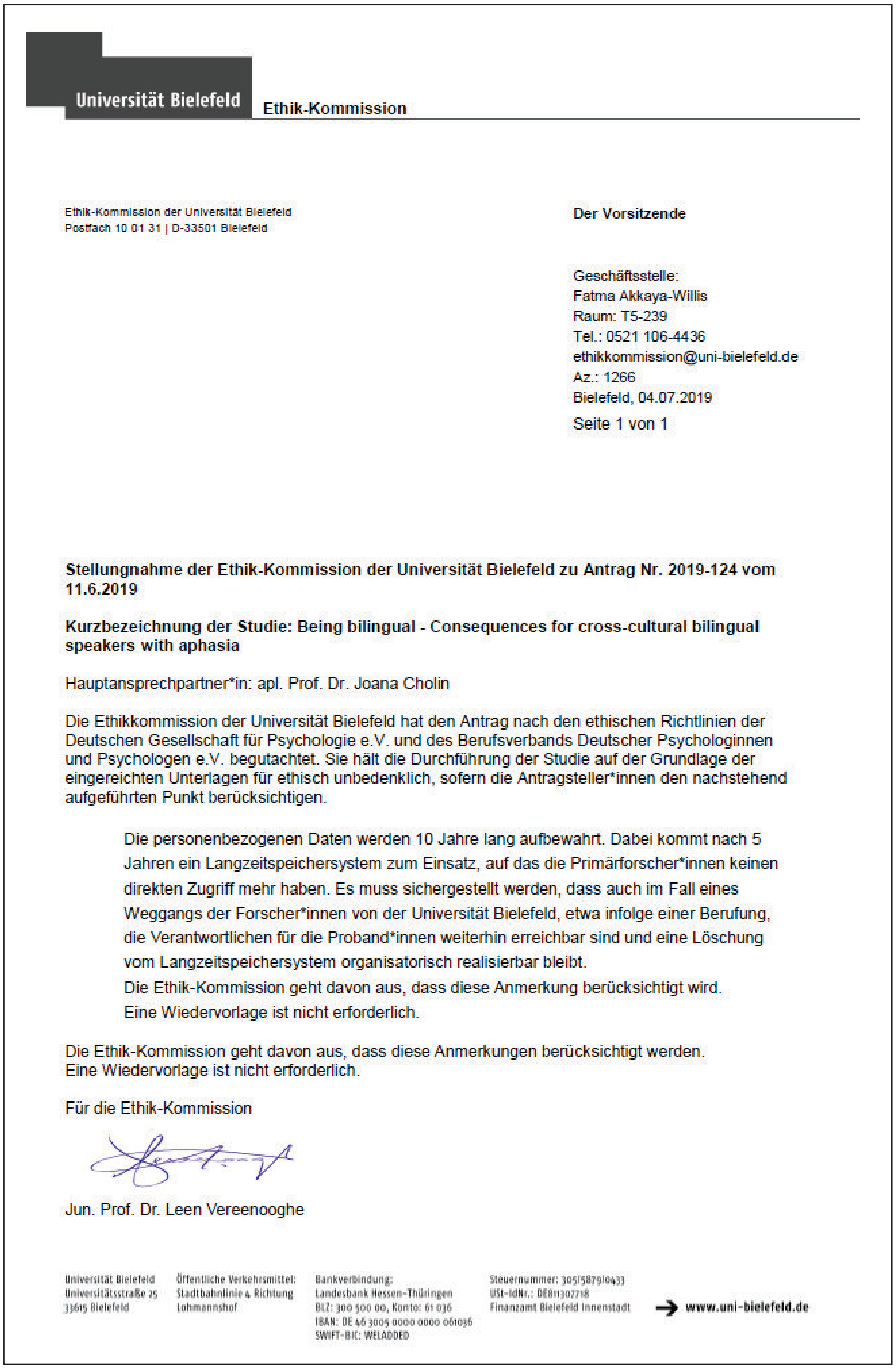
5. Personnel working on this project must be adequately qualified by education, training and experience for their role, or supervised
6. Personnel must disclose any actual or potential conflicts of interest, including any financial or other interest or affiliation, that bears on this project
7. Changes to personnel working on this project must be reported to the Human Research Ethics Office
8. Data and primary materials must be retained and stored in accordance with the Western Australian University Sector Disposal Authority (WAUSDA) and the Curtin University Research Data and Primary Materials policy
9. Where practicable, results of the research should be made available to the research participants in a timely and clear manner
10. Unless prohibited by contractual obligations, results of the research should be disseminated in a manner that will allow public scrutiny; the Human Research Ethics Office must be informed of any constraints on publication
11. Ethics approval is dependent upon ongoing compliance of the research with the Australian Code for the Responsible Conduct of Research, the National Statement on Ethical Conduct in Human Research, applicable legal requirements, and with Curtin University policies, procedures and governance requirements
12. The Human Research Ethics Office may conduct audits on a portion of approved projects.

Should you have any queries regarding consideration of your project, please contact the Ethics Support Officer for your faculty or the Ethics Office at hrec@curtin.edu.au or on 9266 2784.

Yours sincerely

Amy Bowater
Ethics, Team Lead

Ethics Approval Bielefeld University (Germany)



Universität Bielefeld **Ethik-Kommission**

Ethik-Kommission der Universität Bielefeld
Postfach 10 01 31 | D-33501 Bielefeld

Der Vorsitzende

Geschäftsstelle:
Fatma Akkaya-Willis
Raum: T5-239
Tel.: 0521 106-4436
ethikkommission@uni-bielefeld.de

Az.: 1266
Bielefeld, 04.07.2019
Seite 1 von 1

Stellungnahme der Ethik-Kommission der Universität Bielefeld zu Antrag Nr. 2019-124 vom 11.6.2019

Kurzbezeichnung der Studie: Being bilingual - Consequences for cross-cultural bilingual speakers with aphasia

Hauptansprechpartner*in: apl. Prof. Dr. Joana Cholin

Die Ethikkommission der Universität Bielefeld hat den Antrag nach den ethischen Richtlinien der Deutschen Gesellschaft für Psychologie e.V. und des Berufsverbands Deutscher Psychologinnen und Psychologen e.V. begutachtet. Sie hält die Durchführung der Studie auf der Grundlage der eingereichten Unterlagen für ethisch unbedenklich, sofern die Antragsteller*innen den nachstehend aufgeführten Punkt berücksichtigen.

> Die personenbezogenen Daten werden 10 Jahre lang aufbewahrt. Dabei kommt nach 5 Jahren ein Langzeitspeichersystem zum Einsatz, auf das die Primärforscher*innen keinen direkten Zugriff mehr haben. Es muss sichergestellt werden, dass auch im Fall eines Weggangs der Forscher*innen von der Universität Bielefeld, etwa infolge einer Berufung, die Verantwortlichen für die Proband*innen weiterhin erreichbar sind und eine Löschung vom Langzeitspeichersystem organisatorisch realisierbar bleibt.
> Die Ethik-Kommission geht davon aus, dass diese Anmerkung berücksichtigt wird.
> Eine Wiedervorlage ist nicht erforderlich.

Die Ethik-Kommission geht davon aus, dass diese Anmerkungen berücksichtigt werden.
Eine Wiedervorlage ist nicht erforderlich.

Für die Ethik-Kommission

Jun. Prof. Dr. Leen Vereenooghe

Universität Bielefeld
Universitätsstraße 25
33615 Bielefeld

Öffentliche Verkehrsmittel:
Stadtbahnlinie 4 Richtung
Lohmannshof

Bankverbindung:
Landesbank Hessen-Thüringen
BLZ: 300 500 00, Konto: 61 036
IBAN: DE 46 3005 0000 0000 061036
SWIFT-BIC: WELADDED

Steuernummer: 305/5879/0433
USt-IdNr.: DE811307718
Finanzamt Bielefeld Innenstadt

→ www.uni-bielefeld.de

Ethics Approval South Metropolitan Health Service Human Research Ethics Committee (EC00265)

03/04/2020 RGS - Project Letter

PROJECT | 'Being bilingual' - Consequences for cross-cultural bilingual speakers with aphasia

Click on the arrows below to get step by step guidance.

PRN: RGS0000003763 **Project status:** Active **Project ethics approval status:** Pending
Short title: Aphasia and Bilingualism
External HREC ref: None **Risk type:** Low risk **CPI:** Mareike Moormann
My Role(s): CM, EEO, RGO **Lead HREC:** South Metropolitan Health Service Human Research Ethics Committee (EC00265)

Ethics Approved - HREC

South Metropolitan Health Service Human Research Ethics Committee
Level 2, Education Building, Fiona Stanley Hospital
14 Barry Marshall Parade
MURDOCH WA 6150

03 April 2020

Ms Mareike Moormann
Curtin University Perth
Kent Street
Bentley WA 6102

Dear Ms Moormann

PRN: RGS0000003763
Project Title: 'Being bilingual' - Consequences for cross-cultural bilingual speakers with aphasia
Protocol Number: V2, dated 19/03/2020

Thank you for submitting the above research project for ethical review. This project was considered by the South Metropolitan Health Service Human Research Ethics Committee at its meeting held on 10 March 2020. To find the original letter and any possible attachments, click here when logged into RGS.

I am pleased to advise you that the above research project meets the requirements of the *National Statement on Ethical Conduct in Human Research (2007)* and ethical approval for this research project has been granted by South Metropolitan Health Service Human Research Ethics Committee.

The nominated participating sites in this project are:

- Fiona Stanley Hospital
- Fremantle Hospital Health Service

[Note: If additional sites are recruited prior to the commencement of, or during the research project, the Coordinating Principal Investigator is required to notify the Human Research Ethics Committee (HREC). Notification of withdrawn sites should also be provided to the HREC in a timely fashion.]

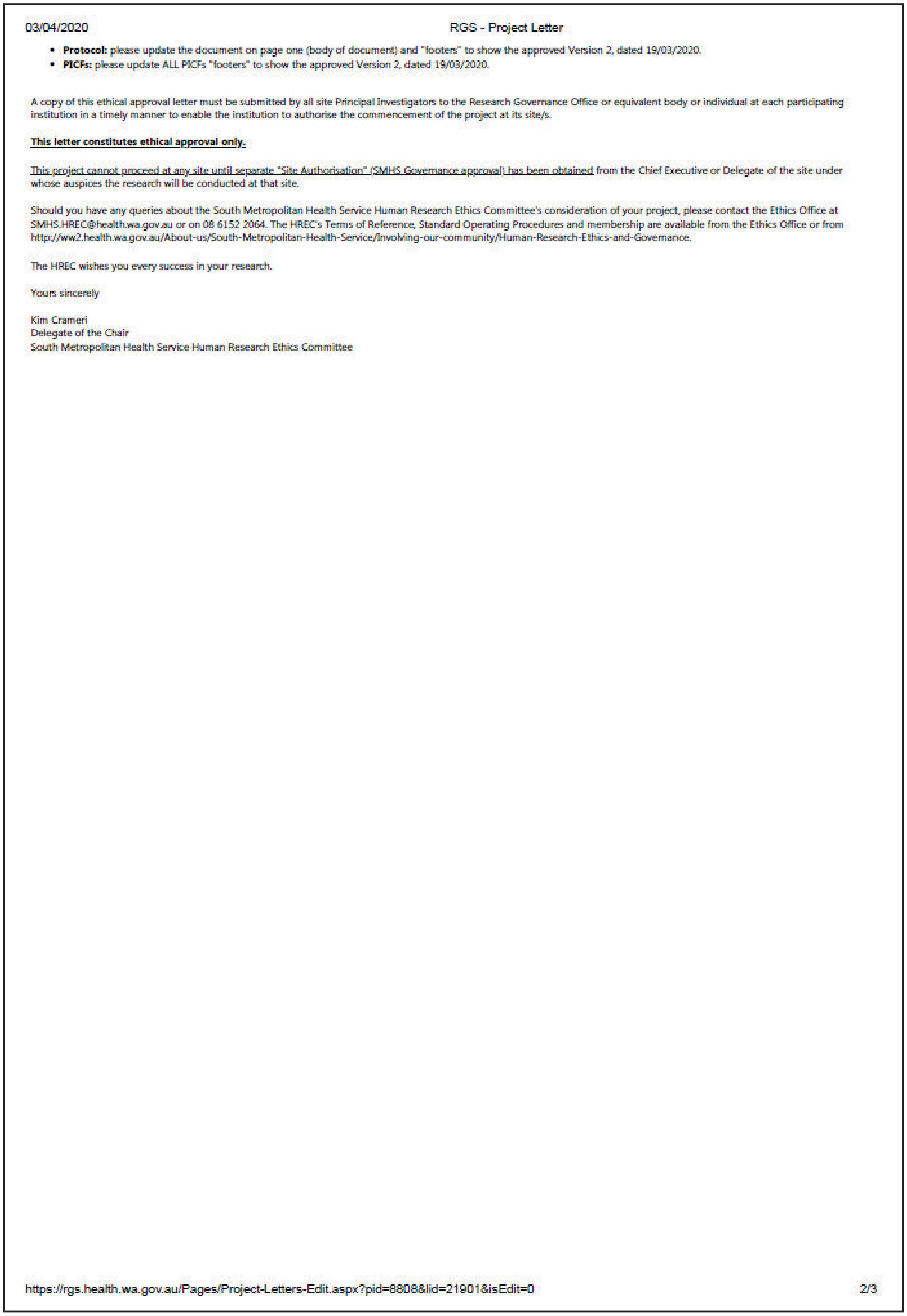
The approved documents include:

Document	Version	Version Date
19.03_App1_Aphasia and Bilingualism_PICF_Study1	2	19/03/2020
19.03_App2_Aphasia and Bilingualism_PICF_Study2	2	19/03/2020
19.03_App3_Aphasia and Bilingualism_PICF_Study3and4	2	19/03/2020
19.03_Research protocol Aphasia and Bilingualism	2	19/03/2020
19.03clear version_App1_Aphasia and Bilingualism_PICF_Study1	2	19/03/2020
19.03clear version_App2_Aphasia and Bilingualism_PICF_Study2	2	19/03/2020
19.03clear version_App3_Aphasia and Bilingualism_PICF_Study3and4	2	19/03/2020
19.03clear version_Research protocol Aphasia and Bilingualism	2	19/03/2020
App5_Aphasia and Bilingualism_Explanation submitting interview guide at a later stage	1	19/02/2020
Ethics Investigator Response Letter	1	19/03/2020

Ethical approval of this project from South Metropolitan Health Service Human Research Ethics Committee is valid from 03 April 2020 to 03 April 2025 subject to compliance with the 'Conditions of Ethics Approval for a Research Project' (Appendix A).

Please complete the following prior to submitting to SMHS Research Governance Office for "Site Authorisation" for the study.

https://rgs.health.wa.gov.au/Pages/Project-Letters-Edit.aspx?pid=8808&lid=21901&isEdit=0 1/3



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- **Protocol:** please update the document on page one (body of document) and "footers" to show the approved Version 2, dated 19/03/2020.
- **PICFs:** please update ALL PICFs "footers" to show the approved Version 2, dated 19/03/2020.

A copy of this ethical approval letter must be submitted by all site Principal Investigators to the Research Governance Office or equivalent body or individual at each participating institution in a timely manner to enable the institution to authorise the commencement of the project at its site/s.

This letter constitutes ethical approval only.

This project cannot proceed at any site until separate "Site Authorisation" (SMHS Governance approval) has been obtained from the Chief Executive or Delegate of the site under whose auspices the research will be conducted at that site.

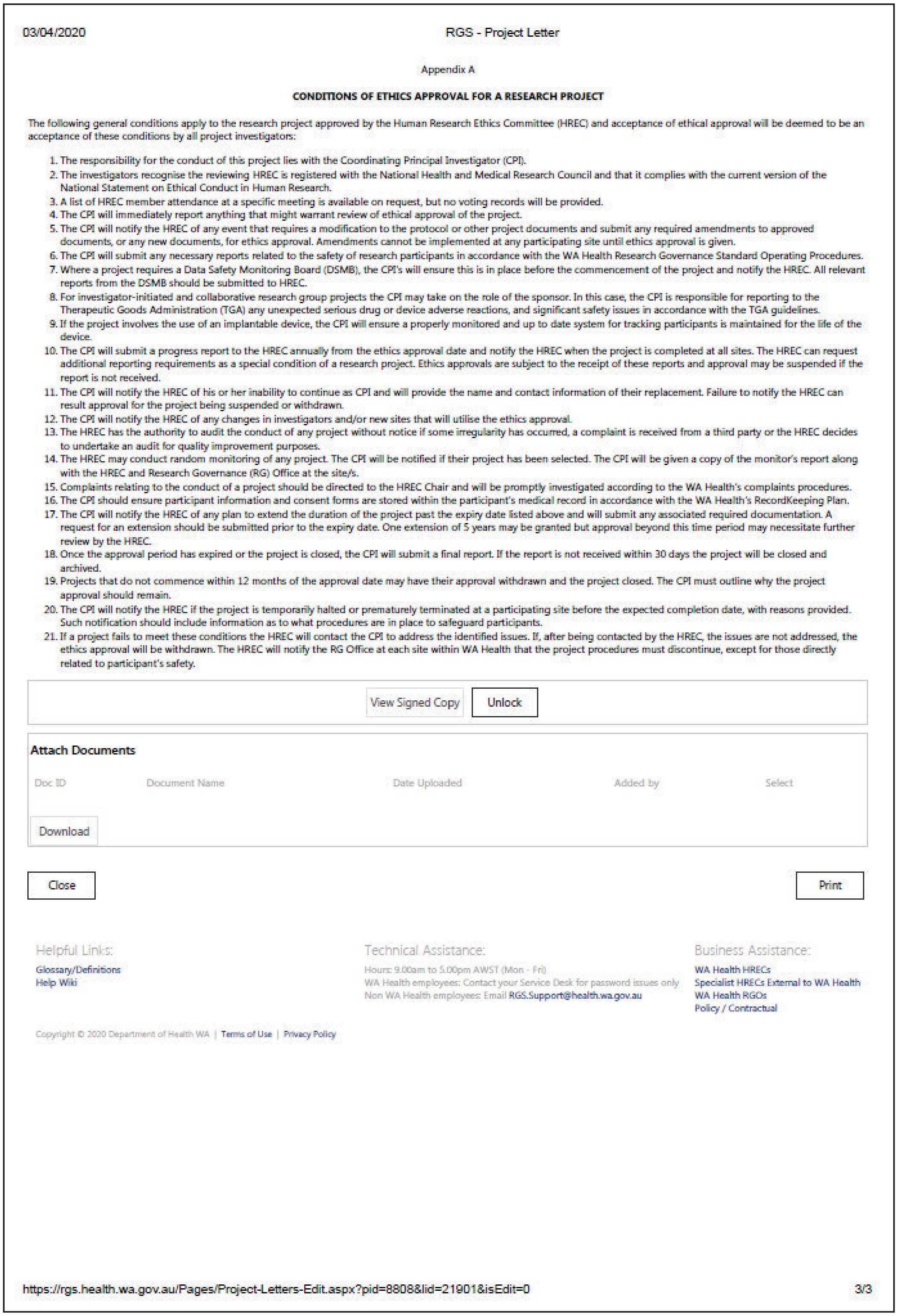
Should you have any queries about the South Metropolitan Health Service Human Research Ethics Committee's consideration of your project, please contact the Ethics Office at SMHS.HREC@health.wa.gov.au or on 08 6152 2064. The HREC's Terms of Reference, Standard Operating Procedures and membership are available from the Ethics Office or from http://ww2.health.wa.gov.au/About-us/South-Metropolitan-Health-Service/Involving-our-community/Human-Research-Ethics-and-Governance.

The HREC wishes you every success in your research.

Yours sincerely

Kim Crameri
Delegate of the Chair
South Metropolitan Health Service Human Research Ethics Committee

https://rgs.health.wa.gov.au/Pages/Project-Letters-Edit.aspx?pid=8808&lid=21901&isEdit=0 2/3



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Appendix A

CONDITIONS OF ETHICS APPROVAL FOR A RESEARCH PROJECT

The following general conditions apply to the research project approved by the Human Research Ethics Committee (HREC) and acceptance of ethical approval will be deemed to be an acceptance of these conditions by all project investigators:

1. The responsibility for the conduct of this project lies with the Coordinating Principal Investigator (CPI).
2. The investigators recognise the reviewing HREC is registered with the National Health and Medical Research Council and that it complies with the current version of the National Statement on Ethical Conduct in Human Research.
3. A list of HREC member attendance at a specific meeting is available on request, but no voting records will be provided.
4. The CPI will immediately report anything that might warrant review of ethical approval of the project.
5. The CPI will notify the HREC of any event that requires a modification to the protocol or other project documents and submit any required amendments to approved documents, or any new documents, for ethics approval. Amendments cannot be implemented at any participating site until ethics approval is given.
6. The CPI will submit any necessary reports related to the safety of research participants in accordance with the WA Health Research Governance Standard Operating Procedures.
7. Where a project requires a Data Safety Monitoring Board (DSMB), the CPI's will ensure this is in place before the commencement of the project and notify the HREC. All relevant reports from the DSMB should be submitted to HREC.
8. For investigator-initiated and collaborative research group projects the CPI may take on the role of the sponsor. In this case, the CPI is responsible for reporting to the Therapeutic Goods Administration (TGA) any unexpected serious drug or device adverse reactions, and significant safety issues in accordance with the TGA guidelines.
9. If the project involves the use of an implantable device, the CPI will ensure a properly monitored and up to date system for tracking participants is maintained for the life of the device.
10. The CPI will submit a progress report to the HREC annually from the ethics approval date and notify the HREC when the project is completed at all sites. The HREC can request additional reporting requirements as a special condition of a research project. Ethics approvals are subject to the receipt of these reports and approval may be suspended if the report is not received.
11. The CPI will notify the HREC of his or her inability to continue as CPI and will provide the name and contact information of their replacement. Failure to notify the HREC can result approval for the project being suspended or withdrawn.
12. The CPI will notify the HREC of any changes in investigators and/or new sites that will utilise the ethics approval.
13. The HREC has the authority to audit the conduct of any project without notice if some irregularity has occurred, a complaint is received from a third party or the HREC decides to undertake an audit for quality improvement purposes.
14. The HREC may conduct random monitoring of any project. The CPI will be notified if their project has been selected. The CPI will be given a copy of the monitor's report along with the HREC and Research Governance (RG) Office at the site/s.
15. Complaints relating to the conduct of a project should be directed to the HREC Chair and will be promptly investigated according to the WA Health's complaints procedures.
16. The CPI should ensure participant information and consent forms are stored within the participant's medical record in accordance with the WA Health's RecordKeeping Plan.
17. The CPI will notify the HREC of any plan to extend the duration of the project past the expiry date listed above and will submit any associated required documentation. A request for an extension should be submitted prior to the expiry date. One extension of 5 years may be granted but approval beyond this time period may necessitate further review by the HREC.
18. Once the approval period has expired or the project is closed, the CPI will submit a final report. If the report is not received within 30 days the project will be closed and archived.
19. Projects that do not commence within 12 months of the approval date may have their approval withdrawn and the project closed. The CPI must outline why the project approval should remain.
20. The CPI will notify the HREC if the project is temporarily halted or prematurely terminated at a participating site before the expected completion date, with reasons provided. Such notification should include information as to what procedures are in place to safeguard participants.
21. If a project fails to meet these conditions the HREC will contact the CPI to address the identified issues. If, after being contacted by the HREC, the issues are not addressed, the ethics approval will be withdrawn. The HREC will notify the RG Office at each site within WA Health that the project procedures must discontinue, except for those directly related to participant's safety.

Attach Documents

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Hours: 9.00am to 5.00pm AWST (Mon - Fri)
WA Health employees: Contact your Service Desk for password issues only
Non WA Health employees: Email RGS.Support@health.wa.gov.au

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Specialist HRECs External to WA Health
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General Appendix E

Background Information of all Bilingual Speakers with Aphasia

Background Information BwA1

Medical Records and Self-Reports – BwA1

Demographic and Medical Data

BwA1 was a 55-year-old Dutch-German speaker (female), who immigrated from the Netherlands to Germany aged 23. The participant was ten years and four months post-onset at the start of the project. She worked pre-onset as an area sales manager for 15 years and as an office administrator for five years. BwA1 had an ischemic left hemisphere infarct in the middle cerebral artery. The stroke resulted in aphasia.

Language Related Data

Based on medical records, immediately post-onset, the participant presented with global aphasia with minimal abilities for verbal production (only yes-responses and no-responses) but with only mildly impaired language comprehension. Medical records described BwA1's language disorder as moderate aphasia with difficulties in spoken word finding, grammar, reading, and writing at the start of the project. General conversation was characterised by being mildly non-fluent. The participant reported a parallel recovery pattern for both her available languages, Dutch (L1) and German (L2).

Bilingual Language Profile – BwA1

BwA1 was a late Dutch-German bilingual. She was fully immersed in German (L2) from the time of her move to Germany. Based on our project's bilingual profile assessments (self-reports, LEAP-Q, language background assessments), her dominant language was German (L2) pre- and post-stroke. The dominant language was determined by BwA1's language proficiency, language exposure and use, and biographical factors (language age of acquisition, environmental languages, language of residence). Language proficiency was determined by the results of the language background assessments, spanning across receptive and expressive tasks (see below). Biographical factors were conducted by the LEAP-Q and self-reports. Language use and exposure were determined by using a scale from 0-8, whereas 0 indicated 'no/minor language use and exposure' and 8 indicated 'high language use and exposure' (language use and exposure scale scores for BwA1: Dutch = 2, German = 8; see also participants section for further information on the scale). She used Dutch when visiting her family in the Netherlands and when listening to Dutch music/radio. She used German in most social contexts since she lived in Germany (interaction with family and friends, daily life activities [e.g., supermarket, medical appointments, restaurant], TV, radio/music, internet/computer/smartphone/social media, reading, writing). The participant was fully immersed in German in her pre-stroke work environment.

Background Language Assessments – BwA1

BwA1's pattern of impairment was consistent with the diagnosis of non-fluent Broca's aphasia (based on clinical observations and the background assessment results). Table E1 shows BwA1's language performance for both languages on various background assessments spanning across receptive and expressive tasks. The LEMO spoken naming subtest resulted in impaired naming abilities for both languages. Naming accuracy was higher for German (L2, dominant) than for Dutch (L1 Dutch LEMO score: 6/20 [30% correct], L2 German LEMO score: 11/20 [55% correct]). BwA1 showed a generally better language performance for German (L2, dominant) than for Dutch (L1 Dutch BAT score: 148/171, L2 German BAT score: 157[43]/171). Spoken Naming within the BAT was impaired in both languages, with higher naming accuracy for German (L2, dominant) compared to Dutch (L1 Dutch BAT naming score: 13/20 [65% correct], L2 German BAT naming score: 18/20 [90% correct]). BwA1 showed higher accuracy in written naming for German (L2, dominant) (first 30 items of Subset 1a of the experimental naming task: L1 Dutch written naming score: 13/30 [43.33% correct], L2 German written naming score: 17/30 [56.67% correct]). When comparing written naming and spoken naming of these 30 items within languages, the participant showed higher accuracy in written naming for both languages (spoken naming score: L1 Dutch non-dominant: 9/30 [30% correct], L2 German dominant: 15/30 [50%]) compared to their written performance (written naming score: L1 Dutch non-dominant 13/30 [43.33% correct], L2 German dominant 17/30 [56.67% correct]).

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[43] To compare the overall BAT score across languages, the score for the verbal fluency subset has been excluded from the German (L2) overall BAT score since this subset result needed to be excluded for the Dutch (L1) version. When including the verbal fluency subset score, the participant's overall L2 German BAT score is 160/174.

Table E1

Language Background Assessments for BwA1

	Dutch (L1)		German (L2)	
Background assessment	Raw score	% correct	Raw score	% correct
Bilingual Aphasia Test (BAT) – Receptive tasks				
Pointing (n=10)	10	100	10	100
Simple and semi-complex commands (n=10)	10	100	10	100
Complex commands (n=20)	20	100	20	100
Verbal auditory discrimination (n=18)	13	72.22	13	72.22
Semantic categories (n=5)	5	100	3	60
Synonyms (n=5)	4	80	5	100
Lexical decision of words and nonsense words (n=30)	27	90	30	100
Lexical decision of words (n=20)	19	95	20	100
Lexical decision of nonwords (n=10)	8	80	10	100
Reading comprehension for words (n=10)	9	90	8	80
Bilingual Aphasia Test (BAT) – Expressive tasks				
Repetition of words and nonsense words (n=30)	27	90	28	93.33
Repetition of words (n=20)	20	100	20	100
Repetition of nonwords (n=10)	7	70	8	80
Series (n=3)	0	0	3	100
Verbal fluency (n=3)	n/a[a]	n/a[a]	3(0[b])	100(0[b])
Spoken Naming (n=20)	13	65	18	90
Reading Aloud (n=10)	10	100	9	90
Overall BAT-score	*148*		*160 (157[b])*	
LEMO 2.0 – Spoken Naming (Subtest 13)				
Naming: Total (n=20)	6	30	11	55
High frequency (n=10)			7	70
Low frequency (n =10)			4	40
Naming Subset 1a (items 1-30)				
Written naming	13	43.33	17	56.67
Spoken naming	9	30	15	50

[a] Subtest results are missing.

[b] Excluding the subset verbal fluency to compare the overall BAT score across languages.

Background Information BwA2

Medical Records and Self-Reports – BwA2

Demographic and Medical Data

BwA2 was a 66-year-old Polish-German speaker (male), who immigrated from Poland to Germany at the age of 35. While living in Germany, BwA2 was a former construction worker (25 years) and facility manager (five years). Prior to his move to Germany, BwA2 worked at the Polish Navy. BwA2 retired after he had the stroke. He was eleven months post-onset at the start of this project. He had an extended ischemic bilateral cerebellar infarct and an infarct in the right superior cerebellar artery and basilar artery. Further infarcts in the following brain areas were reported without a specified hemisphere localisation as follows: Selective infarcts occipital, infarct in the lanky vertebral artery with a V4-occlusion and infarct in the stromal area of the posterior cerebral artery. Ongoing post-stroke difficulties (e.g., motor and lymphatic) indicated infarcts in the left and right hemisphere. Based on his medical records, the stroke resulted in aphasia, but was not further specified.

Language Related Data

Medical records indicated aphasia and dysarthria post-stroke. At the start of the project, the participant received ongoing outpatient speech pathology focussing on his mild to moderate spoken word finding difficulties. The participant reported a parallel recovery pattern for his available languages, Polish (L1) and German (L2).

Bilingual Language Profile – BwA2

BwA2 was a late Polish-German bilingual speaker, who was fully immersed in German (L2) from the time of his move to Germany. Due to the family's migration history, German was spoken once in a while at home by his parents/grandparents when he was a child. The language dominance was equally distributed across the available languages Polish (L1) and German (L2) pre- and post-stroke. The dominance was determined by BwA2's language proficiency, language exposure and use, and biographical factors (language age of acquisition, environmental languages, language of residence). The language background assessments, spanning across receptive and expressive tasks (see below), were used to determine BwA2's language proficiency. Biographical factors were conducted by the LEAP-Q and self-reports. The percentage of language use and exposure was slightly higher in German (L2) pre- and post-stroke, determined by a scale ranging from 0-8 (0 indicated ‘no/minor language use and exposure’, 8 indicated ‘high language use and exposure’; language use and exposure scale score [out of 7, the participant reported no use of a smartphone/social media/internet/computer]: Polish = 4, German = 5). The participant self-rated Polish as his preferred language pre- and post-stroke, which he would choose whenever he could choose (even though his self-rated exposure across languages is lower for Polish [40%] than for German [60%]). The participant reported German and Polish usage when interacting with friends and when he had the choice for reading materials. German was the language for daily activities (e.g., supermarket, medical appointments, restaurant), TV, and radio/music, while Polish was mainly used when BwA2 was in contact with his family (wife, kids, and further relatives) and for writing tasks. His pre-stroke work environment was entirely German-speaking.

Background Language Assessments – BwA2

The pattern of language impairment in BwA2 was consistent with the diagnosis of fluent anomic aphasia (based on clinical observations and the background assessment results). Table E2 shows BwA2’s language performance for both languages on various background assessments. The LEMO subtest for spoken naming resulted in impaired naming abilities for both languages. The participant’s naming accuracy was higher for Polish (L1, non-dominant, preferred language) than for German (L1 Polish LEMO score: 17/20 [85% correct], L2 German LEMO score: 12/20 [60% correct]). BwA2 showed a language impairment in both languages across the thirteen subtests of the BAT. A generally better language performance was shown for Polish (L1, non-dominant, preferred language) compared to German (L1 Polish BAT score: 131/174, L2 German BAT score: 108/174). Spoken naming within the BAT was impaired in both languages, with higher naming accuracy in Polish (L1, non-dominant, preferred language) (L1 Polish BAT naming score: 19/20 [95% correct], L2 German BAT naming score: 12/20 [60% correct]). BwA2 showed higher written naming accuracy for Polish (L1, non-dominant, preferred language) (first 30 items of Subset 1a of the experimental naming task: L1 Polish written naming score 20/30 [66.67% correct], L2 German written naming score 3/30 [10% correct]). The participant’s self-report might indicate that he never learned to write in German. Therefore, German written naming results might be (partly) influenced by the participant’s individual reduced German writing abilities unrelated to the stroke. When comparing written naming and spoken naming of the 30 items of Subset 1a within languages, the participant showed higher accuracy in spoken naming for both languages (spoken naming score: L1 Polish non-dominant: 21/30 [70% correct], L2 German dominant: 11/30 [36.67%]) compared to written naming (written naming score: L1 Polish non-dominant 20/30 [66.67% correct], L2 German dominant 3/30 [10% correct]).

Table E2

Language Background Assessments for BwA2

	Polish (L1)		German (L2)	
Background assessment	Raw score	% correct	Raw score	% correct
Bilingual Aphasia Test (BAT) – Receptive tasks				
Pointing (n=10)	10	100	10	100
Simple and semi-complex commands (n=10)	10	100	6	60
Complex commands (n=20)	0[a]	0[a]	6	30
Verbal auditory discrimination (n=18)	11	61.11	9	50
Semantic categories (n=5)	5	100	3	60
Synonyms (n=5)	3	60	0	0
Lexical decision of words and nonsense words (n=30)	27	90	23	76.67
Lexical decision of words (n=20)	18	90	17	85
Lexical decision of nonwords (n=10)	9	90	6	60
Reading comprehension for words (n=10)	6	60	5	50
Bilingual Aphasia Test (BAT) – Expressive tasks				
Repetition of words and nonsense words (n=30)	26	86.67	20	66.67
Repetition of words (n=20)	18	90	16	80
Repetition of nonwords (n=10)	8	80	4	40
Series (n=3)	3	100	2	66.67
Verbal fluency (n=3)	3	100	2	66.67
Spoken Naming (n=20)	19	95	12	60
Reading Aloud (n=10)	8	80	10	100
Overall BAT-score	*131*		*108*	
LEMO 2.0 – Spoken Naming (Subtest 13)				
Naming: Total (n=20)	17	85	12	60
High frequency (n=10)			8	80
Low frequency (n =10)			4	40
Naming Subset 1a (items 1-30)				
Written naming	20	66.67	3[b]	10[b]
Spoken naming	21	70	11	36.67

[a] Participant does not follow the instructions and starts pointing out to objects while the test administrator (spouse) still reads out the task instructions.

[b] Based on the participant's statement; it is highly likely that he never learned to write in German.

Background Information BwA3

Medical Records and Self-Reports – BwA3

Demographic and Medical Data

BwA3 was a 64-year-old Dutch-German speaker (male), who immigrated from the Netherlands to Germany at the age of 25. BwA3 worked as a farmer and tradesman in the Netherlands and later as a farmer in Germany. He retired after his stroke 28 years prior to this study. BwA3's medical history reported multiple stroke incidents (30 years, 28 years, and 14 years ago prior to this study). The participant had two strokes 30 years ago and three to four transient ischaemic attacks 14 years before this study; he had no language impairment resulting from these. Twenty-eight years before this study, BwA3 had a left hemisphere infarct in the middle cerebral artery. This resulted in one and a half years of coma, followed by four years of rehabilitation in a specialised hospital and rehabilitation centres. BwA3's self-reports and medical records reported aphasia post-onset.

Language Related Data

After the coma, BwA3 was diagnosed with speech apraxia, dysphagia, and global aphasia (including severe impairments in language production, comprehension, writing and reading). Language recovered post-onset comprehensively, with mainly mild spoken word finding difficulties remaining. BwA3 recalled that there was no difference in the recovery patterns across his languages (parallel language recovery pattern).

Bilingual Language Profile – BwA3

BwA3 was a late Dutch-German bilingual speaker. He reported that he was fully immersed in German (L2) from the time of his move to Germany. His dominant language was German (L2) pre- and post-stroke. The dominant language was determined by BwA3's language proficiency, language exposure and use, and biographical factors (language age of acquisition, environmental languages, language of residence). The LEAP-Q and self-reports were used to conduct biographical factors. The results of the language background assessments, spanning across receptive and expressive tasks (see below), determined the participant's language proficiency. By using a scale from 0-8, whereas 0 indicated 'no/minor language use and exposure' and 8 indicated 'high language use and exposure', language use and exposure were determined. Based on the scale, language use and exposure were higher in German (L2) pre- and post-stroke (language use and exposure scale score: Dutch = 1-2, German = 8). The participant used German when interacting with family and friends, for daily life activities (e.g., supermarket, medical appointments, restaurants), TV, radio/music, smartphone/social media/internet/computer, reading, and writing. Dutch has been used when interacting with family (kids who live in the Netherlands) and, in the past, when interacting with friends.

Background Language Assessments – BwA3

The participant's pattern of language impairment was consistent with the diagnosis of fluent anomic aphasia (based on clinical observations and the background assessment results). Table E3 shows BwA3's language performance for both languages on a range of background assessments. The LEMO subtest for spoken naming resulted in impaired naming abilities for both languages. Naming accuracy was higher in Dutch (L1, non-dominant) compared to German (L1 Dutch LEMO score: 15/20 [75% correct], L2 German LEMO score: 10/20 [50% correct]). BwA3 showed a language impairment in both languages. A generally better language performance was observed in German (L2, dominant) compared to Dutch (L1 Dutch BAT score: 144/171, L2 German BAT score: 148[44]/171). Spoken naming within the BAT was impaired in both languages, with higher naming accuracy in Dutch (L1, non-dominant) compared to German (L1 Dutch BAT naming score: 16/20 [80% correct], L2 German BAT naming score: 12/20 [60% correct]). BwA3 showed higher naming accuracy in written naming for German (L2, dominant) compared to Dutch (first 30 items of Subset 1a of the experimental naming task: L1 Dutch written naming score: 17/30 [56.67% correct], L2 German written naming score: 24/30 [80% correct]). The participant showed the same accuracy across written and spoken naming for Dutch (L1, non-dominant) for the 30 items of Subset 1a (spoken naming score: 17/30 [56.67% correct]). Within German naming of Subset 1a, accuracy was higher for written naming (written naming score: L2 German dominant 24/30 [80% correct]) compared to spoken naming (spoken naming score German L2 dominant: 19/30 [63.33% correct]).

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[44] To compare the overall BAT score across languages, the subset score for verbal fluency has been excluded from the German (L2) overall BAT score since this subset result was missing for the Dutch (L1) version. When including the verbal fluency subset score, the participant's overall L2 German BAT score is 151/174.

Table E3

Language Background Assessments for BwA3

	Dutch (L1)		German (L2)	
Background assessment	Raw score	% correct	Raw score	% correct
Bilingual Aphasia Test (BAT) – Receptive tasks				
Pointing (n=10)	10	100	10	100
Simple and semi-complex commands (n=10)	10	100	10	100
Complex commands (n=20)	13	65	9	45
Verbal auditory discrimination (n=18)	15	83.33	17	94.44
Semantic categories (n=5)	3	60	4	80
Synonyms (n=5)	5	100	5	100
Lexical decision of words and nonsense words (n=30)	26	86.67	29	96.67
Lexical decision of words (n=20)	20	100	20	100
Lexical decision of nonwords (n=10)	6	60	9	90
Reading comprehension for words (n=10)	10	90	10	100
Bilingual Aphasia Test (BAT) – Expressive tasks				
Repetition of words and nonsense words (n=30)	26	86.67	29	96.67
Repetition of words (n=20)	19	95	20	100
Repetition of nonwords (n=10)	7	70	9	90
Series (n=3)	0	0	3	100
Verbal fluency (n=3)	n/a[a]	n/a[a]	3(0[b])	100(0[b])
Spoken Naming (n=20)	16	80	12	60
Reading Aloud (n=10)	10	100	10	100
Overall BAT-score	*144*		*151 (148[b])*	
LEMO 2.0 – Spoken Naming (Subtest 13)				
Naming: Total (n=20)	15	75	10	50
High frequency (n=10)			5	50
Low frequency (n =10)			5	50
Naming Subset 1a (items 1-30)				
Written naming	17	56.67	24	80
Spoken naming	17	56.67	19	63.33

[a] Subtest results are missing.

[b] Excluding the subset verbal fluency to compare the overall BAT score across languages.

Background Information BwA4

Medical Records and Self-Reports – BwA4

Demographic and Medical Data

BwA4 was a 75-year-old English-German speaker (female), who was born and raised in South Africa and moved to different countries across her life span (Australia, Germany). The participant was two years and nine months post-onset at the start of the project. BwA4 had a stroke in the middle cerebral left artery, resulting in aphasia.

Language Related Data

Medical records reported a non-fluent aphasia post-onset with severely impaired verbal production immediately post-onset (verbal production was reduced to 'no'-responses) and impaired writing and reading abilities (reading abilities recovered three months post-onset). Language comprehension was only mildly impaired. The participant's language recovered to mild expressive aphasia with moderate to mild spoken word finding difficulties. Her English language (L1) recovered first, while German recovered at a slower pace. Relatives reported a (stronger) English accent post-onset when the participant spoke German, which had not been observed prior to the stroke. At the start of this project, BwA4 described her recovery patterns as balanced, which aligns with a parallel language recovery pattern.

Bilingual Language Profile – BwA4

BwA4 was a 75-year-old late[45] English-German bilingual speaker. The participant moved to Australia at the age of 16 years with her family. She was fully immersed in German (L2) from the time of her move to Germany at the age of 27. She returned to Australia at the age of 59 years. English (L1) was the participant's dominant language pre- and post-stroke, determined by BwA4's language proficiency, language exposure and use, and biographical factors (language age of acquisition, environmental languages, language of residence). The results of the language background assessments, spanning across receptive and expressive tasks (see below), were used to determine the participant's language proficiency. Biographical factors were conducted by the LEAP-Q and self-reports. Language use and exposure were higher in English, determined by using a scale from 0-8, whereas 0 indicated

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[45] BwA4 grew up as an early (simultaneously) bilingual speaker in South Africa, speaking English and Africans, however, Africans was less dominant than English. After moving to Australia at 16, Africans was no longer a present language. The participant reported maintained comprehension abilities and no production abilities left for Africans. BwA4s Africans was not assessed as part of this study.

‘no/minor language use and exposure’ and 8 indicated ‘high language use and exposure’ (language use and exposure scale score: English = 8, German = 3; see also participants section for further information on the scale). After the participant’s re-movement to Australia 16 years prior to this study, English and German have been used in interaction with the family (family language is English and German), when reading and for her minimal usage of smartphone/internet/computer/social media. English has been reported as her language when interacting with friends, for daily life activities (e.g., restaurant, medical appointments, restaurants, etc.), TV, radio/music, and writing.

Background Language Assessments – BwA4

The pattern of impairment in BwA4 was consistent with a diagnosis of fluent anomic aphasia (based on clinical observations and the background assessment results). Table E4 shows BwA4’s language performance for both languages on a range of background assessments. The LEMO subtest for spoken naming resulted in impaired naming abilities for both languages. Results showed higher naming accuracy for English (L1, dominant) than for German (L1 English LEMO score: 16/20 [80% correct], L2 German LEMO score: 13/20 [65% correct]). BwA4 showed a language impairment in both languages. A slightly better language performance was shown for German (L2, non-dominant) than for English (L1 English BAT score: 158[46]/173, L2 German BAT score: 162/173). Spoken naming within the BAT was unimpaired in the dominant language English (L1) but impaired in German (L2) (L1 English BAT naming score: 20/20 [100% correct], L2 German BAT naming score: 16/20 [80% correct]). Participant BwA4 showed higher naming accuracy in written naming for English (L1, dominant) compared to German (first 30 items of Subset 1a of the experimental naming task: L1 English written naming-score: 26/30 [86.67% correct], L2 German written naming-score: 16/30 [53.33% correct]). When naming these 30 items in English (L1, dominant), written naming accuracy was higher relative to spoken naming accuracy (spoken naming score: 24/30 [80% correct]). Within German naming of Subset 1a, accuracy was higher for spoken naming (spoken naming score: German L2 non-dominant: 18/30 [60%

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[46] Five points were deducted within the English version's subtest repetition of words and nonwords. This deduction was based on ambiguity made by the test administrator. Without the administrator's ambiguity error, the score for the BAT in English would increase to 163/173, resulting in a balanced language disorder across BwA4's two languages available when comparing the overall BAT score (L1 English 163/173, L2 German 162/173).

correct]) compared to the written naming performance (written naming score: L2 German non-dominant 16/30 [53.33% correct]).

Table E4

Language Background Assessments for BwA4

	English (L1)		German (L2)	
Background assessment	Raw score	% correct	Raw score	% correct
Bilingual Aphasia Test (BAT) – Receptive tasks				
Pointing (n=10)	10	100	10	100
Simple and semi-complex commands (n=10)	10	100	10	100
Complex commands (n=20)	18	90	18	90
Verbal auditory discrimination (n=18)	15	83.33	15	83.33
Semantic categories (n=5, English n=4)	4	100	5(4[a])	100(100[a])
Synonyms (n=5)	4	80	4	80
Lexical decision of words and nonsense words (n=30)	29	96.67	30	100
Lexical decision of words (n=20)	20	100	20	100
Lexical decision of nonwords (n=10)	9	90	10	100
Reading comprehension for words (n=10)	10	100	10	100
Bilingual Aphasia Test (BAT) – Expressive tasks				
Repetition of words and nonsense words (n=30)	23[b]	76.67	30	100
Repetition of words (n=20)	15	75	20	100
Repetition of nonwords (n=10)	8	80	10	100
Series (n=3)	3	100	3	100
Verbal fluency (n=3)	3	100	3	100
Spoken Naming (n=20)	20	100	16	80
Reading Aloud (n=10)	9	90	9	90
Overall BAT-score	*158*[b]		*163(162*[a]*)*	
LEMO 2.0 – Spoken Naming (Subtest 13)				
Naming: Total (n=20)	16	80	13	65
High frequency (n=10)			8	80
Low frequency (n =10)			5	50
Naming Subset 1a (items 1-30)				
Written naming	26	86.67	16	53.33
Spoken naming	24	80	18	60

[a] Due to an error by the test administrator, one item was excluded from the English semantic categories subtest. This item was also excluded from the German semantic categories subtest to be able to compare the overall BAT score across languages.

[b] Five points were deducted within the English version's subtest repetition of words and nonwords. However, this deduction was based on ambiguity made by the test administrator. Without the administrator's obscurity error, the score for the BAT in English would increase to 163/173.

Background Information BwA5

Medical Records and Self-Reports – BwA5

Demographic and Medical Data

BwA5 was a 64-year-old English-Italian speaker (male) from Australia, who worked as a former office manager and retired after his third stroke (one year and three months prior to this study). The participant had three strokes (four years, one year eight months, and one year three months prior to this study). The first stroke (four years ago) was diagnosed as a transient ischemic attack (left insula, left middle and anterior cerebral artery). It did not notably affect linguistic and cognitive abilities. The second stroke (one year and eight months prior to this study: Major stroke with thrombectomy) was localised in the left hemisphere's parietal, frontal and temporal areas and resulted in motor issues and language difficulties (all modalities). The participant returned to work in April 2019 after a successful recovery process. A month later (one year and three months prior to this study), BwA5 had a third stroke (left frontal areas, left middle cerebral artery [M2], left frontal operculum [anterior]) which resulted in aphasia.

Language Related Data

Based on medical records, the participant’s stroke one year and three months post-onset resulted in non-fluent expressive aphasia, including severe spoken word finding difficulties and difficulties with reading, writing production and comprehension. BwA5’s recovery pattern has been described and defined as a parallel recovery pattern (see background assessment results, including productive and receptive language tasks).

Bilingual Language Profile – BwA5

BwA5 was an early (simultaneously) English-Italian bilingual speaker born and raised in Australia, growing up in an English-Italian-speaking family since his parents immigrated to Australia from Italy. Italian was spoken at home with the parents growing up, and English was the language when the participant spoke to his siblings. Additionally, some music and TV shows were played in Italian. He married an early (simultaneously) English-Italian bilingual speaker (his parents-in-law also immigrated from Italy before his wife was born). English was the participant’s dominant language pre- and post-stroke, based on his language proficiency, language exposure and use, and biographical factors (language age of acquisition, environmental languages, language of residence). Biographical factors were conducted by the LEAP-Q and self-reports, and the results of the language background assessments, spanning across receptive and expressive tasks (see below), determined the participant's language proficiency. Language use and exposure were higher in English, determined by the usage of a scale from 0-8, whereas 0 indicated 'no/minor language use and exposure' and 8 indicated 'high language use and exposure' (language use and exposure scale scores: English = 8, Italian = 1-2; see also participants section for further information on the scale). English has been used in all language contexts (interaction with family and friends, daily life activities [e.g., supermarket, medical appointment, restaurant], TV, radio/music, internet/computer/smartphone/social media, reading, writing). Italian and English language were used when interacting with family (Italian mainly when interacting with parents and parents-in-law). The participant's work environment prior to his stroke was English.

Background Language Assessments – BwA5

The participant's pattern of language impairment was consistent with the diagnosis of non-fluent Broca's aphasia (based on clinical observations and the background assessment results). Table E5 shows BwA5's language performance for both languages across various background assessments. The LEMO subtest of spoken naming assessed impaired naming abilities for both languages. Higher naming accuracy was shown for English (dominant) (English LEMO score: 6/20 [30% correct], Italian LEMO score: 0/20 [0% correct]). BwA5 showed a language impairment in both languages. A generally better language performance was observed for English (dominant) compared to Italian (English BAT score: 104[47]/170, Italian BAT score: 55/170). Spoken naming (n = 16) within the BAT was impaired in both languages, with higher naming accuracy in English (dominant) (English BAT naming score: 10/16 [62.5% correct], Italian BAT naming score: 1/16 [6.25% correct]). When comparing written naming accuracy across languages, BwA5 showed higher naming accuracy in written naming for English (dominant) compared to Italian (first 30 items of Subset 1a of the experimental naming task: English written naming score: 8/30 [26.67% correct], Italian written naming score: 0/30 [0% correct]). Within language comparison of written and spoken naming accuracy of these 30 items, slightly higher accuracy was shown for written naming in English (dominant) compared to spoken naming (spoken naming score: 7/30 [23.33% correct]). In Italian, the spoken and written naming task was unsuccessful (spoken naming score: L1 Italian non-dominant 0/30 [0% correct]).

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[47] The BAT-subtest naming misses four items in the Italian version. To compare the overall BAT-score across languages, these four items have been excluded from the English naming subset. When including these four items the participant's overall English BAT-score is 105/174.

Table E5

Language Background Assessments for BwA5

	English (L1)		Italian (L1)	
Background assessment	Raw score	% correct	Raw score	% correct
Bilingual Aphasia Test (BAT) – Receptive tasks				
Pointing (n=10)	9	90	8	80
Simple and semi-complex commands (n=10)	7	70	0	0
Complex commands (n=20)	0	0	0	0
Verbal auditory discrimination (n=18)	13	72.22	6	33.33
Semantic categories (n=5)	4	80	1	20
Synonyms (n=5)	0	0	0	0
Lexical decision of words and nonsense words (n=30)	26	86.67	16	53.33
Lexical decision of words (n=20)	19	95	15	75
Lexical decision of nonwords (n=10)	7	70	1	10
Reading comprehension for words (n=10)	9	90	3	30
Bilingual Aphasia Test (BAT) – Expressive tasks				
Repetition of words and nonsense words (n=30)	15	50	17	56.67
Repetition of words (n=20)	15	75	13	65
Repetition of nonwords (n=10)	0	0	4	40
Series (n=3)	2	66.67	0	0
Verbal fluency (n=3)	1	33.33	0	0
Spoken Naming (n=20, Italian n=16)	11(10[a])	55(62.5[a])	1	6.25
Reading Aloud (n=10)	8	80	3	30
Overall BAT-score	*105 (104[a])*		*55*	
LEMO 2.0 – Spoken Naming (Subtest 13)				
Naming: Total (n=20)	6	30	0	0
Naming Subset 1a (items 1-30)				
Written naming	8	26.67	0	0
Spoken naming	7	23.33	0	0

[a] The BAT-subtest naming misses four items in the Italian version. These four items have been excluded from the English naming subset to compare the overall BAT score across languages. The participant's overall English BAT score is 105/174 when including these four items.

Background Information BwA6

Medical Records and Self-Reports – BwA6

Demographic and Medical Data

BwA6 was a 65-year-old English-French speaker (female), who was born and grew up in the United Kingdom and immigrated to Australia at the age of 31. She had previously worked as a speech-language pathologist in the UK and Australia. BwA6 had a left-sided embolism in the middle cerebral artery in 2012 when she was 57 (eight years prior to the present study). The stroke initially resulted in dysphagia and aphasia.

Language Related Data

The participant's stroke resulted in dysphagia and aphasia with impaired auditory and reading comprehension, spoken word finding difficulty, and cognitive impairments such as reduced memory and attention. The participant further reported some prosopagnosia and ongoing fatigue. At the start of the project, the following was reported: Fluent aphasia with mild spoken word finding difficulties (especially when tired), mild comprehension and reading difficulties (complex input), mild fatigue and attention difficulties. BwA6 recalled that immediately after her stroke, she experienced language mixing/switching (her two languages seemed 'jumbled', e.g., when experiencing word finding difficulties in English, the equivalent French word would come to mind, which had not been the case pre-stroke). She reported that once this passed, after a short period, there was no difference in the recovery patterns across her languages (hence, the assumption that both languages followed a parallel language recovery pattern).

Bilingual Language Profile – BwA6

BwA6 was an English-French bilingual speaker. She fully immersed in French (L2) at the age of 17 while living in France with a French family and attending a French secondary school for several months. She maintained close ties to France throughout her adult life, visiting regularly and staying in touch with her French friends, even when she immigrated from the United Kingdom to Australia at the age of 31. The native language English (L1) was the participant's dominant language pre- and post-stroke, which was determined by BwA6's language proficiency, language exposure and use, and biographical factors (language age of acquisition, environmental languages, language of residence). Language proficiency was determined by the results of the language background assessments, spanning across receptive and expressive tasks (see below). Biographical factors were conducted by the LEAP-Q and self-reports. Language use and exposure were higher in English (L1), determined by the application of a scale from 0-8, whereas 0 indicated 'no/minor language use and exposure' and 8 indicated 'high language use and exposure' (language use and exposure scale score: English = 8, French = 2; see also participants section for further information on the scale). English was the participant's language in all language contexts (interacting with family and friends, daily life activities [e.g., supermarket, medical appointments, restaurant], TV, radio/music, smartphone/social media/internet/computer, reading, writing). French was used when interacting with friends (via email, telephone, and holidays) and preferred for reading.

Background Language Assessments – BwA6

The pattern of language impairment in BwA6 was consistent with the diagnosis of fluent anomic aphasia (based on clinical observations and the background assessment results). Table E6 shows BwA6's language performance for both languages on a range of background assessments. The LEMO subtest for spoken naming resulted in impaired naming abilities for both languages with slightly higher naming accuracy for English (L1, dominant) (L1 English LEMO score: 15/20 [75% correct], L2 French LEMO score: 13/20 [65% correct]). BwA6 showed a language impairment in both languages. A slightly better language performance was observed for English (L1, dominant) compared to French (L1 English BAT score: 152/173, L2 French BAT score: 149[48]/173). Spoken naming (n = 19) within the BAT was mildly impaired in both languages, with slightly higher naming accuracy for English (L1, dominant) (L1 English BAT naming score: 18/19 [94.74% correct], L2 French BAT naming score: 17/19 [89.47% correct]). BwA6 showed unimpaired written naming results for English (L1, dominant) (first 30 items of subset 1a of the experimental naming task: L1 English written naming score: 30/30 [100% correct]). Written naming was impaired for French (L2) (first 30 items of Subset 1a of the experimental naming task: L2 French written naming score: 15/30 [50% correct]). When comparing written naming and spoken naming of these 30 items within languages, the participant showed slightly higher accuracy in written naming for English (L1, dominant) compared to spoken naming (spoken naming score: 29/30 [96.67% correct], written naming score: 30/30 [100% correct]). Within French naming, the accuracy was 50% across spoken and written naming (spoken naming score: 15/30 [50% correct], written naming score: 15/30 [50% correct]).

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[48] The subset naming misses an item for the English version. This item was excluded for the French version to compare the participant's language performance across languages. When including this item, the overall French BAT score is 150/174.

Table E6

Language Background Assessments for BwA6

	English (L1)		French (L2)	
Background assessment	Raw score	% correct	Raw score	% correct
Bilingual Aphasia Test (BAT) – Receptive tasks				
Pointing (n=10)	10	100	10	100
Simple and semi-complex commands (n=10)	10	100	9	90
Complex commands (n=20)	9	45	14	70
Verbal auditory discrimination (n=18)	15	83.33	17	94.44
Semantic categories (n=5)	4	80	3	60
Synonyms (n=5)	4	80	0	0
Lexical decision of words and nonsense words (n=30)	27	90	24	80
Lexical decision of words (n=20)	19	95	17	85
Lexical decision of nonwords (n=10)	8	80	7	70
Reading comprehension for words (n=10)	10	100	9	90
Bilingual Aphasia Test (BAT) – Expressive tasks				
Repetition of words and nonsense words (n=30)	29	96.67	30	100
Repetition of words (n=20)	20	100	20	100
Repetition of nonwords (n=10)	9	90	10	100
Series (n=3)	3	100	3	100
Verbal fluency (n=3)	3	100	3	100
Spoken Naming (n=20, English n=19)	18	94.74	18(17[a])	90(89.47[a])
Reading Aloud (n=10)	10	100	10	100
Overall BAT-score	*152*		*150 (149[a])*	
LEMO 2.0 – Spoken Naming (Subtest 13)				
Naming: Total (n=20)	15	75	13	65
Naming Subset 1a (items 1-30)				
Written naming	30	100	15	50
Spoken naming	29	96.67	15	50

[a] This naming subset misses an item for the English version. This item was also excluded for French to compare the overall BAT score across languages.

Background Information BwA7

Medical Records and Self-Reports – BwA7

Demographic and Medical Data

BwA7 was a 66-year-old French-English speaker (male), born and raised in Mauritius and immigrated to Australia aged 28. Pre-stroke, he had worked in the hotel industry in Mauritius and Australia. BwA7 had two right-sided ischemic strokes in 2004 when he was 49 years (16 years prior to the present study) which resulted in a left-sided paresis of the upper and lower limbs.

Language Related Data

Medical data were unavailable; however, regular speech therapy visits (post-onset) were reported, including therapy for word finding difficulties and communication training. BwA7 self-reported short-term memory loss and reduced attention. He presented with mild dysphonia, reporting a history of vocal nodules. BwA7 recalled that following the stroke, there was no difference in the recovery patterns across his languages (which would match with a parallel language recovery pattern).

Bilingual Language Profile – BwA7

BwA7 was a late[49] French-English bilingual speaker. He was fully immersed in English (L2) at the age of 13 when he attended an English-speaking secondary school in Mauritius. The data of all the project's bilingual profile assessments (self-reports, LEAP-Q, language background assessments) indicated, that the participant's L2 (English) was his slightly dominant language pre- and post-stroke (determined by BwA7's language proficiency, language exposure and use, and biographical factors [language age of acquisition, environmental languages, language of residence]). Language proficiency was determined by the results of the language background assessments, spanning across receptive and expressive tasks (see below). Biographical factors were conducted by the LEAP-Q and self-reports. Language use and exposure were slightly higher in English, determined by a scale ranging from 0-8, whereas 0 indicated 'no/minor language use and exposure' and 8 indicated 'high language use and exposure' (language use and exposure scale scores for

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[49] BwA7 grew up as an early (simultaneously) bilingual speaker. He learnt both French and Mauritian Creole from birth. Both languages were spoken at home, with French being more dominant since it was spoken at school, amongst friends and in the wider community. The participant reported maintaining proficiency in Mauritian Creole. His Creole was not assessed in this study.

BwA7 [out of 7, due to lack of information about writing]: French = 5, English = 7; see also participants section for further information on the scale). Both languages were used in multiple contexts: Contact with the family (immediate family: English, parents and siblings: French), TV, radio/music, smartphone/internet/computer/social media, and reading. English was additionally the language of daily life activities (e.g., supermarket, medical appointments, restaurant) and when interacting with friends.

Background Language Assessments – BwA7

The participant's pattern of language impairment was consistent with the diagnosis of fluent anomic aphasia (based on clinical observations and the background assessment results). Table E7 shows BwA7's language performance for both languages on various background assessments. The LEMO subtest spoken naming resulted in balanced impaired naming abilities across languages (L1 French LEMO score: 16/20 [80% correct], L2 English LEMO score: 16/20 [80% correct]). BwA7 showed a mild language impairment across both languages (L1 French BAT score: 164/174, L2 English BAT score: 165/174). Spoken naming within the BAT was mildly impaired in both languages (L1 French BAT naming score: 19/20 [95% correct], L2 English BAT naming score: 19/20 [95% correct]). Participant BwA7 showed higher naming accuracy in written naming for English (L2, dominant) compared to French (first 30 items of Subset 1a of the experimental naming task: L1 French written naming-score: 20/30 [66.67% correct], L2 English written naming-score: 24/30 [80% correct]). When comparing written naming and spoken naming of these 30 items within languages, the participant showed higher accuracy for spoken naming in French (L1, non-dominant) compared to written naming (written naming score: 20/30 [66.67% correct], spoken naming score: 22/30 [73.33% correct]). Within Subset 1a naming in English (L2 dominant) the accuracy of written naming was higher than for spoken naming (written naming score: 24/30 [80% correct], spoken naming score: 21/30 [70% correct]).

Table E7

Language Background Assessments for BwA7

	French (L1)		English (L2)	
Background assessment	Raw score	% correct	Raw score	% correct
Bilingual Aphasia Test (BAT) – Receptive tasks				
Pointing (n=10)	10	100	10	100
Simple and semi-complex commands (n=10)	10	100	10	100
Complex commands (n=20)	14	70	16	80
Verbal auditory discrimination (n=18)	15	83.33	16	88.89
Semantic categories (n=5)	5	100	5	100
Synonyms (n=5)	5	100	4	80
Lexical decision of words and nonsense words (n=30)	30	100	29	96.67
Lexical decision of words (n=20)	20	100	20	100
Lexical decision of nonwords (n=10)	10	100	9	90
Reading comprehension for words (n=10)	10	100	10	100
Bilingual Aphasia Test (BAT) – Expressive tasks				
Repetition of words and nonsense words (n=30)	30	100	30	100
Repetition of words (n=20)	20	100	20	100
Repetition of nonwords (n=10)	10	100	10	100
Series (n=3)	3	100	3	100
Verbal fluency (n=3)	3	100	3	100
Spoken Naming (n=20)	19	95	19	95
Reading Aloud (n=10)	10	100	10	100
Overall BAT-score	*164*		*165*	
LEMO 2.0 – Spoken Naming (Subtest 13)				
Naming: Total (n=20)	16	80	16	80
Naming Subset 1a (items 1-30)				
Written naming	20	66.67	24	80
Spoken naming	22	73.33	21	70

Background Information BwA8

Medical Records and Self-Reports – BwA8

Demographic and Medical Data

BwA8 was a 74-year-old French-English speaker (female), who immigrated from Mauritius to Australia in 1973, aged 28. She had worked in a creche in Mauritius and in catering in Australia. BwA8 had several frontal strokes: Twelve years and eight months ago (infarct in left inferior frontal gyrus and right occipital lobe), nine years ago (infarct in the right middle frontal gyrus), and three months[50] ago (left inferior frontal gyrus infarct and a small infarct in the posterior margin of the frontal lobe).

Language Related Data

The infarct 12 years and eight months ago resulted in non-fluent aphasia (for French and English), with writing abilities left. With recruitment for this project (before the third stroke), the participant was diagnosed with mild receptive and expressive aphasia characterised by some word finding difficulty, mild dysarthria and self-reported mild memory impairment. This diagnosis remained after the third stroke. A stronger French accent when speaking in English was reported due to the third stroke. BwA8 recalled no difference in the recovery patterns across her languages.

Bilingual Language Profile – BwA8

Participant BwA8 was a late[51] French-English speaker, who was fully immersed in English (L2) from the time when she immigrated from Mauritius to Australia. The participant's L2 (English) was her dominant language pre- and post-stroke, based on our project's bilingual profile assessments (self-reports, LEAP-Q, language background assessments). Language proficiency, language exposure and use, and biographical factors (language age of acquisition, environmental languages, language of residence) determined the dominant language. The results of the language background assessments, spanning across receptive and expressive tasks (see below) determined the participant's language proficiency,

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[50] BwA8 had a stroke after the recruitment. The stroke resulted in no significant long-term issues and no extended rehabilitation process. She left the hospital at moved back home. BwA8 was willing to participate in the project. Therefore, the project started three months after the stroke.

[51] BwA8 grew up as an early (simultaneously) bilingual speaker. She learnt both French and Mauritian Creole from birth. French was spoken at home, school, work, and community. Creole was spoken in the community; however, the participant was forbidden to speak Mauritian Creole at home. BwA8 reported maintaining proficiency in Mauritian Creole by being a member of a Mauritian community in Australia. Her Creole was not assessed as part of this study.

while data taken from the LEAP-Q and self-reports were used to define BwA8's biographical factors. The participant's language use and exposure were higher in English, determined by a scale from 0-8, whereas 0 indicated 'no/minor language use and exposure' and 8 indicated 'high language use and exposure' (language use and exposure scale scores: French = 2, English = 8; see also participants section for further information on the scale). English was used in all contexts of the participant's life: Interaction with the family (immediate family: English, sister: French), interaction with friends, daily life activities (e.g., supermarket, medical appointments, restaurant), TV, radio/music, smartphone/internet/computer/social media, reading, writing. French was used by the participant when in (daily) contact with her sister(s) and during some leisure activities with friends (e.g., attending a Mauritian choir, an active member of a Mauritian community).

Background Language Assessments – BwA8

The pattern of language impairment in BwA8 was consistent with the diagnosis of fluent anomic aphasia (based on clinical observations and the background assessment results). Table E8 shows BwA8's language performance for both languages across various background assessments. The LEMO subtest spoken naming resulted in impaired naming abilities for both languages with slightly higher naming accuracy for English (L2, dominant) (L1 French LEMO score: 17/20 [85% correct], L2 English LEMO score: 18/20 [90% correct]). BwA8 showed a language impairment in both languages. A generally better language performance was shown for English (L2, dominant) (L1 French BAT score: 147[52]/156, L2 English BAT score: 152/156). Spoken naming within the BAT was unimpaired across languages (L1 French BAT naming score: 20/20 [100% correct], L2 English BAT naming score: 20/20 [100% correct]). BwA8 showed higher naming accuracy in written naming for English (L2, dominant) in comparison to French (first 30 items of Subset 1a of the experimental naming task: L1 French written naming score: 20/30 [66.67% correct], L2 English written naming score: 25/30 [83.33% correct]). The participant showed the same accuracy across written and spoken naming for French (L1, non-dominant) for the 30 items of Subset 1a of the experimental naming task (written naming score: 20/30 [66.67% correct], spoken naming score: 20/30 [66.67% correct]). Within English naming of Subset 1a, the

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[52] The English BAT version misses nine items in the subtest 'repetition and lexical decision of words and nonsense words' (repetition n=9, lexical decision n=9). These items have been excluded from the French subtest to compare the overall BAT score across languages. When including these items in the French subtest, the participant's overall L1 French BAT score is 165/174.

accuracy of spoken naming was higher than written naming (written naming score: 25/30 [83.33% correct]), spoken naming score English L2 dominant: 26/30 [86.67% correct]).

Table E8

Language Background Assessments for BwA8

	French (L1)		English (L2)	
Background assessment	Raw score	% correct	Raw score	% correct
Bilingual Aphasia Test (BAT) – Receptive tasks				
Pointing (n=10)	10	100	10	100
Simple and semi-complex commands (n=10)	10	100	10	100
Complex commands (n=20)	18	90	20	100
Verbal auditory discrimination (n=18)	14	77.78	16	88.89
Semantic categories (n=5)	4	80	5	100
Synonyms (n=5)	5	100	4	80
Lexical decision of words and nonsense words (n=30; English n=21)	29(20[a])	96.67(95.24[a])	20	95.24
Lexical decision of words (n=20; English n=13)	19(12[a])	95(92.31[a])	13	100
Lexical decision of nonwords (n=10; English n=8)	10(8[a])	100(100[a])	7	87.5
Reading comprehension for words (n=10)	9	90	10	100
Bilingual Aphasia Test (BAT) – Expressive tasks				
Repetition of words and nonsense words (n=30; English n=21)	30(21[a])	100(100[a])	21	100
Repetition of words (n=20; English n=13)	20(13[a])	100(100[a])	13	100
Repetition of nonwords (n=10; English n=8)	10(8[a])	100(100[a])	8	100
Series (n=3)	3	100	3	100
Verbal fluency (n=3)	3	100	3	100
Spoken Naming (n=20)	20	100	20	100
Reading Aloud (n=10)	10	100	10	100
Overall BAT-score	*165(147[a])*		*152*	
LEMO 2.0 – Spoken Naming (Subtest 13)				
Naming: Total (n=20)	17	85	18	90
Naming Subset 1a (items 1-30)				
Written naming	20	66.67	25	83.33
Spoken naming	20	66.67	26	86.67

[a] The English BAT version misses nine items in the subtest ‘repetition and lexical decision of words and nonsense words’ (repetition n=9, lexical decision n=9). These items have been excluded from the French subtest to compare the overall BAT score across languages. The participant’s overall L1 French BAT score is 165/174 when including these items in the French subtest.

General Appendix F

Error Types Guide

Table F1

Definition of Error Types with Examples for the Target and Non-target Language (Examples are Based on an English-German Bilingual Speaker, Target Language: English)

Error type	Target language	Non-target language
Phonological error	A phonological error is a phonological deviation to the target, which is specified by a second code to signpost the type of phonological error (phonologically related non-word, phonologically related real-word [formal error], conduite d'approche, blend, phonological jargon): • A phonologically related non-word is defined by a response with phonological changes to the target, whereas the target remains recognizable by phonological similarity. Phonological changes include substitution (e.g., target *horse*, response *lorse*), omission/elision (e.g., target *desk*, response *esk*), addition (e.g., target *chair*, response *chlair*), metathesis (e.g., target *telephone*, response *tephelone*), and mixed phonological changes (e.g., target *dinosaur*, response *dinesores*). Phonological similarity to the target is defined by a 50% cut-off limit to differentiate phonological related and unrelated non-words (if 51% of the target is preserved in the correct sequence the response is classified as related). • A phonologically related real-word, also known as formal error, is defined by a real-word replacement with phonological similarity to the	A phonological error in the non-target language is a phonological deviation to the target of the non-target language, which is specified by a second code to signpost the type of phonological error (phonologically related non-word, phonologically related real-word [formal error], conduite d'approche, blend, phonological jargon): • A phonologically related non-word is defined by a response with phonological changes to the target of the non-target language, whereas the target of the non-target language remains recognizable by phonological similarity. Phonological changes include substitution (e.g., target *horse*, response *Pfefd* [substitution in the non-target language target *Pferd*), omission/elision (e.g., target *desk*, response *isch* [omission/elision in the non-target language target *Tisch*), addition (e.g., target *chair*, response *Stluhl* [addition in the non-target language target *Stuhl*), metathesis (e.g., target *telephone*, response *tefelon* [metathesis in the non-target language target *Telefon*), and mixed phonological changes (e.g., target *dinosaur*, response *dinauslorier* [mixed phonological changes in the non-target language target

	target (no semantic relation) that is mostly a minimal pair/phonological neighbour (e.g., target *house*, response *louse*). • A conduite d'approche is a gradual phonological approach to the target in a self-correction attempt. The search behaviour manifests itself in several repeated, immediately successive self-correction attempts. At least two incorrect attempts (otherwise it is self-correction) need to be present (e.g., target *plate,* response *pa pla plan plate*). • Phonological jargon: A meaningless string of phonologically related or unrelated non-words in fluent speech production (e.g., target *wheel*, response *betan be- taran bewemenemen b-bot man no that otomat toraten*).	*Dinosaurier*). Phonological similarity to the target in the non-target language is defined by a 50% cut-off limit to differentiate phonological related and unrelated non-words (if 51% of the target is preserved in the correct sequence the response is classified as related). • A phonologically related real-word (in the non-target language), also known as formal error, is defined by a non-target language real-word replacement with phonological similarity to the target (no semantic relation) that is mostly a minimal pair/phonological neighbour (e.g., target *house*, response *Laus* [German equivalent to *louse* which is a cognate]). • A conduite d'approche is a gradual phonological approach in the non-target language to the target in a self-correction attempt. The search behaviour manifests itself in several repeated, immediately successive self-correction attempts. At least two incorrect attempts (otherwise it is self-correction) need to be present (e.g., target *plate,* response *Te Tel Telo Telor Teller*). • Phonological jargon: A meaningless string of phonological related or unrelated non-words in the non-target language in fluent speech production (e.g., target *wheel*, response *Übet lattäfel bä- tarföbfel belämanötane b-bolt hatüte* [meaningless string of phonological unrelated words in German]).
Phonologically unrelated non-word	This error type is defined by a response with a change of phonemes leading to a not recognizable word. The result is a non-word that does not meet the criteria of phonological similarity (see phonological error for a definition of phonological similarity) (e.g., target *bed*, response *ucsenchail*).	This error type is defined by a non-target language response with a change of phonemes leading to a not recognizable non-target language word. The result is a non-word that does not meet the criteria for phonological

		similarity (see phonological error for a definition of phonological similarity) (e.g., target *bed*, response *ülänak* [German non-word]).
Semantic error	A noun response to the target that has a clear semantic relation (e.g., target *pillow*, response *blanket*) or an associative relation to the target. In the former case the noun response can be a category coordinate (e.g., target *carrot*, response *pea*), a superordinate (e.g., target *carrot*, response *vegetable*), a subordinate (e.g., target *flower*, response *daisy)* or associated (e.g., target *cinema,* response *movie*). Additionally, semantic errors can be proper noun responses with a semantic relationship to the target (e.g., target *four-wheel drive (4WD)*, response *Landcruiser*) or a related proper name to the target, which notes an association (e.g., target *star*, response *Cowboys*).	A non-target language noun response to the target that has a clear semantic relation (e.g., target *pillow*, response *Decke* [German equivalent to *blanket*]) or an associative relation to the target. In the latter case the non-target language noun response can be a category coordinate (e.g., target *carrot*, response *Erbse* [German equivalent to *pea*]), a superordinate (e.g., target *carrot*, response *Germuese* [German equivalent to *vegetable*]), a subordinate (e.g., target *flower*, response *Gaensebluemchen* [German equivalent for *daisy*]) or associated (e.g., target *cinema,* response *Film* [German equivalent to *movie*]). Additionally, semantic errors can be proper non-target language noun responses with a semantic relationship to the target (e.g., target *tissue*, response *Tempo)* or a related non-target language proper name to the target, which notes an association (e.g., target *medal*, response *Polizist*).
Semantically unrelated error	A real-word noun response with no semantic relation and without a phonological similarity to the target (e.g., target *airplane*, response *kitchen*).	A real-word noun response in the non-target language with no semantic relation and without a phonological similarity to the target (e.g., target *airplane*, response *Küche* [German equivalent to *kitchen*]).
Semantically unrelated non-word	Compound words that are not common in the standard target language (e.g., target *chair,* response *eeggarden*).	Non-target language compound words that are not common in the standard non-target language (e.g., target *chair,* response *Eiergarten* [German equivalent - to *eeggarden* - not common in the standard German language]).

Semantic-then-phonological error	Responses that are semantically related to the target and contain phonological errors (e.g., target *apple*, response *banuna*).	Non-target language responses that are semantically related to the target and contain phonological errors (e.g., target *apple*, response *Bänane* [phonological error of *Banane,* the German equivalent to *banana*]).
Mixed error	Real-word responses that are semantically related and have a phonologically similarity to the target (definition phonological similarity see above) (e.g., target *strawberries*, response *cherries*).	Non- target language real-word responses that are semantically related and have a phonologically similarity to the target (definition phonological similarity see above) (e.g., target *rice*, response *Fleisch* [German word for meat]).
Morphological error	This error type is a morphologically related response (flexion or derivation) to the target. The given response can be an addition or deletion of a plural form (e.g., target *book*, response *books*), a production of a verb (e.g., target *boxer*, response *boxing*) or an adjective (e.g., target *home*, response *homely*), that is related to the target.	This error type is a morphologically related response in the non-target language (flexion or derivation) to the target. The given response in the non-target language can be an addition or deletion of a plural form (e.g., target *book*, response *Bücher* [German equivalent to *books*]), a production of a verb (e.g., target *boxer*, response *boxen* [German equivalent to *boxing*]) or an adjective (e.g., target *home*, response *häuslich* [German equivalent to *homely*]), that is related to the target.
Unspecified error	An unspecified error is a response to the target that has semantic, phonological and morphological error components. It can be characterized by an addition, substitution (e.g., target *microscope*, response *telescope*) or omission (e.g., target *fireman*, response *fire*) of a morpheme in a compound/multi-morphemic word.	An unspecified error in the non-target language is a non-target language response to the target that has semantic, phonological and morphological error components. It can be characterized by an addition, substitution (e.g., target *microscope*, response *Teleskop* [German equivalent to *telescope*]) or omission (e.g., target *fireman*, response *Feuer* [German equivalent to *fire*) of a morpheme in a compound/multi-morphemic word.

Multiword circumlocution	A multiword circumlocution response provides characteristics of the target or attempts to explain the targets' function or purpose (e.g., target *spoon*, response *to eat a soup*). Additionally, this error type includes responses in the form of 'type of X', whereas the X is defined as a superordinate (e.g., target *carrot*, response *type of vegetable*).	A multiword circumlocution response in the non-target language provides characteristics of the target or attempts to explain the targets' function or purpose in the non-target language (e.g., target *spoon*, response *um eine Suppe zu essen* [German equivalent to *to eat a soup*]). Additionally, this error type includes responses in the non-target language in the form of 'type of X', whereas the X is defined as a superordinate (e.g., target *carrot*, response e*ine Art Gemuese* [German equivalent to *type of vegetable*]).
Single word circumlocution	This error type is specified by a one-word response that is a verb (e.g., target *sandwich*, response *eating*), adjective (e.g., target *strawberry*, response *sweet*) or adverb (e.g., target *scarf*, response *outside*) with a semantic relationship to the target. A single word circumlocution error additionally includes compound responses with a semantic relationship to the target (e.g., target *salad*, response *vegetablemix*).	This error type is specified by a one-word response in the non-target language that is a verb (e.g., target *sandwich*, response *essen* [German equivalent to *eating*]), adjective (e.g., target *strawberry*, response *suess* [German equivalent to *sweet*]) or adverb (e.g., target *scarf*, response *draussen* [German equivalent to *outside*]) with a semantic relationship to the target. A single word circumlocution error additionally includes compounds responses in the non-target language with a semantic relationship to the target (e.g., target *salad*, response *Gemuesemischung* [German equivalent to *vegetablemix*]).
Visual error	A visual error is defined by a response that is visually but not semantically related to the target (e.g., target *bow*, response *harp*). Verbal or non-verbal responses illustrating a non-recognition are coded as visual errors, too (e.g., target *bow*, response *What's that? That's a weird picture.*).	A visual error is defined by a non-target language response that is visually but not semantically related to the target (e.g., target *bow*, response *Harfe* [German equivalent to *harp*]). Verbal or non-verbal responses illustrating a non-recognition are coded as visual errors, too (e.g., target *bow*, response *Was ist das? Das ist ein komisches Bild.* [German equivalent to *What's that? That's a weird picture.*]).
Acceptable alternative	This error type includes responses that are an acceptable semantic alternative/synonym to the target (e.g., target *sink*, response *basin*) or	This error type includes non-target language responses that are an acceptable semantic alternative/synonym to the target (e.g., target *fruit*,

	responses with an additionally modifier, resulting in a compound word (e.g., target *glasses*, response *eyeglasses*)	response *Obst* [German equivalent is *Fruechte*, *Obst* is an acceptable alternative/synonym]) or responses with an additional modifier, resulting in a compound word (e.g., target *bone*, response *Hundeknochen* [German equivalent – compound word – to *dogs' bone*]).
Use-of-language error	A use-of-language error is defined by a response that is a common use in a language, e.g., the use of diminutives (e.g., target *dog*, response *doggy*).	A use-of-language error is defined by a response in the non-target language that is a common us in the non-target language, e.g., the use of diminutives (e.g., target *dog*, response *Huendchen* [German equivalent to *doggy]*).
Other error	This category includes a number or error types: The response to the target is a spelling (e.g., target *frog*, response *f-r-o-g*) or includes a spelling (e.g., target *beanie*, response *starts with a B*), a sound effect (e.g., target *dog*, response *woof-woof*), a non-specific comment (e.g., target *radio*, response *this thing*) or a personal comment (e.g., target *grapes* response *had them this morning*). Additionally, visual in picture/picture part errors are included. This error type is defined by a real-word response that is a component of the depicted target (e.g., target *Dracula,* response *gown* [picture shows Dracula wearing a gown]) or a word representing the context (background) of which the target is a component (e.g., target *scar* response *knee* [picture shows a scar on a visible knee]).	This category includes a number or error types in the non-target language: The non-target language response is a spelling (e.g., target *frog*, response *F-r-o-sch* [German equivalent to *f-r-o-g*]) or includes a spelling (e.g., target *beanie*, response *beginnt mit einem B* [German equivalent to *starts with a B*]), a sound effect (e.g., target *dog*, response *wau-wau* [German equivalent to *woof-woof*), a non-specific comment (e.g., target *radio*, response *dieses Ding* [German equivalent to *this thing*]) or a personal comment (e.g., target *grapes* response *hatte die diesen Morgen* [German equivalent to *had them this morning*]). Additionally, visual in picture/picture part errors are included. This error type is defined by a real-word response in the non-target language that is a component of the depicted target (e.g., target *Dracula,* response *Umhang* [German equivalent to *gown*, picture shows Dracula wearing a gown]) or a word representing the context (background) of which the target is a component (e.g., target *scar* response *Knie* [German equivalent to *knee*, picture shows a scar on a visible knee]).

Note. References: Berg, 2006, Blanken, 1990, Corsten & Mende, 2011, Grande & Hußmann, 2016, Roach et al., 1996, Schlenck, 1997, Stadie et al., 2013, Whitworth et al., 2014.

Table F2

Definition of Further Error Types with Examples

Error type	Definition
No response	No responses, responses given after ten seconds or verbal indications that the item cannot be named (e.g., target *milk*, response *I don't know*) are coded as a no response. Fragments, filler words, automatism, determiners, and self-interruptions within the first ten seconds will not be coded.
Correct in non-target language	Responses to the target that are correct in the non-target language are coded as correct in non-target language error (e.g., target *chair*, response *Stuhl* [German equivalent to *chair*]).
Language mixing error	A language mixing error is specified by a response to the target that includes components of the target and the non-target language. Language mixing errors can manifest on morpheme (e.g., target *pear*, response *pearne* [language mixing of the target *pear* and the German equivalent *Birne*], syllable (e.g., target *shower*, response *showsche* [language mixing of the target *shower* and the German equivalent *Dusche*]) or word level (e.g., target *bedroom*, response *bedzimmer* [language mixing of the target *bedroom* and the German equivalent *Schlafzimmer*]).
Back-translation error	Responses that refer to the non-target language translation equivalent as the bases for creating an unidiomatic solution into the target language are coded as back-translation error. These responses are a literal back-translation from the non-target language equivalent word (to the target word) into the target language (e.g., target *medusa* [French for *jellyfish*], response *poisson de gellée* [literal back-translation into French of the English translation equivalent *jellyfish*].

Note. References: Berg, 2006, Blanken, 1990, Corsten & Mende, 2011, Grande & Hußmann, 2016, Roach et al., 1996, Schlenck, 1997, Stadie et al., 2013, Whitworth et al., 2014.

General Appendix G

Error Types Examples for each Bilingual Speaker with Aphasia

Table G1

Response Examples per Error Type for Each Bilingual Speaker with Aphasia

Error	Error language	BwA1	BwA2	BwA3	BwA4	BwA5	BwA6	BwA7	BwA8
Phonological error	Target	T: schwert	T: cukierek	T: kleid	T: bruecke	T: bed	T: poivron	T: pumkin	T: scorpion
		R: schwart	R: czukierek	R: keid	R: brucke	R: ben	R: poivre	R: pumki	R: scorpon
	Non-target	T: trui	T: qualle	T: struisvogel	T: reissverschluss	T: --	T: robot	T: --	T: --
		R: pullo	R: meduze	R: straussvogel$^{\text{(s not sch)}}$	R: fip	R: --	R: romot	R: --	R: --
Phonologically unrelated non-word	Target	T: vogelscheuche	T: schuessel	T: duim	T: torwart	T: --	T: pomme	T: --	T: --
		R: bope	R: tschusse	R: held	R: gop	R: --	R: pal	R: --	R: --
	Non-target	Target: --	T: --	T: --	T: --	T: --	T: --	T: --	T: crâne
		Response: --	R: --	R: --	R: --	R: --	R: --	R: --	R: skirt
Semantic error	Target	T: motor	T: diabelskie koło	T: vliegveld	T: judge	T: lake	T: wave	T: doll	T: mouse
		R: auto	R: karuzela	R: hangaar	R: professor	R: river	R: sea	R: girl	R: rat
	Non-target	T: schaap	T: lis(ica)	T: hai	T: pirate	T: coro	T: cerf-volant	T: --	T: --
		R: ziege	R: wolf	R: walvis	R: ritter	R: church	R: parachute	R: --	R: --
Semantically unrelated error	Target	T: galgen	T: dach	T: kinn	T: penguin	T: choir	T: assiette	T: koala	T: os
		R: hexehaus	R: fliegen	R: bett	R: Peppy Can	R: chair	R: serviette	R: grenouille	R: eux
	Non-target	T: --	T: --	T: --	T: waschbecken	T: rullo	T: --	T: --	T: --
		R: --	R: --	R: --	R: bassinet	R: bench	R: --	R: --	R: --
Semantically unrelated non-word	Target	T: telefoon	T: --	T: --	T: --	T: --	T: --	T: --	T: --
		R: beker	R: --	R: --	R: --	R: --	R: --	R: --	R: --
	Non-target	T: --	T: --	T: --	T: --	T: --	T: --	T: --	T: --
		R: --	R: --	R: --	R: --	R: --	R: --	R: --	R: --
Semantic-then-phonological error	Target	T: trompete	T: dudy	T: hoek	T: schwein	T: --	T: hache	T: --	T: microscope
		R: posan	R: fajfa	R: hangkasje	R: spahnferkel$^{\text{(s not sch)}}$	R: --	R: sciel	R: --	R: tethoscope
	Non-target	T: --	T: --	T: --	T: bogen	T: --	T: --	T: --	T: compas

		R: --	R: --	R: --	R: arror	R: --	R: --	R: --	R: protacteur
Mixed error	Target	T: draak	T: --	T: --	T: --	T: --	T: --	T: --	T: poing
		R: dracula	R: --	R: --	R: --	R: --	R: --	R: --	R: poignée
	Non-target	T: --	T: --	T: --	T: --	T: --	T: --	T: --	T: --
		R: --	R: --	R: --	R: --	R: --	R: --	R: --	R: --
Morphological error	Target	T: tomaat	T: auge	T: lineal	T: hose	T: dog	T: glove	T: flipper	T: trumpet
		R: tomaten	R: augen	R: lineale	R: hosen	R: dogs	R: gloves	R: flippers	R: trumpets
	Non-target	T: giraf	T: --	T: --	T: umarmung	T: guanto	T: grille-pain	T: --	T: --
		R: giraffen	R: --	R: --	R: hugs	R: gloves	R: toast	R: --	R: --
Unspecified error	Target	T: wasserhahn	T: kostka do gry	T: bloemkool	T: taschenlampe	T: fish tank	T: fireman	T: windmill	T: sunflower
		R: hahn	R: kostka	R: kool	R: taschentuech	R: fish	R: man	R: mill	R: flower
	Non-target	T: stuur	T: skrzynka na listy	T: --	T: --	T: teiera	T: cornemuse	T: --	T: --
		R: rad	R: briefkassette	R: --	R: --	R: tea	R: pipes	R: --	R: --
Multiword circumlocution	Target	T: limousine	T: brunnen	T: limousine	T: drachen	T: parachute	T: flèche	T: teapot	T: --
		R: lange auto	R: wasser frisch	R: hele grote auto	R: ach ja das fliegt	R: up in the air	R: à droite	R: pot of tea	R: --
	Non-target	T: zwemmer	T: --	T: --	T: --	T: ombrello	T: --	T: --	T: --
		R: schwimmende persoon	R: --	R: --	R: --	R: waiting for the rain	R: --	R: --	R: --
Single-word circumlocution	Target	T: fledermaus	T: biblia	T: salade	T: --	T: lighter	T: chalk	T: --	T: --
		R: abends	R: książka kościęłna	R: groentemix	R: --	R: smoking	R: write	R: --	R: --
	Non-target	T: zeemeermin	T: --	T: --	T: --	T: --	T: --	T: --	T: --
		R: fischmensch	R: --	R: --	R: --	R: --	R: --	R: --	R: --
Visual error	Target	T: thermometer	T: mauer	T: batterij	T: keyboard	T: --	T: cloud	T: printer	T: compass
		R: stift	R: strasse	R: soundbox	R: wall	R: --	R: blob	R: couch	R: medal
	Non-target	T: kompas	T: --	T: --	T: --	T: --	T: --	T: --	T: --
		R: kette	R: --	R: --	R: --	R: --	R: --	R: --	R: --
Acceptable alternative	Target	T: hase	T: astronauta	T: lenkrad	T: krawatte	T: salad	T: pepper	T: fish tank	T: lightblub
		R: kaninchen	R: kosmonauta	R: steuer	R: schlips	R: greens	R: capsicum	R: aquarium	R: globe
	Non-target	T: --	T: trommel	T: --	T: --	T: motore	T: --	T: tonneau	T: --
		R: --	R: welbel	R: --	R: --	R: engine	R: --	R: drum	R: --
Use-of-language error	Target	T: oorbel	T: pędzel	T: cadeau	T: bike	T: television	T: limo	T: rino	T: hippo
		R: orbeletje	R: pędzelek	R: cadeautje	R: bicycle	R: TV	R: limousine	R: rhinoceros	R: hippopotamus

Other error	Non-target	T: --	T: --	T: --	T: kuehlschrank	T: telefono	T: facteur	T: --	T: --
		R: --	R: --	R: --	R: refrigerator	R: phone	R: postie	R: --	R: --
	Target	T: dusche	T: schnabel	T: nacht	T: teacher	T: peg	T: tattoo	T: chin	T: chalk
		R: duschkop	R: oben laufen	R: baume	R: blackboard	R: when I go out	R: ankle	R: lips	R: blackboard
	Non-target	T: --	T: --	T: --	T: --	T: uovo	T: infirmière	T: --	T: casque
		R: --	R: --	R: --	R: --	R: I did that last night	R: that's her again	R: --	R: I know the English word
Correct in non-target language		T: feuer	T: żaba	T: vlieg	T: sweet	T: insalata	T: soutien-gorge	T: appareil photo	T: fée
		R: vurr	R: frosch	R: fliege	R: bonbon	R: salade	R: bra	R: camera	R: fairy
Language mixing error		T: slaapkamer	T: --	T: eekhoorn	T: --	T: --	T: --	T: bull	T: --
		R: slaapzimmer	R: --	R: eikhoorntje	R: --	R: --	R: --	R: booro	R: --
Back translation error		T: leuchtturm	T: --	T: vlieger	T: flughafen	T: --	T: trousse	T: trousse	T: pile
		R: feuertum	R: --	R: draak	R: lufthafen	R: --	R: sac crayon	R: sac à crayons	R: batré

Note. T = Target, R = Response.

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