

**School of Occupational Therapy, Social Work and Speech Pathology**

**Understanding the Mechanisms of Facial Emotion  
Recognition in Adults with Autism Spectrum Disorders:  
Insights from Eye Tracking and Electroencephalography**

**Melissa Heather Black**

**This thesis is presented for the Degree of  
Doctor of Philosophy  
of Curtin University**

**August, 2018**

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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 acknowledgement has been made.

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

The research presented and reported in this thesis was conducted in accordance with the National Health and Medical Research Council National Statement on Ethical Conduct in Human Research (2007) – updated March 2014. The proposed research study received human research ethics approval from the Curtin University Human Research Ethics Committee (EC00262), Approval number (HR52/2012).

Signed:

A handwritten signature in blue ink, appearing to be 'mhd', is written over a faint circular stamp.

Date: 20 August, 2018

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## **DEDICATION**

Mum and Dad, I am forever grateful for the sacrifices you have made to support me throughout all of my endeavours. Knowing that “you’ll be proud of me - no matter what I do – as long as I’m happy”, gave me the confidence to try, even when I was afraid of failing. I dedicate this thesis to you.

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## **ABSTRACT**

Pervasive difficulty in the domains of social interaction and communication are experienced by those with a diagnosis of Autism Spectrum Disorder (ASD). Impairments in facial emotion recognition (FER) are suspected to contribute to, and underlie these broader social difficulties, with deficits in accurately recognising emotion in others widely associated with this population. While behaviourally, impairments in FER tasks have been observed in autistic individuals, the underlying mechanisms contributing to these deficits remain unknown. Obtaining insight into the underlying origins of ASD-linked FER impairment is essential to not only further the collective understanding of ASD and related conditions, but also to provide avenues for improvements in diagnosis, prognosis and intervention.

Eye tracking and Electroencephalography (EEG) provide a means of examining the attentional and neural complexities of cognitive processes, making these measures valuable in understanding the mechanisms underlying impairments in FER. While previous eye tracking and EEG investigation has provided some insight into the processes underlying FER in autistic individuals, they have been largely restricted to experimental paradigms which may not reflect the contextual dynamics associated with day to day interaction and may not adequately capture the everyday social functioning of autistic adults. This thesis sought to employ socially relevant stimuli to further the understanding of the contributory mechanisms to ASD-linked FER impairment. To provide avenues for these findings in contributing to prognosis and intervention, these measures were further examined in regard to their potential utility as biomarkers for the classification of ASD in adulthood.

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This thesis consists of eight chapters, six of which are comprised of manuscripts for peer-review publication. Chapters One and Two provide an overview of pertinent literature in the field, with Chapter Two presenting a systematic review investigating the eye tracking and EEG characteristics of autistic individuals during FER tasks. This systematic review synthesises findings from 54 articles examining eye tracking and EEG in autistic individuals using a developmental approach. While this review identified a number of EEG and gaze-based characteristics in autistic individuals, heterogeneity between studies was observed, namely in eye tracking literature. Collectively, EEG and gaze-based findings provide evidence to suggest altered social brain function in autistic individuals. A number of insights and future directions for research are discussed.

Chapter Three discusses the importance of conducting research using complex and socially relevant stimuli. This chapter examines the Cambridge Mind Reading Face-Voice Battery (CAMs), a battery of complex, dynamic FER stimuli which have been used throughout this thesis to provide a socially relevant measure of FER. This study provides normative data on the facial emotion stimuli presented in the CAMs for a typically developing sample using both a dimensional and discrete approach to conceptualising emotion.

Chapter Four examines the gaze behaviour of autistic adults during a complex, dynamic FER task to determine whether aberrant gaze behaviour observed in previous paradigms extends into stimuli which has a greater direct practical relevance to the day to day social interactions of autistic adults. It was found that autistic adults gazed more to the mouth compared to typically developing adults, and while not statistically significant, descriptively speaking also gazed less to the eyes than typically developing adults. Results

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contribute to heterogeneity within the body of literature, lending support to the need to employ socially relevant stimuli in the investigation of the gaze-based mechanisms of FER impairment in ASD. Chapters Five and Six then examine neural oscillation and imaginary coherency measures to examine the neural correlates and functional communication between brain networks which may underlie altered processing of emotional information in autistic adults. Findings these chapters showed altered spectral power activity in autistic adults, particularly in the theta band, as well as altered connectivity, characterised by reduced long range inter and intra-hemispheric connectivity and enhanced short range intra-hemispheric connectivity. Findings suggest that autistic adults may respond hyper-reactivity to emotions, supporting postulations that altered neural activity in FER may contribute to ASD-linked FER impairment.

Finally, Chapter Seven employs a bottom-up data driven approach to determine the effectiveness of neural oscillations collected during FER to classify ASD. The combination of a commonly used screen for autistic-like traits in combination with EEG-biomarkers provided a high accuracy in detecting ASD, though preliminary in nature, this Chapter provide support for the potential of EEG-based biomarkers to support diagnosis, prognosis and intervention for autistic adults.

The findings of this thesis contribute new knowledge to the understanding of ASD-linked FER impairment. Through the use of complex, dynamic stimuli, novel insights into the eye tracking and EEG-based mechanisms underlying FER in autistic adults are provided, with findings arguably having a greater direct practical relevance to the day to day functioning of autistic adults.

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Appendix E. Authorship contribution forms for papers submitted as part of this thesis (Papers I – IV)

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## ABBREVIATIONS LIST

ADHD	Attention Deficit Hyperactivity Disorder
AOI	Area of Interest
ANOVA	Analysis of Variance
ASD	Autism Spectrum Disorders
CAMs	Cambridge Mind Reading Face-Voice Battery
cICA	Constrained Independent Component Analysis
DSM	Diagnostic and Statistical Manual for Mental Disorders
EEG	Electroencephalography
ET	Eye Tracking
ERP	Event Related Potential
FER	Facial Emotion Recognition
FFA	Fusiform Face Area
FSIQ	Full Scale Intelligence Quotient

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ICA	Independent Component Analysis
IQ	Intelligence Quotient
TEA	Test of Everyday Attention
TD	Typically Developing
PRI	Perceptual Reasoning Index
rmANOVA	Repeated Measures ANOVA
SMI	SensoMotoric Instruments
SRS	Social Responsiveness Scale
VCI	Verbal Comprehension Index
WASI	Wechsler Abbreviated Scale of Intelligence

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## LIST OF PUBLICATIONS

### Paper I

Black, M. H., Chen, N. T., Iyer, K. K., Lipp, O. V., Bölte, S., Falkmer, M., . . . Girdler, S. (2017). Mechanisms of facial emotion recognition in autism spectrum disorders: Insights from eye tracking and electroencephalography. *Neuroscience and Biobehavioral Reviews*, *80*, 488-515. doi: h10.1016/j.neubiorev.2017.06.016. Impact factor 8.1 (5-year impact 10.02). Citations: 4

### Paper II

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### Paper III

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## **Paper IV**

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## **Paper V**

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## **LIST OF CONFERENCE PRESENTATIONS**

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Black, M.H., Almabruk, T., Albrecht, M.A., Lipp, O.V., Bölte, S., Tan, T. & Girdler, S. (2018). Altered connectivity in autistic during complex facial emotion recognition: A study of EEG imaginary coherence. IEEE Engineering in Medicine and Biology. Honolulu, Hawaii.

### **Conference Posters**

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- Dr Nigel Chen
- Professor Sven Bölte

### Statistical Assistance

- Dr Richard Parsons

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## EXPLANATION OF TERMINOLOGY

Within this thesis ‘Autism Spectrum Disorder’ (ASD) refers to individuals with a confirmed diagnosis of ASD as per the guidelines of the most recent version of the Diagnostic and Statistical Manual for Mental Disorders (DSM-5)<sup>1</sup>.

This most recent version of the DSM-5, released in 2013, represents key changes in the diagnostic criteria for ASD. Under the previous version of the DSM (DSM-4)<sup>2</sup>, ASD included a number of conditions, including Autistic Disorder, Pervasive Developmental Disorder-Not Otherwise Specified (PDD-NOS), and Asperger Syndrome. These terms are however not included in the DSM-5 and are encompassed within the common term of ASD. As the population of interest within this thesis were adults, it is likely that these individuals have received a diagnosis according to criteria presented in the DSM-4, thus the diagnostic terms outlined in the DSM-4 are used within this thesis.

It must be acknowledged that significant debate exists surrounding the terminology used to refer to ASD<sup>3</sup>. Within research and in the community a wide range of terms are used to refer to individuals with a diagnosis of ASD, including ‘individuals with ASD’, ‘autistic individuals’ or ‘individuals on the autism spectrum’.

‘Autistic’ has been suggested to be favoured by individuals with a diagnosis of ASD<sup>3</sup>, and is one of the preferred terms for research into adulthood of the Autism Cooperative Research Centre (Autism CRC)<sup>4</sup>, the world’s first national cooperative research centre

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<sup>1</sup> American Psychiatric Association. (2013). Diagnostic and Statistical Manual of Mental Disorders (DSM-5®)

<sup>2</sup> American Psychiatric Association. (2010). Diagnostic and Statistical Manual for Mental Disorders (DSM-IV-R)

<sup>3</sup> Kenny, L., Hattersley, C., Molins, B., Buckley, C., Povey, C., & Pellicano, E. (2015). Which terms should be used to describe autism? Perspectives from the UK autism community. *Autism*, 1-21.

<sup>4</sup> Autism CRC. (2018). Autism CRC. from [www.autismcrc.com.au](http://www.autismcrc.com.au)

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focused on ASD. In recognition of the preferences of the autistic community, ‘autistic’ is the preferred term applied in this thesis when referring to individuals with a clinical diagnosis of ASD. As the chapters presented in this thesis however present manuscripts for publication, terms such as ‘ASD’ or ‘Autism Spectrum Disorder’ have also been used where necessary due to the preferred terminology of the journals. Therefore both ‘autistic’ and ‘individuals with Autism Spectrum Disorder’ or ‘ASD’ have been used interchangeably through this thesis.



## **CHAPTER ONE**

### **INTRODUCTION**



The ability to recognize facially expressed emotion is an essential aspect of social communication. Impairments in facial emotion recognition (FER) are commonly experienced by individuals with a diagnosis Autism Spectrum Disorders (ASD), with deficits in the accurate and timely recognition of facially expressed emotion apparent across the lifespan.

A considerable degree of research has attempted to understand the origins of impaired FER in autistic individuals, however, the precise nature of the mechanisms contributing to ASD-linked FER difficulty remain unclear. This thesis attempts to extend the investigation of the mechanisms of FER in autistic adults. Within this thesis, a combination of eye tracking and electroencephalography (EEG) measures are used to provide insight into the attentional and neural processes of FER in autistic individuals. A focus is further placed on the use of complex emotional concepts to increase the social relevance and real-world applicability of findings.

This introduction chapter provides an overview and brief discussion of the core concepts and literature pertinent to this thesis.

## **CONCEPTUALIZING EMOTION**

While this thesis is primarily focused on facial emotion recognition (FER), emotion and its conceptualization more generally must be discussed.

The concept of emotion is extremely complex and multifaceted. Attempts to define the concept of emotion have revealed that no one single definition for emotion exists (Izard, 2010). Despite the lack of any clear and agreed upon definition, Izard (2010) has provided a description of emotion:

“Emotion consists of neural circuits (that are at least partially dedicated), response systems, and a feeling state/process that motivates and organizes cognition and action. Emotion also provides information to the person experiencing it and may include antecedent cognitive appraisals and ongoing cognition including an interpretation of its feeling state, expressions or social-communicative signals, and may motivate approach or avoidant behaviour, exercise control/regulation of responses, and be social or relational in nature.” (p.367)

Conceptualizing the phenomenon of emotion has received significant attention within the psychological and emotion-based literature (Izard, 2010). Theories of emotion may be broadly divided into two core approaches, discrete and dimensional theories. While these two approaches have traditionally been presented as opposing hypotheses, recent arguments suggest that a combination of both discrete and dimensional approaches may prove beneficial to the understanding of emotion (Harmon-Jones, Harmon-Jones, & Summerell, 2017).

### **Discrete Approaches**

Discrete conceptualizations propose that emotions are distinct and independent. Original proponents of discrete emotion theories hypothesized the existence of a number of biologically based and innate core emotions with clearly defined antecedents and behavioural outcomes (Darwin, 1872; Ekman, 1992). To account for the highly context-dependent nature of emotion, and the significant heterogeneity evident in behavioural responding, more recent discrete approaches propose a more dynamic structure of emotion, whereby emotions remain ‘discrete’, however take the form of coherent patterns of various processes (Colembetti, 2009).

While several discrete emotion theories exist, the concept of basic emotions proposed by Ekman (1992), has arguably become the most dominant approach to conceptualising emotion to date. Basic emotion theories purport the existence of six basic emotions (happiness, anger, sadness, fear, disgust, surprise) which are innate, universally distinguishable and observed cross-culturally (Ekman & Friesen, 1971). Similar hypotheses of fundamental emotions have been made by others. Izard (1977) for example postulated the existence of 10 foundational emotions in the Differential Emotion Theory (Izard, 1977), while Tomkins (Tomkins, 1962, 1963) posited the existence of nine fundamental affects.

These basic or fundamental emotions have been theorized to form the basis for the development of more complex emotional concepts or ‘emotion families’ (Ekman & Cordaro, 2011; Izard, 2007). Unlike the basic emotions which are believed to be universally and cross-culturally distinguishable, complex emotions (such as guilt, jealousy, interested, amusement), built on the foundation of basic or fundamental emotions, may be influenced by the social and cultural context in which an individual is situated (Baron-Cohen & Cross, 1993). Complex emotions rely more heavily on belief or cognitive processing (Johnson-Laird & Oatley, 1989), requiring the ability to attribute facial expressions to possible underlying beliefs or thoughts (Baron-Cohen & Cross, 1993). For example, understanding the emotional concept of ‘relief’ requires an understanding that the observed facial expression of ‘relief’ is related to an individual’s internal state of realizing that a believed negative event may no longer occur (Sauter, 2017). Other complex emotions may be more reliant on an understanding of social contexts (Baron-Cohen & Cross, 1993), the recognition of embarrassment for example requires the understanding of expected social rules (Ekman & Cordaro, 2011).

## **Dimensional Approaches**

Dimensional models arose from the observation that individuals typically did not perceive emotions as isolated categories, often perceiving emotion as indistinct and inter-connected (Russell, 1980). Dimensional approaches therefore posit that rather than emotions being distinct and arising from unshared patterns of neural processes, emotions may arise from shared or intersecting neuropsychological systems or dimensions (Russell, 1980).

While some previous dimensional theories of emotion have proposed that emotions may be conceptualised using one dimension alone, the majority of well-known dimensional models posit the existence of at least two dimensions (Scherer, 2000). The most commonly identified dimensions include valence, referring to how pleasant or unpleasant an emotion is, and arousal referring to the physiological activation associated with the emotion (e.g., calm or excited) (Feldman & Russell, 1998). Dimensional models built on the two dimensions of valence and arousal include the Circumplex Model of Affect, (Feldman & Russell, 1998; Rubin & Talarico, 2009; Russell, 1980) and the Vector Model (Rubin & Talarico, 2009).

Other dimensional models of emotion have proposed the existence of a third dimension, dominance (Bakker, Van der Voordt, Boon, & Vink, 2014; Osgood, 1952; Osgood, Succi, & Tannenbaum, 1957). This dimension of dominance refers to how dominant, in control, or autonomous individuals feels ranging from feelings of dominance to submissiveness (Figure 1).

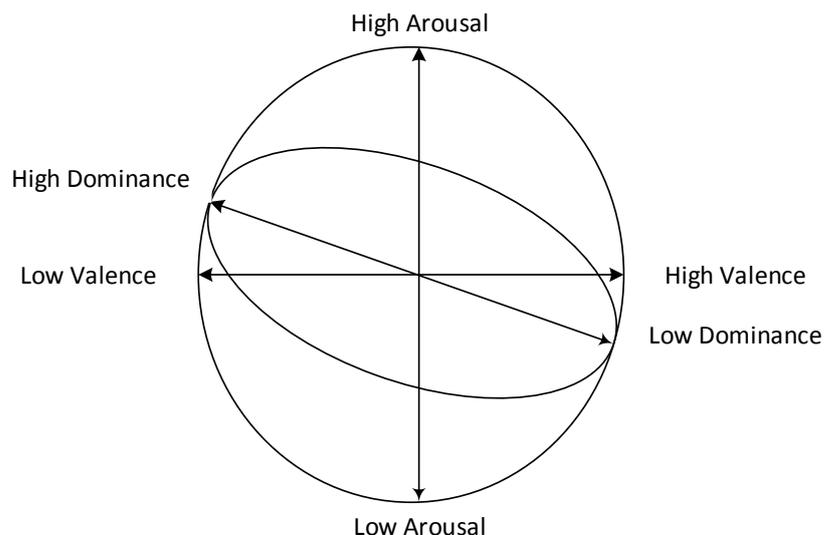


Figure 1. Representation of three-dimensional model of emotion, based on Bakker, I., Van der Voordt, T., Boon, J., & Vink, P. (2014). *Pleasure, arousal, dominance: Mehrabian and Russell revisited. Current Psychology*, 33(3), 405-421. © Springer Science+Business Media New York 2014

A motivational approach has also been used to develop a dimensional model of emotion. These theories are based on the notion that two basic motivational systems exist, appetitive or aversive (Lang, Bradley, & Cuthbert, 1998). Appetitive stimuli are associated with approach motivation and aversive stimuli is associated with a withdrawal response (Lang, Bradley, et al., 1998).

While the research presented in this thesis primarily utilizes a discrete conceptualization of emotion, Chapter Three employs both a discrete and dimensional approach to emotion to investigate complex emotional stimuli presented in the Cambridge Mind-Reading Face Battery (Golan, Baron-Cohen, & Hill, 2006).

## **FACIAL EMOTION RECOGNITION**

Facially expressed emotions provide fundamental information about an individual's underlying affective and mental states, providing valuable cues to their intentions (Darwin, 1872; Ekman, 1977). The ability to decode facial expression for its underlying emotion, referred to as facial emotion recognition (FER) is a fundamental skill required for successful adaptive interaction within social contexts (Darwin, 1872; Ekman 1977).

Typically developing individuals are particularly adept at FER, with these abilities beginning to develop in early infancy and maturing during childhood and adolescence (Kolb, Wilson, & Taylor, 1992; Mondloch, Geldart, Maurer, & Le Grand, 2003; Tonks, Williams, Frampton, Yates, & Slater, 2006). From infancy, typically developing individuals have an interest in socially relevant information, with a preference for faces increasing between three to nine months of age (Frank, Vul, & Johnson, 2009). Though some debate exists regarding when infants develop the ability to accurately distinguish emotions, it is generally agreed that FER abilities may begin to develop by six or seven months of age (Caron, Caron, & Myers, 1985; Phillip, Wagner, Fells, & Lynch, 1990; Walker-Andrews, 1998). Some limited evidence has however suggested that these processes may begin earlier. One study has shown that newborns as young as 31 to 87 hours old may be able to discriminate between happy and fearful images of faces (Farroni, Menon, Silvia, & Johnson, 2007).

The basic emotions show divergent maturation trajectories (Rodger, Vizioli, Ouyang, & Caldara, 2015). The recognition of happiness and fearful expressions may reach maturation by five years of age, whereas surprise, sadness, disgust and anger may continue to develop through to adulthood (Rodger et al., 2015). When morphing stimuli are used to examine sensitivity to fearful and anger expressions in children, adolescents and adults,

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reduced sensitivity to these expressions is observed in both children (7 – 13 years of age) and adolescents (14 – 18 years of age) compared to adults (Thomas, De Bellis, Graham, & LaBar, 2007), suggesting that maturation of structures involved in the detection of these basic emotions are not yet fully developed until late adolescence or young adulthood (Thomas et al., 2007).

The maturation process of complex emotions is less well defined. Recognition of complex emotions (for example jealousy, guilt, intimacy) is influenced by the social and cultural context of an individual, with development of this ability likely influenced by exposure to increasingly complex social environments as an individual matures through adolescence and adulthood (Tonks et al., 2006). Improved ability to recognise complex emotions also depends on the continued development of neural structures and networks involved in social processing and emotion recognition (Tonks et al., 2006). Evidence suggests that neural structures involved in cognition and social functioning continue to mature during late adolescence and adulthood (Blakemore & Choudury, 2006).

## **NEURAL BASIS OF FACIAL EMOTION RECOGNITION**

FER involves diffuse neural networks and structures within the ‘social brain’ (Adolphs, 2002b, 2009), including networks in the frontal, temporal and limbic lobes (Adolphs, 2002a, 2002b, 2009). These brain regions engage in both feedback and feedforward processes during the processing of facial emotion (Adolphs, 2002a, 2002b). While numerous regions within the brain are associated with the recognition of facial emotion at various stages, the role of a number of core regions are outlined briefly in this thesis (Figure 2).

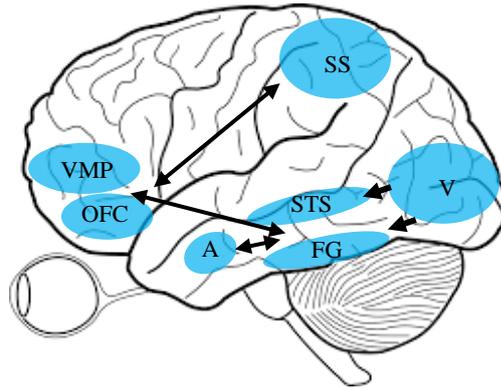


Figure 2. Simplified diagram of regions involved in facial emotion recognition. A; Amygdala, FG; Fusiform Gyrus, OFC; Orbitofrontal Cortex, STS; Superior Temporal Sulcus, SS; Somatosensory Cortex, V; Visual Cortex. Based on Adolphs, R. (2002). *Recognizing emotion from facial expressions: Psychological and neurological mechanisms. Behavioral and Cognitive Neuroscience Reviews, 1(1), 21-62.* © 2002 Sage Publications.

## Visual Cortex

Early visual processing occurs in the occipital and temporal visual regions whereby visual information obtained from the eyes is initially perceived and processed (Braddick, 2001). This information from the visual cortices is then transmitted to associated visual processing regions for fine-grained perceptual processing (Adolphs, 2002a). Activity in this area is modulated by the valence and arousal of stimuli (Lang, Badley, et al., 1998), suggesting that visual processing is enhanced by motivational, emotional and attentional inputs from anterior brain regions, such as the amygdala and fronto-parietal networks (Lang, Badley, et al., 1998; Vuilleumier & Driver, 2007).

## Fusiform Gyrus

The fusiform face area is believed to process configural information, which refers to the ability to perceive relationships between facial features (Maurer, Le Grand, & Mondloch, 2002). While the FFA is typically associated with facial identity processing, given the need for configural processing during FER, there has been some suggestion that the FFA

may also be involved during facial emotion processing (Zhao et al., 2014). While studies have failed to find FFA activity associated with FER (Zhang et al., 2016), others have found contradictory evidence to suggest that the FFA may indeed be involved in facial emotion processing (Harry, Williams, Davis, & Kim, 2013; Xu & Biederman, 2010).

### **Superior Temporal Sulcus**

The superior temporal sulcus is observed to be associated with a number of processes, including theory of mind, biological motion processing and face processing (Hein & Knight, 2008). A review found that the superior temporal sulcus may be involved in a number of networks, with co-activations with other brain regions observed during different cognitive tasks, such as the medial pre-frontal cortex during theory of mind tasks (Hein & Knight, 2008). This structure has been shown to be involved in the perceiving facial movement or variable aspects of faces such as facial emotion and eye gaze direction (Haxby, Hoffman, & Gobbini, 2000; Narumoto, Okada, Sadato, Fukui, & Yonekura, 2001), with emotional faces eliciting enhanced right superior temporal sulcus activity (Narumoto et al., 2001).

### **Amygdala**

The amygdala is a structure situated in the limbic system; through its vast cortical connections, the amygdala is an important component of the social brain (Adolphs, 2009) involved in processes such as emotion perception (Adolphs, 2002b) and memory (McGaugh, 2004), emotion regulation (Banks, Eddy, Angstadt, Nathan, & Phan, 2007) and social behaviour (Bickart, Wright, Dautoff, Dickerson, & Felman Barrett, 2011). Amygdala activity has been observed in response to several emotions (Costafreda,

Brammer, David, & Fu, 2008; Cunningham & Kirkland, 2014), although is commonly associated with the processing of fear and threat-related stimuli (LeDoux, 2003).

While the amygdala receives information from the visual cortices, it may also feedback to these visual processing regions (Vuilleumier, 2005). Through projections with visual processing regions, the amygdala may tune perceptual processing and function to prioritize or direct attention to salient information (Vuilleumier, 2005). Indeed, amygdala damage has been associated with reduced gaze towards the eyes during FER, an area largely believed to be high in social salience (Adolphs et al., 2005).

### **Ventral Medial Prefrontal Cortex**

Similar to the amygdala, the ventral medial prefrontal cortex may be involved in visual attention during FER. During the recognition of fearful expressions, ventral medial prefrontal cortex damage results in reduced gaze towards the eye region (Wolf, Phillippi, Motzkin, Baskaya, & Koenigs, 2014), suggesting that damage to this region may interrupt the perception and direction of attention to salient stimuli, and may influence FER through top-down attentional control (Wolf et al., 2014). Other studies have also found that the ventral medial prefrontal cortex also plays a role in decision making and judgements during social situations (Grossman et al., 2011).

### **Orbitofrontal Cortex**

The orbitofrontal cortex is purported to be involved in a number of functions related to social cognition (Barbey, Krueger, & Grafman, 2009), and in evaluating stimuli for reward and punishment (Kringelbach & Rolls, 2004). Through its connections with sensory processing regions (Carmichael & Price, 1995; Salzman & Fusi, 2010), some research has also suggested that this region is involved in the top down modulation of perceptual

processes (Adolphs, 2002a), and in linking perceptual and conceptual understandings of emotion (Adolphs, 2002b). One study using dynamic representations of facially expressed emotion found that the orbitofrontal cortex may continuously monitor affective information and modulate responses (Goodkind et al., 2012). Damage to this area has been shown to result in FER impairment, particularly in the negative emotions (Willis, Palermo, McGrillen, & Miller, 2014).

### **Somatosensory Cortex**

During emotion recognition it is proposed that individuals develop internal representations or simulations of observed facial expressions. Through developing these internal simulations of expression, neural activity involved in experiencing that emotion are activated (Adolphs, 2002b). It is believed that these processes undertaken in the somatosensory cortex are essential to developing and accurate understanding of the underlying emotion experienced by others (Adolphs, Damasio, Tranel, Cooper, & Damasio, 2000; Haxby et al., 2000). The somatosensory cortex is also believed to be part of the mirror neuron system (Acharya & Shukla, 2012). Mirror neurons are specific neurons within the brain which activate when actions are both performed and observed (Rizzolatti, 2005). Through this function it is suggested that this mirror neuron system provides a means for developing an understanding of an individual's thoughts, feelings and intentions (Acharya & Shukla, 2012; Rizzolatti, 2005).

## **MEASURES FOR EXAMINING THE NEURAL BASIS OF FACIAL EMOTION RECOGNITION**

Many measures are capable of providing insights into the neural and cognitive mechanisms underlying FER such as eye tracking, electroencephalography (EEG),

functional magnetic resonance imaging or magnetoencephalography. As this thesis focuses primarily on EEG and eye tracking, these measures are discussed below.

## **Electroencephalography**

The brain is composed largely of neurons and glia cells which form the elementary units for all cognition and behaviour (Mota & Herculano-Houzel, 2014). Neurons are specialized electrically excitable cells which respond to stimuli, and receive and transmit information within the central nervous system (Haken, 2008; Jackson & Bolger, 2014; Sanei & Chambers, 2007). When a stimulus is above a certain threshold, an action potential, or change in membrane potential is generated, transmitting information between neurons (Haken, 2008; Jackson & Bolger, 2014; Sanei & Chambers, 2007).

The electrical activity generated by large groups of neurons can be measured at the surface of the scalp through electroencephalography (EEG) (Jackson & Bolger, 2014; Sanei & Chambers, 2007). Through measuring this electrical activity, EEG provides a means to examine the neural mechanisms underlying cognition and behaviour (Sanei & Chambers, 2007). Though EEG is not able to provide the spatial resolution of fMRI and other neuroimaging techniques, EEG offers greater temporal precision, making it a valuable measure to examine the neural basis of cognitive and emotional processes (Sanei & Chambers, 2007). EEG data can be analysed using several different methods which have been discussed briefly.

### ***Event Related Potentials***

The positive and negative deflections of the electrical activity generate by large groups of neurons can be measured in terms of event related potentials (ERPs), which refer to a specific neural response time-locked to a particular event (Woodman, 2010). Temporally

specific ERP components (positive or negative peaks in the waveform) (Figure 3) are capable of providing insights into specific cognitive processes (Woodman, 2010). During FER and emotion processing several ERPs are of interest.

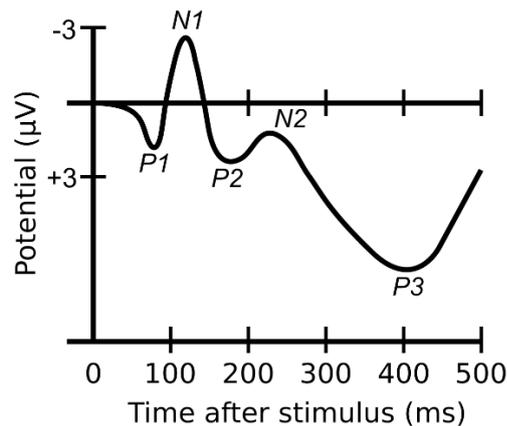


Figure 3. Diagram of event related potential components from EEG. Original: ChomsVector:Mononomic [CC BY-SA 3.0 (<http://creativecommons.org/licenses/by-sa/3.0/>)], via Wikimedia Commons.

### P100

The P100 ERP is a positively occurring ERP peaking 80 -120 milliseconds after stimulus presentation. This ERP is associated with early stages of visual processing, regarded as a major correlate for selective visual attention (Luck & Hillyard, 1994; Mangun, 1995). This ERP appears to be generated in lateral extrastriate cortical areas (Clark, Fan, & Hillyard, 1995; Colomatto & McCarthy, 2017; Mangun, 1995). Some research has further suggested that the P100 may also be reflective of initial face perception (Hermann, Ehlis, Muehlberger, & Fallgatter, 2005).

### *N170*

The N170 ERP is a negatively occurring ERP measured over temporal-occipital sites and peaking between 130 and 200 milliseconds after stimulus presentation. The N170 ERP is considered to be a face specific ERP (Eimer, 2011) and is associated with the structural encoding of facial information (Itier & Taylor, 2004). It has been postulated that the N170 may be modulated by facial emotion, with studies finding effects of facial emotion on both the amplitude and latency of this ERP (Batty & Taylor, 2003; Blau, Maurer, Tottenham, & McCandliss, 2007). It must be noted however that these effects of facial emotion on the N170 ERP are inconsistently observed (Eimer & Holmes, 2002), particularly when other potential stimulus confounds are considered (Eimer & Holmes, 2007). Source localization has provided evidence to suggest that the N170 may be generated by the superior temporal sulcus (Itier & Taylor, 2004), or occipital-temporal regions (Schweinberger, Pickering, Jentzsh, Burton, & Kaufmann, 2002). Greater activation has also been observed in areas such as fusiform gyrus, parietal-occipital temporal and medial frontal cortex regions (Hermann et al., 2005).

### *N250*

The N250 ERP is also a negative occurring ERP typically measured approximately 250ms following stimulus presentation. At temporal sites, this ERP is commonly associated with the processing of face familiarity (Schweinberger et al., 2002; Tanaka, Curran, Porterfield, & Collins, 2006). During repetition paradigms, source localization techniques have shown that the fusiform gyrus may generate this ERP (Schweinberger et al., 2002). When examined at frontal-central sites, the N250 ERP has been associated with facial emotion processing (Eimer & Holmes, 2007; Liu et al., 2012; Streit, Wolwer, Brinkmeyer, Ihl, &

Gaebel, 2000; Wynn, Lee, Horan, & Green, 2008), proposed to be associated with the decoding of emotional aspects of faces (Liu et al., 2012; Streit et al., 2000).

### *P300*

The P300 ERP is a later occurring component observed approximately 300ms following stimulus presentation. This ERP is thought to be reflective of attentional resource allocation (Olofsson, Nordin, Sequira, & Polich, 2008; Polich & Pitzer, 1999) and initial memory processes (Olofsson et al., 2008). This ERP has been shown to be influenced by the valence (Liu et al., 2012), arousal (Olofsson et al., 2008), and motivational significance (Olofsson et al., 2008) of stimuli. Findings have shown that emotional stimuli typically elicit larger P300 amplitudes than neutral stimuli (Liu et al., 2012).

### ***Neural Oscillations***

In addition to ERPs, EEG can also be measured by examining neural oscillations. Neural oscillations, commonly referred to as ‘brain waves’ are rhythmic patterns of electrical activity generated by the synchronous activity of neurons (Figure 4). These oscillations are typically examined in terms of frequency (measured in Hertz [cycles per second]), power (amplitude) and phase (stage or position of a cycle in a particular point in time) (Maguire & Abel, 2013; Ward, 2003). Different bandwidths of neural oscillations have been associated with different cognitive processes. Commonly examined bandwidths include delta (<4 Hertz), theta (4-7.5/8 Hertz), alpha (8-13 Hertz), beta (16-30 Hertz) and gamma (30- 100 Hertz). Examining EEG in terms of neural oscillations provides a means to examine how neural networks may operate and communicate (Maguire & Abel, 2013).

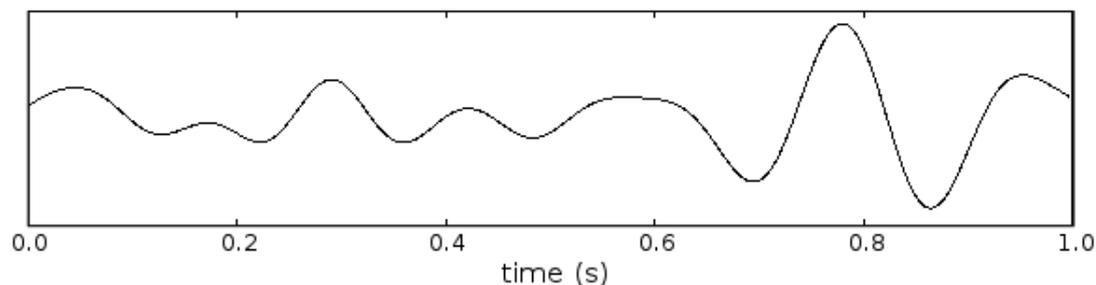


Figure 4. Example of neural oscillation recorded from EEG (theta band). Adapted from: Hugo Gamboa [CC BY-SA 3.0 (<http://creativecommons.org/licenses/by-sa/3.0/>)], via Wikimedia Commons

### Alpha

Alpha activity is typically measured between 8 – 13 Hertz. Reduced alpha activity is observed during tasks requiring information processing and memory (Klimesch, Sauseng, & Hanslmayr, 2007). Some theorize that this frequency band may be implicated in the top-down control of information processing through inhibitory/dis-inhibitory control processes (Klimesch et al., 2007; Wang, Rajagovindan, Han, & Ding, 2016). Lateralization of alpha during the viewing of positive and negative stimuli is often observed, indicative of motivational systems (Briesmeister, Tamm, Heine, & Jacobs, 2013; Harmon-Jones, Gable, & Peterson, 2010). Stimuli eliciting higher withdrawal motivation is shown to produce greater alpha activity in the right frontal regions compared to the left while stimuli eliciting approach motivation may show a left lateralization effect (Briesmeister et al., 2013). Evidence seeking to understand whether positively valenced emotion had similar lateralization effects found that it was the approach motivation aspects of positive emotion which elicited the left lateralization effect of alpha activity (Harmon-Jones et al., 2010). Lateralization effects of alpha are most commonly observed in frontal regions (Briesmeister et al., 2013), however lateralization effects have also been observed in parietal regions (Harmon-Jones et al., 2010).

### *Theta*

Theta activity between 4 – 7.5 Hertz has been associated with a number of cognitive and emotional processes (Knayazev, 2007). In particular, theta activity may play a critical role in interactions occurring between the hippocampus, a structure within the limbic system, and the prefrontal cortex (Başar, Başar-Eroglu, Karakas, & Shurmann, 1999; Başar, Shurmann, & Sakowitz, 2001). During emotion processing specifically, some evidence has been found to suggest that this frequency is involved in the integration of emotion-processing networks including the amygdala, visual processing areas and the prefrontal cortex (Maratos, Mogg, Bradley, Rippon, & Senior, 2009).

Theta activity primarily in frontal-central regions has been proposed to be indicative of cognitive control mechanisms (Cavanagh & Frank, 2014) and may reflect control processes occurring during the processing of negative emotion (Shackman et al., 2011). Theta activity is more prominent when stimuli is threatening (González-Roldan et al., 2011) or arousing, perhaps associated with the motivational (Aftanas, Varlamov, Pavlov, Makhnev, & Reva, 2002) or emotional significance of stimuli (Balconi & Lucchiarai, 2006).

### *Beta*

The beta frequency (16 – 30 Hertz) has been commonly associated with sensorimotor functions (Güntekin & Basar, 2014). Other studies have found that beta frequency may be associated with attention, with greater beta power associated with increased alertness (Kamiński, Brzezicka, Gola, & Wróbel, 2012). When observed over occipital regions, beta power has been proposed to be reflective of visual attention (Gola, Magnuski, Szumska, & Wrobel, 2013). During the viewing of emotional stimuli, alterations in the beta frequency have also been observed, leading to postulations that this frequency may

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also be involved with the processing of emotional stimuli (Güntekin & Basar, 2014). Beta power increases when viewing emotional stimuli, and is particularly enhanced during the viewing of unpleasant stimuli (Güntekin & Basar, 2010). Increased beta power in frontal and central regions has been observed during the viewing of angry compared to happy faces (Güntekin & Basar, 2007)

### *Gamma and Delta*

The gamma frequency band (30 – 100 Hertz) and delta (<4 Hertz) were not examined within this thesis, however are important to note. Gamma rhythms are associated with a number of cognitive functions including memory, attention and consciousness (Ward, 2003). Activity in the gamma frequency is purported to play a critical role perceptual binding (Başar, 2013) and holistic processing (Tallon-Baudry & Bertrand, 1999), involving the integration of activity and information across brain regions. During emotion perception paradigms, gamma power increases when viewing emotional faces compared to neutral faces (Balconi & Pozzoli, 2007) and is modulated by emotional arousal or affective processing (Keil et al., 2001).

The delta frequency is particularly involved in processes related attention and motivation (e.g., reward/appetitive or aversive/defensive responses to stimuli) (Knyazev, 2012). Other research has shown that this frequency band may also be involved in inhibitory functions during cognitive tasks (Harmony, 2013). Greater delta synchronization is observed to emotional stimuli compared to neutral stimuli in emotion perception tasks (Knyazev, Slobodskoj-Plusnin, & Bocharov, 2009).

### *Mu Rhythm*

The Mu Rhythm is typically measured over sensorimotor regions within the alpha frequency (8-13 Hertz). Suppression of this frequency is believed to index mirror neuron activity (Fox et al., 2016). The mirror neuron system is observed to activate both while performing action, but also when observing actions performed by others (Rizzolatti, 2005). It is proposed that activation of the mirror neuron system provides a means of understanding and making sense of the actions of others (Cattaneo & Rizzolatti, 2009; Rizzolatti, 2005). During emotion perception, the mirror neuron system may be involved in simulating the observed emotions of others, assisting in the recognition and understanding of the emotion observed (Bastianensen, Thioux, & Keysers, 2009). Suppression of mu rhythm activity has been observed during FER indicating that the mirror neuron system is involved during facial emotion processing (Moore, Gorodnitsky, & Pineda, 2012; Moore & Franz, 2017)

### **Eye Tracking**

The brain receives visual information about the environment from the eyes, thus the locus of vision determines what information is received and processed by the brain (Just & Carpenter, 1980). Based on this assumption, eye tracking measuring the movements of the eyes is capable of providing a means of examining the attentional and cognitive mechanisms underlying the processing of visual information (Rayner, 1998; Yarus, 1967).

While humans have a visual field extending approximately 114 degrees, a high level of visual acuity is only available in 2 degrees of this field. This area is referred to as central or foveal vision (Holmqvist et al., 2011). Due to the small range in which this high level of visual acuity is available, the eye must move to place objects within its central vision

(Holmqvist et al., 2011; Singh & Singh, 2012). On this basis, eye tracking assumes that the point of gaze of the eye is likely where an individual is directing their visual attention and processing visual information (Holmqvist et al., 2011).

Eye tracking is measured in regard to fixations and saccades which together constitute the scan path (Figure 5). Fixations refer to periods of time where the eye remains relatively stable and fixated on a particular area of interest (Holmqvist et al., 2011). During fixations, it is believed that visual information is retrieved and processed (Rayner, 2009). Saccades on the other hand refer to ballistic eye movements which occur between fixations. Saccades may represent shifts in visuo-spatial attention, with research showing that shifts in attention precede saccadic eye movements (Deubel, 2008).



*Figure 5. Example scan path, circles indicate fixations and lines indicate saccades.*

Given that visual information processing is believed to occur during fixations, fixations were the primary eye tracking outcome of this thesis. While the eye is relatively stable on an area of interest during a fixation, it is not stationary. Fixational eye movements such as drift, tremor and microsaccades function to ensure that objects of interest are maintained within the central vision and to prevent visual fading (Martinez-Conde, Macknik, & Hubel, 2004). Fixations are therefore generally defined as the mean  $x$  and  $y$  coordinates

of a fixation point within an area of  $a \times a$  degrees for a minimum of  $t$  seconds (Falkmer, Dahlman, & Dukic, 2008; Falkmer & Gregerson, 2005).

Faces capture the visual attention of typically developing individuals, with visual search tasks providing evidence to suggest that this may be the case even when they are irrelevant to the task at hand (Langton, Law, Burton, & Schweinberger, 2008). When viewing faces, such as in facial identity or facial emotion tasks, typical individuals show a relatively consistent and stable pattern of gaze behaviour (Barabanschikov, 2015). This has previously been referred to as the ‘face information triangle’ whereby typical individuals may tend to fixate on the two eyes and mouth, forming the shape of a triangle (Yarbus, 1967).

During FER, it has been demonstrated that typically developing individuals differentiate their gaze depending on the emotion expressed (Bombardi et al., 2013; Schurgin et al., 2014). The basic emotions show different patterns of muscle activation (Ekman, 1977, 1992; Ekman & Rosenberg, 1997) and will differ in the salience of information they offer. Typically developing individuals thus differentiate their gaze in response to the most relevant, diagnostic feature of an emotion (Barabanschikov, 2015).

The inner facial features, including the eyes, nose, mouth and nasion are particularly important during FER. In typically developing adults, nearly 90% of fixation time is allocated to these areas (Schurgin et al., 2014). This study found that for joyful and disgust expressions, the upper lip was fixated on the most, whereas for fear, anger and sadness expressions the eyes accounted for a greater fixation time. These differential fixation patterns are likely indicative of the salience of these regions during FER (Schurgin et al., 2014). The intensity of facial expressions being viewed may however also influence fixation patterns during FER (Barabanschikov, 2015). When facial expressions are

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intense, it was found that 80% of fixation time was spent on the eyes, nose, nasion and mouth, however this was reduced to 64% when the facial emotions were less intense (Barabanschikov, 2015).

## **AUTISM SPECTRUM DISORDERS**

Autism Spectrum Disorders (ASD) are a group of neurodevelopmental disorders characterized by life-long and pervasive impairments in social interaction and reciprocal communication with the presence of restrictive or repetitive behaviour or interests and sensory processing atypicalities (American Psychiatric Association, 2010, 2013). While ASD is conceptualized as one disorder under the 5<sup>th</sup> iteration of the DSM (American Psychiatric Association, 2013), previous editions of the manual have classified ASD as a group of disorders including Autism, Asperger's Syndrome and Pervasive Developmental Disorders – Not Otherwise Specified (PDD-NOS) (American Psychiatric Association, 2010). Though it is recognized that the diagnostic labels of Autism, Asperger's Syndrome and Pervasive Developmental Disorders – Not Otherwise Specified (PDD-NOS) no longer exist in the current DSM-5, as this thesis was primarily concerned with adults, diagnosed using these labels, they are applied through this thesis. Co-occurring intellectual impairment may also be present in autistic individuals. This thesis focuses on autistic individuals with average intellectual abilities (American Psychiatric Association, 2013). For this reason, for the remainder of this thesis and its publications, 'ASD' or 'autistic refers' to autistic individuals without co-occurring intellectual impairment.

Several theories attempt to account for the observed deficits associated with ASD. The 'mindblindness' hypothesis (Baron-Cohen, Leslie, & Frith, 1985) has been used to account for the social communication and interaction difficulties experienced by autistic individuals. This hypothesis is based on the notion that typically developing individuals

are able to understand, interpret and predict the thoughts or emotions of others, essentially ‘reading the minds’ of others (Baron-Cohen et al., 1985). It is proposed that autistic individuals have deficits in theory of mind (Happé & Frith, 1995), or this ability to ‘mind read’, thus resulting in their difficulties in social interaction.

The Weak Central Coherence (WCC) theory (Frith, 1989) also provides an account for not only the social difficulties of ASD, but also the atypical perceptual processing also observed in this population (Dakin & Frith, 2005). While typically developing individuals have a tendency towards global or holistic processing (e.g., perceiving the gestalt before detail), autistic individuals in contrast have been observed to have a bias towards local or detailed information (Dakin & Frith, 2005; Frith, 1989). This local processing bias is purported to arise from a weakness or impairment in the ability to perceive global information (Dakin & Frith, 2005; Frith, 1989), thus from a social communication standpoint, may result in difficulty integrating various aspects of social information into a cohesive picture. Postulations of this reduced central coherency has led to the notion of ‘context blindness’ in autistic individuals, or the lack of ability to integrate and make use of contextual information (Vermeulen, 2014). More recent discussion of WCC has however questioned whether the local biases observed in autistic individuals does in fact come as a result from weaknesses in global processing (Happé & Frith, 2006) and indeed, others have postulated that these local biases may instead arise from superior local processing (Mottron, Dawson, Soulie`res, Hubert, & Burack, 2006).

Built upon observations of disrupted brain network functioning in autistic individuals, some theories have taken a neurological approach (Just, Cherkassky, Keller, & Minshew, 2004; Just, Keller, Malave, Kana, & Varma, 2012). Observations of reduced functional connectivity in global, large scale networks, paired with simultaneous over-connectivity

in localized regions in autistic individuals has led to the under-connectivity theory of ASD (Just et al., 2004). It is proposed that this atypical pattern of network functioning may result in the phenotypic presentation of ASD, with reduced connectivity contributing to impairments in social interaction, and theory of mind, with pockets of enhanced activity resulting in superiority in some cognitive areas (such as local/detail information processing) (Just et al., 2004). Similar hypothesises are made by the Temporal Binding Hypothesis which proposes that the characteristic of ASD may arise from impairments in temporal binding, or the timely integration of information between and within networks (Brock, Brown, Boucher, & Rippon, 2002).

Taken together, these theories converge to suggest that autistic individuals have difficulties in a board range of social communicative and interactive areas, at least in part, reflective of more general atypical perceptual processing underlain by functional differences in brain connectivity. Given the far reaching social communicative difficulties experienced by this population, FER is likely a critical component affected in autistic individuals, likely underlain by fundamental attentional and neural differences.

## **FACIAL EMOTION RECONITION IN AUTISM SPECTRUM DISORDERS**

The social communication and interaction challenges core to ASD (American Psychiatric Association, 2013), are presumed to be mediated by social cognition impairments (Baron-Cohen, 1990), including altered FER (Harms, Martin, & Wallace, 2010; Uljarevic & Hamilton, 2013).

Behavioural studies seeking to understand FER impairment in autistic individuals have employed numerous experimental paradigms, inclusive of different task demands and

participant demographics (Harms et al., 2010; Rump, Giovannelli, Minshew, & Strauss, 2009). These paradigms most often use matching tasks whereby individuals are required to match static or dynamic emotions to each other, or labelling tasks, requiring participants to assign labels to emotional stimuli. The six basic emotions are the most commonly used when examining FER in ASD (Harms et al., 2010). While typically static representations of the six basic emotions are examined, others have used dynamic representations, or stimuli that vary in intensity (Harms et al., 2010).

Behavioural studies examining FER to the six basic emotions have shown conflicting results (Harms et al., 2010). Some studies investigating FER to the six basic emotions have found ASD-linked impairment compared to controls (Bölte & Poustka, 2003; Lindner & Rosén, 2006), while other studies have found no impairment (Castelli, 2005; Hubert, Wicker, Monfardini, & Deruelle, 2009), or impairment only to certain emotions (Boraston, Blakemore, Chilvers, & Skuse, 2007; Humphreys, Minshew, Leonard, & Behrmann, 2007; Jones et al., 2010). For example, one study conducted with adolescents found no FER impairments to the six basic emotions, with deficits only found for surprise (Jones et al., 2010). A further study with adults found impaired happy recognition but spared anger recognition compared to typically developing controls (Sato et al., 2017). Though heterogeneity within the basic emotion literature is noted, results from a meta-analysis show that autistic individuals show impairment in the recognition of the basic emotions regardless of age or intellectual capabilities with limited evidence found for only happiness recognition being spared (Uljarevic & Hamilton, 2013).

Heterogeneity within the current body of behavioural findings have been proposed to be resultant of differing participant characteristics and task demands (Harms et al., 2010; Rump et al., 2009). When examining participant characteristics, it has been shown that

autistic symptomology may influence FER abilities, with individuals with greater autistic-like traits having a greater FER impairment (Williams & Gray, 2013). The age of participants may also play a role (Rump et al., 2009). One study found that while typically developing individuals show continual improvement in the recognition of basic emotions from childhood through to adulthood, this trajectory was not observed in autistic individuals. Compared to typically developing samples, autistic children and adults were impaired in the recognition of dynamic and subtle representations of the basic emotions, however adolescents were not (Rump et al., 2009). These results provide evidence for an altered developmental trajectory of FER in ASD suggesting that autistic adults may fail to reach the FER expertise of typically developing individuals (Rump et al., 2009).

During FER tasks, it is possible that autistic individuals employ compensatory strategies thus masking observable behavioural differences. This may be particularly true for autistic adults with average intellectual abilities. It is possible that autistic individuals remediate behavioural deficits through verbal mediation strategies, or develop strategies to recognize emotions based on the recognition of specific diagnostic features (mouthed curved upwards means happiness) (Baron-Cohen, Wheelwright, & Jolliffe, 1997; Harms et al., 2010).

It has also been suggested that differing task demands contribute to the heterogeneity in findings (Harms et al., 2010). It has been proposed that greater task demands, such as the use of more subtle expressions or imposing time constraints may elicit observable behavioural FER impairment in autistic individuals (Rump et al., 2009). As a result, there has been increasing interest in the use of ecologically valid or complex emotions to investigate FER in autistic individuals, and it has been proposed that complex emotions

may more reliably elicit ASD-linked FER impairment (Golan, Baron-Cohen, & Hill, 2006).

When viewing more complex emotional concepts, ASD-linked impairments have been observed in both autistic children and adults. In children, one study seeking to understand FER impairment in autistic children across three countries found that cross-culturally, autistic children demonstrated impairment in the recognition of both basic and complex emotions (Fridenson-Hayo et al., 2016). Deficits in complex FER have also been observed in autistic children during the viewing of more complex multi-modal social scenes (Golan, Baron-Cohen, & Golan, 2008). Similarly, FER impairments during complex emotion recognition are observed in autistic adults. Using static representations of emotion, Baron-Cohen et al. (1997) found that while autistic adults had spared basic emotion recognition, they demonstrated impairments in recognizing complex emotional concepts. When only the eye or mouth region of these stimuli were displayed, autistic adults had significantly greater difficulty recognizing these emotions from the eyes alone compared to their typical counterparts. It was proposed that these results were indicative of difficulties extracting pertinent information from the eye region in autistic adults, possibly resulting in the use of other feature-based strategies (Baron-Cohen et al., 1997). While these feature-based strategies assisted in remediating basic emotion impairment, this may not have been the case for the complex emotional concepts, demonstrating the importance of complex emotions in the investigation of ASD-linked FER impairment (Baron-Cohen et al., 1997).

Similar results have also been observed using dynamic representations of complex emotional concepts. Autistic adults show reduced accuracy compared to typically developing controls when required to recognise emotions from the face only (Golan,

Baron-Cohen, & Hill, 2006), as well as when recognising emotion from social scenes including both visual and auditory stimuli (Golan, Baron-Cohen, Hill, & Golan, 2006).

## **MECHANISMS OF FACIAL EMOTION RECOGNITION IN AUTISM SPECTRUM DISORDERS**

A significant body of EEG and eye tracking-based research has sought to investigate the neural and attentional basis for FER impairment in autistic individuals.

### **Insights from EEG**

The majority of EEG based investigations of ASD-linked FER impairment has been conducted using the basic emotions and has focused on ERP analysis. Current ERP investigation of FER in ASD has had a particular focus on examining early stages of visual information processing, such as the N170 and P100 ERPs. The amplitude and latency of the N170 ERP are consistently delayed and smaller in autistic children (Batty, Meaux, Wittemeyer, Roge, & Taylor, 2011; de Jong, Van Engeland, & Kemner, 2008), and adults (O'Connor, Hamm, & Kirk, 2005, 2007) during emotion recognition tasks. Observations of altered N170 ERP function are not restricted solely to FER tasks, with atypical N170 ERP amplitudes and latencies also commonly observed in other tasks requiring face processing (Dawson, Webb, & McPartland, 2005). Though less consistent, altered modulation of the P100 ERP in response to facial emotion are also observed in autistic populations (Akechi et al., 2010; Batty et al., 2011; O'Connor et al., 2005; Vlamings, Jonkman, van Daalen, van der Gaag, & Kemner, 2010). Given the function of these early stage ERPs, it is possible that these previous findings are indicative of impairments in the early encoding stages of facial information (Dawson et al., 2005; Eimer, 2000), with atypical modulation of the N170 ERP in particular possibly indicating impairments in

configural processing of facial information (Dawson et al., 2005; O'Connor et al., 2005). As emotional stimuli has been shown to modulate the N170 ERP, it is also possible that atypical modulation of this ERP is indicative of impairments in early processing stages involved with facial emotion specifically (Blau et al., 2007).

Investigation of quantified EEG through examining the frequency spectra is less well examined than the aforementioned ERPs. Reduced theta coherence has been associated with greater autistic symptomology during FER tasks and autistic children have demonstrated reduced theta coherence in right frontal regions compared to typically developing children (Yeung, Han, Sze, & Chan, 2014). Weaker theta synchronization has also been observed in autistic adolescents and adults during FER (Tseng, Yang, Savostyanov, Chien, & Liou, 2015; Yang, Savostyanov, Tsai, & Liou, 2011). Less consistent findings have also been observed in other frequency bands. Reduced gamma power has been observed in autistic adolescents when viewing anger and disgust emotions (Gross et al., 2012). Altered alpha and beta synchronization has also been observed in adults (Yang et al., 2011). While evidence to date is limited, there is emerging evidence to suggest altered mu rhythm suppression may underlie FER and other social-cognitive impairment in ASD. Altered mu rhythm suppression has been observed in autistic individuals, characterised as reduced mu suppression during action observation (Bernier, Dawson, Webb, & Murias, 2007; Oberman et al., 2005). Further, typically developing adults with high autistic-like traits have shown altered mu rhythm suppression during FER suggesting that atypical function of the mirror neuron system may also underlie FER impairment in ASD (Cooper, Simpson, Till, Simmons, & Puzzo, 2013).

## Insights from Eye Tracking

Eye tracking has been widely used to investigate the attentional mechanisms contributing to the social-communicative difficulties associated with ASD. Eye tracking has uncovered distinct differences in the visual attention of autistic individuals during a variety of social tasks (Guillon, Hadjikhani, Baduel, & Rogé, 2014). In fact, differences in gaze behavior have been observed in children as young as six months, with one study finding that children who later received a diagnosis of ASD had reduced visual attention to social scenes (Chawarska, Macari, & Shic, 2013), with a further study showing that altered disengagement of visual attention may present as a first early indicator of ASD (Elsabbagh et al., 2013).

Similar to behavioral and EEG investigation, eye tracking based investigation seeking to understand FER impairment in autistic individuals has been largely restricted to static representations of the basic emotions. Numerous studies have shown that during FER, autistic individuals fail to readily orient to socially salient information, focusing less on the core facial features of emotional faces in favour of peripheral non-feature regions (Pelphrey et al., 2002), displaying altered gaze to the mouth region (Boraston, Corden, Miles, Skuse, & Blakemore, 2008; Corden, Chilvers, & Skuse, 2008; Hernandez et al., 2009; Neumann, Spezio, Piven, & Adolphs, 2006; Spezio, Adolphs, Hurley, & Piven, 2007; Wieckowski & White, 2017) and gazing less towards the eyes, than their typically developing counterparts (Baron-Cohen et al., 1997; Boraston et al., 2008; Corden et al., 2008; Falkmer, Bjallmark, Larsson, & Falkmer, 2011; Hernandez et al., 2009).

Several theories have been proposed to account for this altered gaze and impaired FER in ASD. The social motivation hypothesis has proposed a lack of motivation to engage with socially relevant information in ASD (Chevallier, Kohls, Troiani, Brodtkin, & Schultz,

2012), while typically developing individuals may be driven to gaze towards the eye region, or the most socially salient information during FER, this may not be the case for autistic individuals (Schurgin et al., 2014; Wegrzyn, Vogt, Kireclioglu, Schneider, & Kissler, 2017). It has also been proposed that autistic individuals may have difficulty extracting information from the eye region, possibly resulting in preferential gaze to other facial features, such as the mouth (Neumann et al., 2006). Other theories have proposed that heightened physiological arousal during the processing of social stimuli may cause autistic individuals to avoid the eye region (Tanaka & Sung, 2016).

While diminished gaze to the eyes is commonly associated with autistic individuals (Baron-Cohen et al., 1997; Boraston et al., 2008; Falkmer et al., 2011; Hernandez et al., 2009), evidence for reduced gaze to the eyes during FER is not consistently reported in the literature, with a number of studies failing to report reduced gaze to the eye region in autistic populations during FER tasks (Bekele et al., 2014; Dalton, Holsen, Abbeduto, & Davidson, 2008; de Wit, Falck-Ytter, & von Hofsten, 2008; Falck-Ytter, Fernell, Gillberg, & von Hofsten, 2010; Kirchner, Hatri, Heekeren, & Dziobek, 2011; Rutherford, Troubridge, & Walsh, 2012; Sawyer, Williamson, & Young, 2012; Van der Geest, Kemner, Verbaten, & Van Engeland, 2002; Wagner, Hirsch, Vogel-Farley, Redcay, & Nelson, 2013). Similarly, evidence for altered gaze to other facial features such as the mouth region is particularly inconsistent (Boraston et al., 2008; Falkmer et al., 2011; Hernandez et al., 2009; Kirchner et al., 2011; Neumann et al., 2006). It has been proposed that heterogeneity in gaze findings and visual attention in autistic individuals may be due to the variability of ASD symptoms (McPartland, Webb, Keehn, & Dawson, 2011), or may be developmentally mediated (Fedor et al., 2017; McPartland et al., 2011). It is also possible that other experimental factors may play a role, with one study examining visual

attention to faces and objects in autistic individuals advocating for the use of naturalistic stimuli to examine this potential influence (McPartland et al., 2011).

## **PRESENT RESEARCH**

While previous research has provided significant insight to assist in elucidating the mechanisms underlying ASD-linked FER impairment, there are limitations in the current body of literature which are necessary to address. Namely, the majority of investigation to date has been conducted by examining FER in autistic individuals using static representations of the basic emotions and there is a dearth of research examining the mechanisms of FER in ASD using socially relevant stimuli. As indicated by multiple studies, it is likely that the task demands involved in the majority of studies to date may not be adequate to elicit ASD-linked impairment and may not be commensurate to the day to day functioning of autistic adults.

In order to extend the current understanding of ASD-linked FER impairment, research presented in this thesis sought to examine the EEG and eye tracking based mechanisms of FER in autistic adults using emotional stimuli which is both dynamic and complex in nature. This thesis is comprised of eight chapters (Figure 6) as outlined below.

## **THESIS OVERVIEW**

### **Chapter 1: Introduction**

Chapter One introduces this thesis and covers pertinent core concepts and literature.

### **Chapter 2: Mechanisms of Facial Emotion Recognition in Autism Spectrum Disorders (paper I)**

Chapter Two presents a manuscript published in *Neuroscience and Biobehavioural Reviews* (Paper I). This chapter systematically reviews current eye tracking and EEG investigation in ASD during FER. Here results are examined using a developmental approach to assist in providing insights into the mechanisms underlying FER across the developmental trajectory.

### **Chapter 3: More than Valence? Using a Dimensional and Discrete Approach to Investigate Complex Facial Emotion Processing (Paper II)**

Chapter Three presents findings from a survey study (Paper II) pending publication. This chapter seeks to understand the underlying dimensions of the CAMS stimuli battery. This chapter primarily aims to address key issues related to the investigation of complex emotion, namely the multitude of complex emotions in existence. This manuscript attempts to reduce the complex emotions presented in the CAMs to their underlying dimensions and fundamental basic emotions. Normative data is provided for a typically developing sample.

### **Chapter 4: Brief Report: Complex Facial Emotion Recognition and Atypical Gaze Patterns in Autistic Adults (Paper III)**

Chapter Four is based on a manuscript (Paper III) under review. This chapter uses eye tracking to examine the eye gaze behaviour of autistic and typically developing adults while completing a FER task using the CAMs stimuli. This study provides insights into gaze behaviour of autistic adults during ecologically valid and socially relevant emotion recognition.

### **Chapter 5: Altered Reactivity to Complex Facial Emotion: A Study of EEG Spectral Power in Autistic Adults (Paper IV)**

Chapter Five is based on a manuscript pending publication (Paper IV). This chapter examines the neural correlates of complex FER in autistic adults using the participant sample presented in Chapter Four. Oscillatory patterns in the alpha, beta, theta and mu rhythms were examined to determine the underlying neural processes in autistic adults while completing FER of socially relevant stimuli.

### **Chapter 6: Altered Connectivity in Autistic Adults during Complex Facial Emotion Recognition: A Study of EEG Imaginary Coherence (Paper V)**

Chapter Six (Paper V) presents findings from a conference paper published with IEEE Engineering in Medicine and Biology. This paper builds on EEG data collected for Chapter Five. Imaginary coherency analyses are applied to determine the functional networks involved in the FER of socially-relevant complex emotion stimuli in autistic adults.

## **Chapter 7: Can EEG-Based Biomarkers During Facial Emotion Recognition Provide an Effective Means of Classifying ASD in Adulthood? (Paper VI)**

Chapter Seven presents a manuscript (Paper VI) pending publication. The majority of previous research to date has used top-down approaches to investigate the mechanisms contributing to FER impairment in ASD. Though these previous studies have provided insights into the FER in ASD, they are largely driven by empirical a priori hypothesis testing. Chapter Seven (Paper VI) uses data presented in chapter five to present a more novel bottom-up data driven approach to investigate the utility of EEG-based biomarkers in classifying ASD from typical development.

## **Chapter 8: Synthesis of Findings and Future Directions**

Chapter Eight provides an overview and synthesis of the research findings of this thesis and discusses a number of implications and future directions.

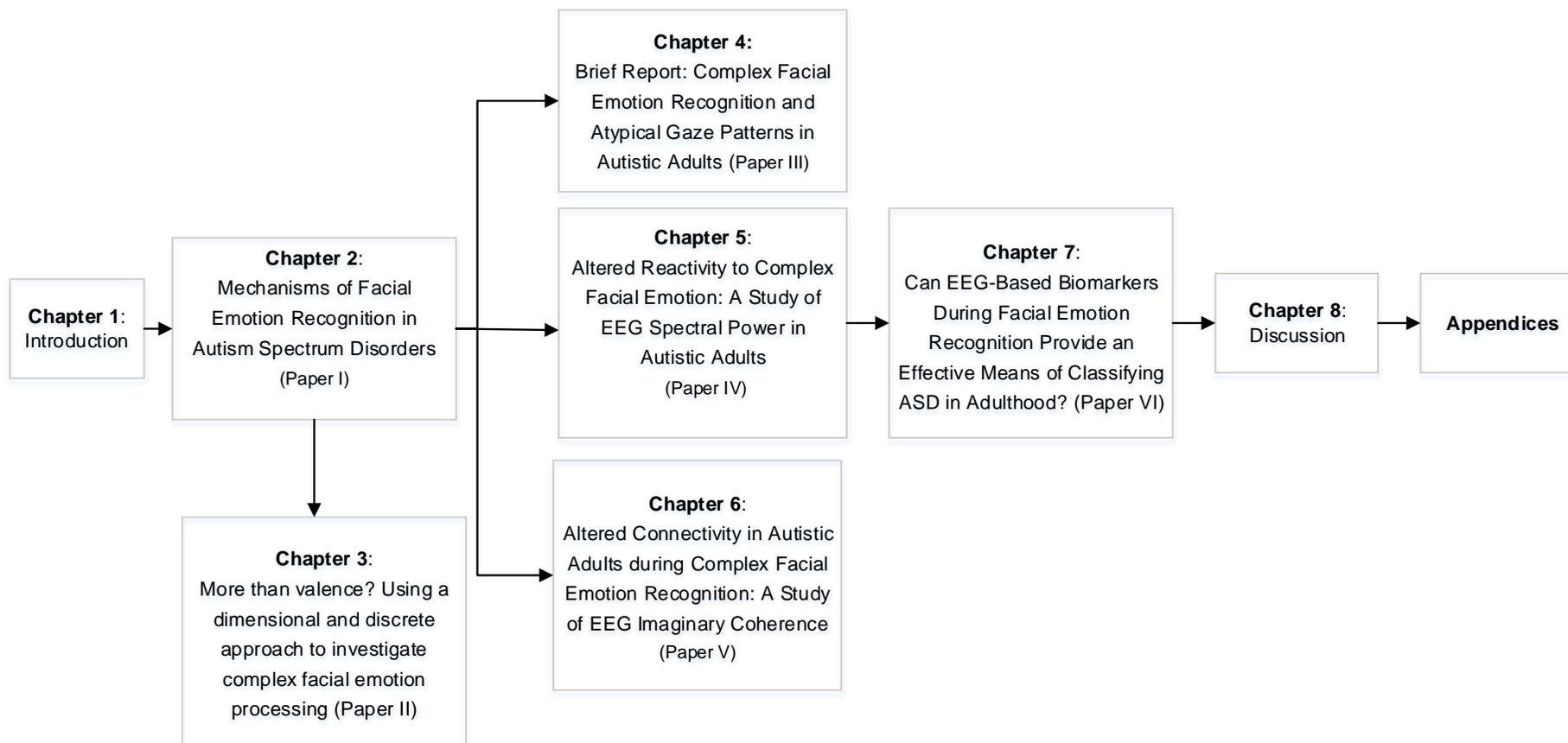


Figure 6. Overview of thesis structure

*Table 1. Overview of methods used in studies included in this thesis*

<b>Chapter Paper</b>	<b>Two I</b>	<b>Three II</b>	<b>Four III</b>	<b>Five IV</b>	<b>Six V</b>	<b>Seven VI</b>
Approach	Systematic review.	Cross-sectional survey study.	Experimental case-control study investigating eye tracking during FER.	Experimental case-control study investigating EEG frequency power during FER.	Experimental case- control study investigating EEG imaginary coherency during FER.	Machine learning classification of ASD and TD adults based on EEG frequency power.
Analysis design	Systematic review of eye tracking and EEG based investigation of FER in ASD and critical appraisal of methodology.	Single group design to investigate perception of complex emotional concepts in typical population.	Comparison of between group differences.	Comparison of between and within group differences.	Comparison of between group differences.	Classification accuracy of ASD vs. TD.
Data examined	Text, k=54 articles.	Likert scale ratings.	Eye gaze data (total fixation time) Behavioural data (accuracy).	EEG frequency power data Behavioural data (accuracy).	EEG imaginary coherence data.	EEG frequency power data SRS-2 data.
No. of participants with ASD	-	-	20 adults.	22 adults.	22 adults (Same sample as paper IV).	22 adults (same sample as paper IV).

*Table 1. Continued*

<b>Chapter Paper</b>	<b>Two I</b>	<b>Three II</b>	<b>Four III</b>	<b>Five IV</b>	<b>Six V</b>	<b>Seven VI</b>
No. of typically developing controls	-	141 adults.	20 adults.	23 adults.	23 adults (Same sample as paper IV).	27 adults (inclusion of 4 additional adults from previous sample).
Statistical methods	-	Kolmogorov-Smirnov test, Mann-Whitney U-test, Independent Samples T-test. Mean and standard deviation, network analysis.	Kolmogorov-Smirnov test, Mann-Whitney U tests, Independent Samples T-Tests Repeated Measures Analysis of Variance.	Kolmogorov-Smirnov test, Mann-Whitney U tests, Independent Samples T-Tests Repeated Measures Analysis of Variance.	Kolmogorov-Smirnov test Coherence deviation thresholds.	Kolmogorov-Smirnov test, Mann-Whitney U tests, Independent Samples T-Tests Machine learning algorithms (Naïve Bayes, Sequential Minimal Optimization, Multilayer Perception, Decision Stump, Random Forest and Random Tree).

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## CHAPTER TWO

### MECHANISMS OF FACIAL EMOTION RECOGNITION IN AUTISM SPECTRUM DISORDERS: INSIGHTS FROM EYE TRACKING AND ELECTROENCEPHALOGRAPHY

This chapter presents a manuscript published in *Neuroscience and Biobehavioural Reviews* <https://doi.org/10.1016/j.neubiorev.2017.06.016>. Please refer to Appendix A for the article as it appears in *Neuroscience and Biobehavioural Reviews* and Appendix B for the publishing agreement.

**Black, M.**, Chen, N., Iyer, K., Lipp, O., Bölte, S., Falkmer, M., . . . Girdler, S. (2017). Mechanisms of facial emotion recognition in autism spectrum disorders: Insights from eye tracking and electroencephalography. *Neuroscience and Biobehavioural Reviews*, 80, 488-515. Doi: 10.1016/j.neubiorev.2017.06.016

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## PREFACE

Eye tracking and EEG are capable of providing insights into the attentional and cognitive dynamics that may characterise ASD-linked FER impairment. The utility of these measures is reflected in the significant body of research which has employed eye tracking and EEG to investigate the basis for FER impairment in autistic individuals.

Given the range of outcome measures afforded by both eye tracking and EEG, and the variability associated with task demands and participant characteristics, there is a need to synthesise these findings. This chapter presents a systematic review of 54 articles examining the eye tracking and EEG outcomes of autistic individuals during FER. In undertaking this systematic review, a developmental approach was taken to investigate changes in these outcomes across the developmental trajectory.

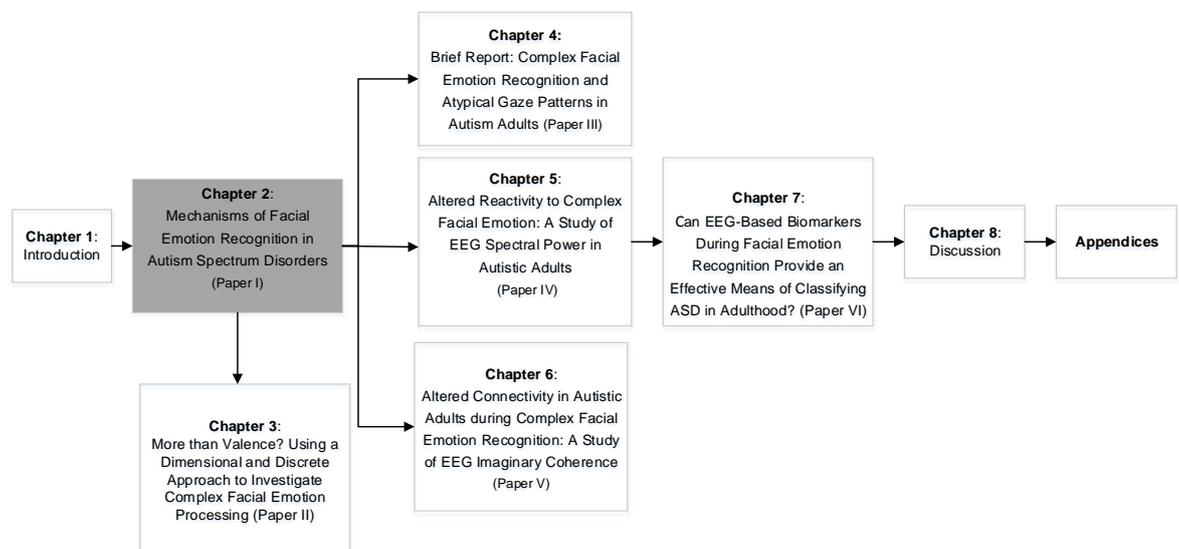


Figure 1. Thesis outline chapter two

**ABSTRACT**

While behavioural difficulties in facial emotion recognition (FER) have been observed in individuals with Autism Spectrum Disorder (ASD), behavioural studies alone are not suited to elucidate the specific nature of FER challenges in ASD. Eye tracking (ET) and electroencephalography (EEG) provide insights into the attentional and neurological correlates of performance and may therefore provide insight into the mechanisms underpinning FER in ASD. Given that these processes develop over the course of the developmental trajectory, there is a need to synthesise findings in regard to the developmental stages to determine how the maturation of these systems may impact FER in ASD. We conducted a systematic review of fifty-four studies investigating ET or EEG meeting inclusion criteria. Findings indicate divergence of visual processing pathways in individuals with ASD. Altered function of the social brain in ASD impacts the processing of facial emotion across the developmental trajectory, resulting in observable differences in ET and EEG outcomes.

## INTRODUCTION

A considerable degree of human communication occurs through nonverbal means, with actions, gestures and postures conveying signals to others about an individuals' thoughts, feelings and intentions (Darwin, 1872; Meeran, van Heijnsbergen, & Gelder, 2005). Facially expressed emotions contribute significantly to this communication with movements presented on the face relaying information about internal emotional and mental states (Ekman & Friesen, 1978; Ekman & Oster, 1979). In typical development, the ability to recognise emotions begins in early infancy, developing and improving throughout adolescence and adulthood (Herba & Phillips, 2004; Somerville, Farni, & McClure, 2011). Emotion recognition abilities typically begin with the six basic emotions (happiness, sadness, fear, anger, disgust, surprise) with discrimination of these emotions reported to be present in children aged five to seven months (Barrera & Maurer, 1981). By 10 years of age, children are postulated to perform at a level similar to adults when asked to match neutral, surprised, happy and disgusted expressions (Mondloch, Geldart, Maurer, & Grand, 2003). Complex emotions (such as jealousy or guilt) are distinct from basic emotions in that they are typically more nuanced, rely more heavily on context, and usually involve greater theory of mind and belief-based decision making (Johnson & Oatley, 1989). Given the increased complexity of these emotions, their processing reaches maturity considerably later (Tonks, Williams, Frampton, Yates, & Slater, 2006), improving throughout adolescence and adulthood (Rodger, Vizioli, Ouyang, & Caldara, 2015; Thomas, Bellis, Graham, & LaBar, 2007).

Impairments in FER are consistently associated with Autism Spectrum Disorder (ASD); an early onset neurodevelopmental condition characterised by deficits in social communication and social interaction alongside stereotypic, repetitive, restricted

behaviours and interests causing adaptive impairments (American Psychiatric Association, 2013). In previous research these behavioural difficulties have, in part, been attributed to challenges in recognising the emotions of others (Baron-Cohen, Leslie, & Frith, 1985; Bölte & Poustka, 2003; Harms, Martin, & Wallace, 2010; Kuuskikko et al., 2009; Lozier, Vanmeter, & Marsh, 2014; Uljarevic & Hamilton, 2013). A meta-analysis concluded that these impairments are apparent across the developmental trajectory and the six basic emotions, and cannot be accounted for by the intellectual capabilities of the individual with ASD (Uljarevic & Hamilton, 2013). Recent research conducted with both children and adults suggests that ASD linked difficulties in FER appear cross-culturally, indicating a universal nature of FER challenges in the ASD population (Fridenson-Hayo et al., 2016).

While it appears that emotion recognition is an area of significant challenge for those with ASD, questions have arisen surrounding the extent of these alterations (Lozier et al., 2014; Rutherford, Troubridge, & Walsh, 2012). Studies have reported that individuals with ASD perform no differently to their typically developing (TD) peers on emotion recognition tasks (Castelli, 2005; Evers, Kerkhof, Steyaert, Noens, & Wagemans, 2014; Tracy, Robins, Schriber, & Solomon, 2011), while others have postulated that perhaps not all, but a subset of the ASD population experience difficulty with emotion recognition (Nuske, Vivanti, & Dissanayake, 2013). These disparate findings have been attributed to a variety of participant and experiment related factors (Harms et al., 2010; Nuske et al., 2013; Uljarevic & Hamilton, 2013). Primarily, the demographic characteristics of the participants included in studies, for example age, intellectual capacity (Harms et al., 2010; Uljarevic & Hamilton, 2013) or comorbid conditions (Berggren, Engström, & Bölte, 2016) have been identified as playing a potential role in the variability of findings. Other

possible explanations relate to the compensatory strategies employed by individuals with ASD, which possibly remediate any observable behavioural deficits (Harms et al., 2010).

While individuals with ASD may exhibit impairments in FER, further empirical efforts have sought to elucidate the mechanisms which may characterize ASD-linked impairment in FER, of note, research incorporating eye tracking (ET) and electroencephalography (EEG) methods has been used to provide crucial insights into these processes which may underpin FER impairments.

ET is a valuable tool in elucidating underlying visual processing strategies (Rayner, 1998). As emotions are expressed on the face through the differential activation of facial muscles (Ekman & Friesen, 1978), eye gaze patterns that most effectively assist in identifying different emotions will vary across expressions. In typical development ET research has shown that gaze patterns differ in relation to the valence of emotions, whereby individuals fixate more on the eyes of negatively valenced emotions and the mouths of emotions that are positively valenced (Eisenbarth & Georg, 2011; Messinger, Mattson, Mahoor, & Cohn, 2012).

In addition to ET, EEG may provide insights into the neurological correlates of information processing during FER. EEG measures the electrical activity of the brain and provides superior temporal resolution to measures such as Functional Magnetic Resonance Imaging (fMRI) and Positron Emission Tomography (PET) (Scheuer, 2002). Electrical activity time locked to events, or event related potentials (ERPs) are one of the most common measures extracted from EEG. In the processing of facial expressions, a number of early and late occurring ERPs appear to change and mature throughout development (de Haan, Johnson, & Halit, 2003), notably including P100, N170 and N250. The P100 is largest over occipital areas between 80 milliseconds-120 milliseconds after

stimulus presentation and associated with the early processing of visual information. The N170 component, a negative ERP, occurs between 130 – 200 milliseconds over the temporal –occipital areas and is selectively enhanced in response to faces (Eimer, Gosling, Nicholas, & Kiss, 2011). This component is posited to reflect the structural processing of faces (Schyns, Jentzsch, Johnson, Schweinberger, & Gosselin, 2003) and is potentially indicative of the processing of higher order configural information (Eimer et al., 2011). The N250 ERP has been associated with valence specific processing, peaking at 250 milliseconds (Liu et al., 2012; Streit, Wölwer, Brinkmeyer, Ihl, & Gaebel, 2001). In children, other ERPs such as the N290 and P400 components have been identified (Leppänen, Moulson, Vogel-Farley, & Nelson, 2007) as presenting as possible precursors to the adult N170 (Halit, Csibra, Volein, & Johnson, 2004). Although less frequently investigated in research on FER, EEG analysed in the frequency domain may provide measures of cortical activity, and the topographical coordination of such activity over time, which may be reflective of a number of relevant cognitive processes (Sauseng & Klimesch, 2008). Desynchronization of alpha frequencies (8-15 Hertz) have been associated with increasing task demands and attention (Klimesch, 1999; Ward, 2003) and an increase in theta power (4-7 Hertz) has been associated with memory and encoding (Klimesch, 1999). Gamma frequencies have been associated with processes such as working memory (Barr et al., 2014) and attention (Ward, 2003), while beta (15-30 Hertz) has been associated with local information processing (Schutter & Knyazev, 2012).

To date, no review has been conducted in order to specifically examine the differences in ET and EEG characteristics of individuals with ASD during FER. Both ET and EEG provide insights in to the temporal dynamics of attention and cognition during the processing of facially expressed emotion. Therefore, the objective of this review was to

systematically appraise the literature examining ET or EEG during FER in individuals with ASD, providing an overview of the current state of the field.

## **METHOD**

### **Study Design**

This systematic review was conducted in accordance with PRISMA guidelines for systematic reviews and meta-analyses (Moher, Liberati, Tetzlaff, Altman, & The PRISMA Group, 2009). Six databases including Cinahl, Embase, Medline, Proquest, Psycinfo and Scopus were searched for full-length articles published up to the 20th (Psycinfo) or 27th (all other databases) of January, 2016. Searches were conducted using a combination of MeSH terms and key words. The following is a sample of the expressions used: (“Autistic Disorder” OR “Child Development Disorders, Pervasive” OR, “Autism Spectrum Disorder”) AND (“Evoked Potentials”, OR “Electroencephalography” OR “Eye Movements”, OR “Fixation, Ocular”) AND (“Emotions”, “Expressed Emotion”, OR “Affect”). These search terms were tailored to match specific databases (refer to Appendix B) and limited to studies in the English language. The reference lists of included articles were manually searched for articles meeting the eligibility criteria.

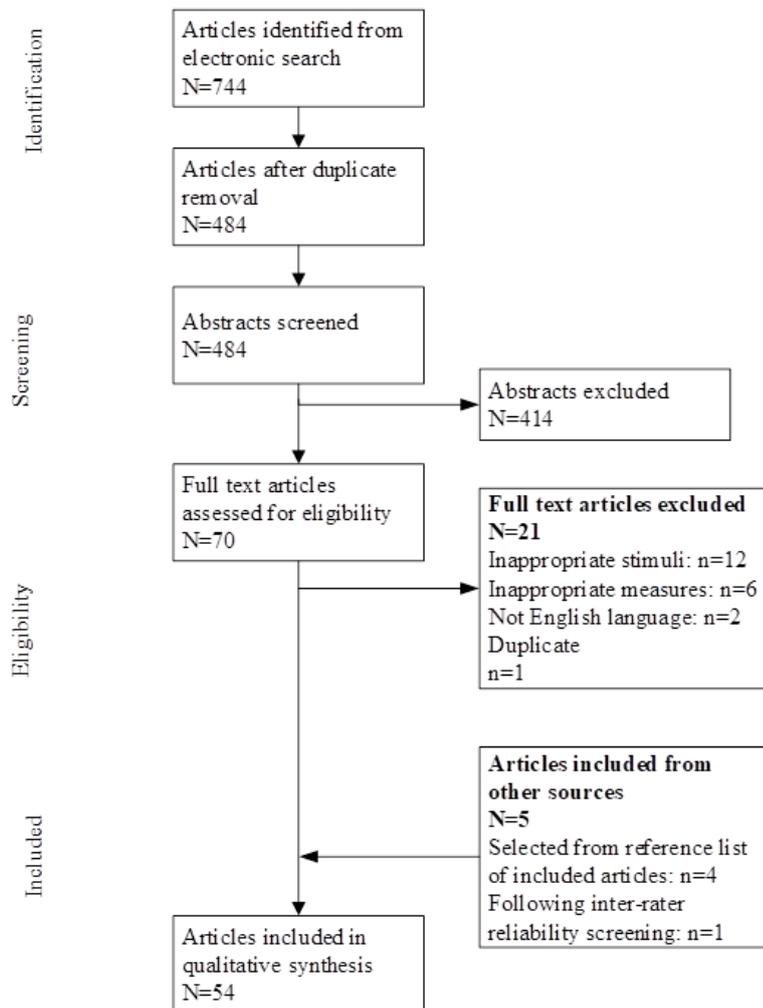


Figure 2. Flow chart demonstrating method of study identification and screening.

## Study Inclusion Criteria

Studies were included if they had a sample of individuals with ASD or individuals with high autistic symptomology, broader autism phenotype or risk of ASD development. As the majority of studies (77%) were conducted prior to 2013, i.e. before the release of the latest version of the Diagnostic and Statistical Manual for Mental Disorders – 5<sup>th</sup> Edition (DSM-5) (American Psychiatric Association, 2013), the DSM-IV (American Psychiatric Association, 2010) was utilised to classify ASD in this review. Therefore, for the purposes

of this review ASD was classified as Autism, Asperger syndrome (AS), Pervasive Developmental Disorder Not Otherwise Specified (PDD-NOS), and childhood disintegrative disorder (American Psychiatric Association, 2010). No specification was made as to whether the study included individuals with high functioning Autism (HFA; at least average IQ) or low functioning Autism (LFA; below average IQ). Studies primarily involving participants with Rett syndrome were excluded. No limits were placed on age, demographics or intelligence level of the sample with ASD. Studies were required to employ a facial emotion recognition paradigm with studies primarily investigating social scene perception, object recognition or non-emotionally relevant face processing excluded. Finally, studies were required to provide a measure of ET or EEG or a combination of both to be eligible for inclusion. Figure 2 presents a flow chart of the method of data selection in accordance with the eligibility criteria.

### **Data Extraction and Synthesis**

Data were extracted in accordance with the Cochrane handbook for systematic reviews (Higgins & Green, 2011). Participant demographic data was extracted in relation to clinical and comparison samples including number of participants, diagnosis, age and participant matching procedure. Information pertaining to the experimental design and stimuli were also extracted, this included the emotions utilised as well as whether the task was an explicit or implicit FER task. For the purposes of this review, implicit tasks were defined as tasks which required either the passive free-viewing of facial expressions or tasks that required the viewing of facial expressions while completing other recognition tasks (such as gender recognition, or target detection). Further distinction was made in regard to the type of emotion examined in the study. For the purposes of this review basic emotions have been defined as happiness, anger, sadness, fear, disgust, and surprise in

accordance with previous literature (Ekman, 1992) and complex emotions as any other emotions. Results extracted related to differences between groups in regard to ET, ERP or quantified EEG outcomes and pertinent within group differences. A summary of extracted data for each study is presented in Tables 1, 2 and 3.

Initial extraction revealed clear trends in relation to the heterogeneity across studies owing to differences in sample ages, stimulus type, outcome measures and the reporting of results. This appeared to be particularly evident in the studies examining ET measures. Due to the considerable variance observed across studies, a narrative review was deemed the most appropriate to summarise and explore the findings in the various experimental paradigms. Data synthesis examined ET and EEG studies with respect to their various characteristics. For ET studies synthesis involved the number of fixations and duration of fixations to defined areas of interest as well as scan paths, with ET findings presented according to age and stimulus type. In synthesising EEG studies, ERP and EEG frequency features were extracted. Due to the large number of ERP and EEG measures examined within the studies, this review focused on the most frequently examined ERPs within each age category, such as the N170 and P100. Other less common components are discussed briefly. Due to the expected developmental changes studies were allocated to one of three sets. Studies with participants aged 0-12 years of age were classified as child studies, 13–17 years were classified as adolescent and adult pertained to studies of participants aged 18 and above.

### **Study Evaluation**

Two reviewers independently assessed the quality of included studies according to the Kmet Form for quantitative analysis (Kmet, Lee, & Cook, 2004). The Kmet form provides a means of appraising the quality of studies on 14 criteria relating to the research

hypothesis, methods, study samples, reporting of results, and conclusions. Two criteria of the Kmet form did not apply to the studies included in this review (intervention blinding of assessor and subject), so the form used for the current systematic review included only 12 criteria (Appendix B). For each of the 12 criteria, the study is allocated a score of 2 (yes/addressed), 1 (partially addressed) or 0 (not addressed) according to the degree to which the criterion was met, therefore the maximum score that any study could achieve was 24 (e.g.,  $2 \times 12$ ). Studies achieving a score of 80% or greater are rated as strong, 70-80% are good, 50-69% are adequate and scores of 50% or lower are considered limited.

Table 1. Child eye tracking and electrophysiological studies

Citation	Sample						Matching procedure	Task Format	Stimuli	Emotions	Key Findings	Methodology Quality
	Clinical			Comparison								
	Diagnosis	N	Mean age (SD)	Diagnosis	N	Mean age (SD)						
<i>Eye Tracking</i>												
Nuske, Vivanti, Hudry, Dissanayake, 2014	Autism, ASD	19	3.97 (1)	TD	21	4.27 (0.60)	CA	Implicit	<b>Static</b> , Photographs 30ms, 300ms and 2s exposure times.	Fear, Neutral	ASD fixation time on fear face for 30ms and 2sec condition < TD. ASD fixation time on eyes of fearful faces < TD (all conditions – driven by 2sec condition). ASD fixation time to neutral face in 2sec condition < TD. ASD fixation time on eyes and mouth < TD (driven by 2sec condition). Fixation time not correlated with ASD symptomology.	<b>87% (21/24)</b> . Participants matched on CA. Correlations with IQ explored. Stimuli not randomized.
Nuske, Vivanti, Dissanayake, 2014	Autism, ASD	21	3.98 (1.05)	TD	21	4.27 (0.60)	CA	Implicit	<b>Dynamic</b> , videos of familiar and unfamiliar faces expressing emotion. 4 second neutral followed by 4 second fearful expression exposure time.	Fear, Neutral	ASD # of fixations on fear = TD. ASD # of fixations on neutral < TD. ASD # of fixations on fear > neutral. TD # of fixations on fear = neutral. ASD fixation time on eyes and mouth of neutral familiar and unfamiliar faces < TD.	<b>87% (21/24)</b> . Participants matched on CA. Correlations with IQ explored. Counterbalanced exposure duration of stimuli.

*Table 1. Continued*

Citation	Sample						Matching procedure	Task Format	Stimuli	Emotions	Key Findings	Methodology Quality
	Clinical			Comparison								
	Diagnosis	N	Mean age (SD)	Diagnosis	N	Mean age (SD)						
De Wit et al., 2008	AS, PDD-NOS, Autism	13	5.17 (.89)	TD	14	4.93 (.11)	N/A	Implicit	Static, photographs 10s exposure time.	Calm, Happy, Anger, Fear	ASD fixation time < TD. ASD fixation time on eye region = TD. Social and communication impairment scores negatively correlated with overall fixation time on the screen and fixation time on the mouth.	<b>83% (20/24).</b> Sample size small. Participant matching procedure unclear. Stimuli pseudo-randomized. Partial discussion of limitations.

Table 1. Continued

Citation	Sample						Matching procedure	Task Format	Stimuli	Emotions	Key Findings	Methodology Quality
	Clinical			Comparison								
	Diagnosis	N	Mean age (SD)	Diagnosis	N	Mean age (SD)						
Falck-Ytter et al., 2010. Study 1+2	Autism, AS, PDD-NOS	1;15, 2;13	5.17 (.91)	TD	15	4.91 (.08)	N/A	Implicit	Static, photographs followed by dynamic videos, 4 s exposure time. Upright and Inverted stimuli	Anger, Happy, Disgust, Fear, Neutral, Unlabelled Grimace	Study 1: ASD fixation time on eyes and mouth = TD. Social impairment positively correlated with fixation time on mouth and negatively correlated with fixation time on eyes. Communication impairment positively correlated with fixation time on eyes and negatively correlated with fixation time on mouth. Dynamic faces showed same results but no correlation between communication impairment and fixation time on eyes. Same pattern as above also for each separate emotion and opposite for happy and disgusted faces. In inverted faces, there was a positive correlation of social impairment and fixation time on mouth. Study 2: positive correlation of fixation time on face in action and fixation time on eyes in study 1 in both groups. In ASD, negative correlation of social impairment and fixation time on face during action execution and opposite for communication impairment.	<b>83% (20/24).</b> Sample size small. Participant matching procedure unclear although estimate of developmental age calculated using PEP-R and GMDS. Partial stimuli randomization. Limitations not well described.

Table 1. Continued

Citation	Sample						Matching procedure	Task Format	Stimuli	Emotions	Key Findings	Methodology Quality
	Clinical			Comparison								
	Diagnosis	N	Mean age (SD)	Diagnosis	N	Mean age (SD)						
Falk-Ytter et al., 2010. Study 3	Autism, AS PDD-NOS	12	6.58 (.67)					Implicit	<b>Dynamic</b> , videos, 4s exposure time, upright and inverted stimuli.	Anger, Fear, Happy, Neutral	Positive correlation of fixation time on mouth and social impairment score on SCQ	As Above
Bal et al., 2010	Autism, PDD-NOS	17 (12 ET)	10.3 (2.2)	TD	36 (30 ET)	11.16 (2.89)	CA, K-BIT	Implicit and Labelling (ET behaviour obtained only during implicit task)	<b>Dynamic</b> , morphing stimuli Exposure time 15-33s	Anger, Disgust, Fear, Happy, Surprise, Sad	ASD fixation time on areas not eyes and mouth = TD. ASD fixation time on non-core/outside regions > TD when viewing fear. ASD children who had shorter fixation time on mouth and longer on eyes more accurate at disgust recognition. TD greater fixation time on eyes and shorter fixation time on mouth more accurate at surprise recognition and greater fixation time on eyes related to faster fear recognition.	<b>92% (22/24)</b> . ASD sample for eye tracking analysis small. Results reported in partially sufficient detail.
Van der Geest et al., 2002	Autism, PDD-NOS	17	10.6 (2.1)	TD	17	10.1 (1.3)	CA, WSI	Implicit	<b>Static</b> , Photographs 10s exposure time.	Anger, Happy, Neutral, Surprise	ASD fixation time and # of fixations on all regions = TD. ASD first fixation location = TD.	<b>96% (23/24)</b> Stimuli pseudo-randomized.

Table 1. Continued

Citation	Sample						Matching procedure	Task Format	Stimuli	Emotions	Key Findings	Methodology Quality
	Clinical			Comparison								
	Diagnosis	N	Mean age (SD)	Diagnosis	N	Mean age (SD)						
Leung et al., 2013	autism, AS	26	10.6 (1.3)	TD	26	10.8(1.1)	CA	Matching	<b>Static</b> , puzzled photograph stimuli presented for 10 s followed by whole face 'choice' stimuli exposed until participant choice selection.	Anger, Happy, Surprised	ASD fixation time on whole face and puzzled stimuli = TD. ASD fixation time > TD.	<b>88% (21/24)</b> . Participants matched only on CA. Stimuli not randomized.
Crawford et al., 2015	Autism, AS, PDD-NOS	15	11 (3.48)	1; FXS, 2;TD child, 3; TD adult	1; 13, 2; 16, 3; 12	1; 19.7(9), 2; 7.13 (1.61), 3; 21.92 (2.97)	VABS (matched to FXS only)	Implicit	<b>Static</b> , photograph s presented side by side. Exposure time 1.5s	Happy, Disgust, Neutral	ASD and FXS fixation time to disgust > neutral. Similar results for TD. ASD fixation time to eyes of neutral faces > FXS. ASD fixation time on mouth = FXS.	<b>92% (22/24)</b> . Sample size small. Stimuli pseudo-randomized.

*Table 1. Continued*

Citation	Sample						Matching procedure	Task Format	Stimuli	Emotions	Key Findings	Methodology Quality
	Clinical			Comparison								
	Diagnosis	N	Mean age (SD)	Diagnosis	N	Mean age (SD)						
<i>EEG</i> Key et al., 2015	High risk	16	.75	Low risk	15	.75	CA, Gender, Ethnicity, Maternal education	Implicit	<b>Static</b> , photographs, 750ms stimuli exposure time.	Neutral, Small Smile, Duchenne Smile	High risk posterior N290 amplitude and latency and P400 and Nc amplitude = low risk. High risk had faster P400 to small smiles than low risk. High risk siblings showed faster latencies to small smiles versus Duchenne smiles, low risk did not discriminate. High risk Nc amplitude to small smiles = neutral. Low risk Nc amplitude to small smiles > neutral.	<b>92% (22/24).</b> Sample size small. Stimuli counter-balanced.

*Table 1. Continued*

Citation	Sample						Matching procedure	Task Format	Stimuli	Emotions	Key Findings	Methodology Quality
	Clinical			Comparison								
	Diagnosis	N	Mean age (SD)	Diagnosis	N	Mean age (SD)						
Dawson et al., 2004	Autism, PDD-NOS	1; 29 2; 11	1; 3.78 (0.83) 2; 2.31 (0.75) (mental age)	TD	1; 22 2; 11	1; 3.64 (0.58) 2; 4.03 (0.6) (mental age)	CA, Gender, SES (1) MSEL (2)	Implicit	<b>Static</b> , photographs, 500ms exposure time.	Neutral, Fear	<b>Chronological age matched:</b> ASD P200 slower and smaller than TD to neutral. ASD N300 amplitude and latency for fear = neutral. TD faster and larger N300 for fear versus neutral. ASD N300 latency to neutral in right hemisphere = left hemisphere. TD faster N300 to neutral in right hemisphere versus left hemisphere. ASD NSW amplitude for neutral = fear. TD NSW amplitude for fear > neutral. P300, Nc and P500 in ASD = TD. <b>Mental age matched:</b> ASD P200 amplitude in right and midline region > TD. ASD N300 amplitude and latency for fear = neutral. TD N300 amplitude for fear > neutral. ASD N300 latency in left hemisphere > TD. ASD P300 amplitude for neutral > fear. TD P300 amplitude for neutral < fear. TD NSW amplitude to fear > neutral. ASD NSW to fear = neutral. ASD Nc and P500 = TD.	<b>96% (23/24).</b> Stimuli pseudo-randomized.

Table 1. Continued

Citation	Sample						Matching procedure	Task Format	Stimuli	Emotions	Key Findings	Methodology Quality
	Clinical			Comparison								
	Diagnosis	N	Mean age (SD)	Diagnosis	N	Mean age (SD)						
Vlamings et al., 2010	ASD	22	4 (0.1)	DD	17	4.3 (0.2)	CA, Gender, SON-R, WPPSI-R, MSEL, PEP, Reynell Test for Language	Implicit	<b>Static</b> , photographs, High and low spatial frequencies, 500ms exposure time.	Neutral, Fear	ASD P100 amplitude to fear > neutral in high spatial frequency condition. TD P100 amplitude to fear < neutral in low spatial frequency condition.	<b>92% (22/24)</b> . Analytic method partially described. Limited discussion of study limitations.
Wong et al., 2008	Autism	12	8.5 (1.5)	TD	12	8.5 (1.4)	CA, RPM	Implicit and Labelling (neutral/e motion)	<b>Static</b> , photographs, stimuli exposure time 750ms	Happy, Sad, Anger, Fear, Neutral	ASD P100, N170 and P200 amplitude and latency = TD. Dipole source at occipital, temporal, frontal and parietal regions in ASD found cortical regions in ASD weaker or delayed at sub-second latencies.	<b>92% (22/24)</b> . Sample size small. Stimuli pseudo-randomized.
Yeung et al., 2014	ASD	18	9.61 (3.13)	TD	18	10.72 (3.61)	CA, Gender, WISC IV (Hong Kong) CVT	Labelling	<b>Static</b> , photographs, stimuli presented until participant response.	Happy, Fear, Anger, Disgust, Surprise, Sad, Neural	ASD lower right frontal theta coherence for sadness, disgust and surprise. TD higher theta coherence when viewing emotions (except anger) compared to neutral faces. ASD Theta not higher for emotional faces versus neutral. ASD: increase in right frontal theta coherence in emotion modulation associated with lower autistic symptomology.	<b>96% (23/24)</b> . Stimuli pre-set randomized.

*Table 1. Continued*

Citation	Sample						Matching procedure	Task Format	Stimuli	Emotions	Key Findings	Methodology Quality
	Clinical			Comparison								
	Diagnosis	N	Mean age (SD)	Diagnosis	N	Mean age (SD)						
Apicella et al., 2012	Autism	10	10.2	TD	12	9.7	N/A	Implicit	<b>Static</b> , photographs, Stimuli exposure time 850ms.	Happy, Fear, Neutral	ASD ppN170 = TD.	<b>71% (17/24)</b> . Sample size small. Limited discussion of participant characteristics or participant source. Participant matching procedure unclear. Results in partial detail. Limited discussion of limitations.
Batty et al., 2011	Autism	15	10.55(3.31)	1; TD VE 2; TD CA	1; 15, 2; 15	1; 7.70 (3.8), 2;10.51 (3.2)	CA (1), PPVT (French), RPM, WISC III	Implicit	<b>Static</b> , photographs, 500ms exposure time.	Happy, Anger, Disgust, Sad, Surprise, Fear	<b>CA matched.</b> ASD P100 amplitude < TD. ASD P100 slower than TD. ASD delayed N170. <b>VE matched:</b> ASD P100 amplitude < TD. ASD P100 latency = TD.	<b>92% (22/24)</b> . Sample size small. Limited discussion of study limitations.

Table 1. Continued

Citation	Sample						Matching procedure	Task Format	Stimuli	Emotions	Key Findings	Methodology Quality
	Clinical			Comparison								
	Diagnosis	N	Mean age (SD)	Diagnosis	N	Mean age (SD)						
De Jong et al., 2008	Autism, ASD	30	10.7 (1.8)	TD	30	10.6 (1.6)	CA Gender WISC III	Implicit	<b>Static and Dynamic,</b> (morphing) High and low spatial frequency, direct and averted gaze. Stimuli with direct and averted gaze exposure time = 373ms, morphing stimuli = 440ms (40ms, 11 frames)	Fear, Neutral	ASD N170 amplitude for fear = neutral. TD N170 amplitude for fear > neutral. ASD N170 amplitude to fear < TD. Low spatial frequency versus high spatial frequency effect smaller in ASD group. Morphing stimuli showed gaze cue effect in neutral to fear transition in TD and ASD immediate cue-validity effects (N200 latency). TD greater cue-validity effect in low spatial frequency > high spatial frequency.	<b>100% (24/24)</b>
O'Connor et al., 2005	AS	15	11.6 (1.9)	TD	15	11.2 (1.8)	CA, Gender	Labelling	<b>Static,</b> photographs, Stimuli 1s exposure time.	Happy, Sad, Anger, Fear	ASD N170, P100 and P200 amplitude and latency = TD.	<b>92% (22/24).</b> Sample size small. Participants matched on CA.

Table 1. Continued

Citation	Sample						Matching procedure	Task Format	Stimuli	Emotions	Key Findings	Methodology Quality
	Clinical			Comparison								
	Diagnosis	N	Mean age (SD)	Diagnosis	N	Mean age (SD)						
Tye et al., 2014	1;ASD, autism, 2; ASD, autism + ADHD	1; 19, 2; 29	1;11.69;2;10.53	1; TD, 2; ADHD	1; 26, 2; 18	1; 10.56 (1.79), 2; 10.48(1.91)	CA, verbal IQ	Implicit	<b>Static</b> , photographs, exposure time 1.3s	Disgust, Fear, Anger, Joy, Neutral	ASD/ASD+ADHD N170 amplitude < TD. ASD/ASD+ADHD N170 amplitude to fear < neutral. TD and ADHD only N170 amplitude for fear = neutral. ASD+ADHD N170 shorter to angry compared to neutral. ASD shorter N170 to neutral compared to angry. ASD + ADHD longer N170 to happy compared to fear and ASD longer N170 latency to fear compared to happy. N400 latency shorter in ASD compared to TD.	<b>92% (22/24)</b> . Participants matched only on CA and verbal IQ. Stimuli not randomized but randomized inter-stimuli period.

Abbreviations: ASD; Autism Spectrum Disorder, TD; Typically developing, CA; Chronological age, PDD-NOS; Pervasive Developmental Disorder Not Otherwise Specified, AS; Asperger Syndrome, K-BIT; Kauffman Brief Intelligence Test, WSI; Wechsler Scale of Intelligence FXS; Fragile X Syndrome, VABS; Vineland Adaptive Behavior Scales SES; Socio-economic Status, MSEL; Mullen Scales of Early Learning SON-R;, Snijders-Oomen Nonverbal Intelligence Test – Revised WPPSI-R; Wechsler Preschool and Primary Scale of Intelligence – Revised, PEP; Psychoeducational Profile, RPM; Ravens Progressive Matrices, WISC; Wechsler Intelligence Scale for Children, CVT; Chinese Vocabulary Test, PPVT; Peabody Picture Vocabulary Test, VE; Verbal Equivalent, ADHD; Attention Deficit Hyperactivity Disorder. N/A denotes areas where sufficient information was not provided by study.

Table 2. Adolescent eye tracking and electrophysiological studies

Citation	Sample						Matching procedure	Task Format	Stimuli	Emotions	Key Findings	Methodology Quality
	Clinical			Comparison								
	Diagnosis	N	Mean age (SD)	Diagnosis	N	Mean age (SD)						
<i>Eye tracking</i>												
Bekele et al., 2013	ASD	10	14.7 (1.1)	TD	10	14.6 (1.2)	CA	Labelling	<b>Dynamic</b> , VR avatar, 25-40s exposure time of neutral face lip syncing followed by expression presented for 5s.	Enjoyment, Surprise, Contempt, Sad, Fear, Disgust, Anger	Trend for ASD fixation time on eyes and nose < TD. ASD fixation time on forehead > TD and fixation time on mouth < TD. ASD fixation time outside of face > TD. ASD fixation time on face < TD. Similar results for correct/incorrect trials.	<b>92% (22/24)</b> . Small sample size. Participants only matched on CA
Bekele et al., 2014	ASD	10	14.7 (1.1)	TD	10	14.6 (1.2)	CA, DAS, SB, WISC (ASD), WASI (TD)	Labelling	<b>Dynamic</b> , VR avatar, 10-15s exposure time of neutral face lip syncing followed by expression of varying intensity for 5s	Enjoyment, Surprise, Contempt, Sad, Fear, Disgust, Anger	ASD fixation time to eyes, nose and other = TD. ASD fixation time on mouth < TD. ASD fixation time on forehead > TD.	<b>92% (22/24)</b> . Sample size small. Outcome measure partially described.
McCabe et al., 2013	Autism, AS, PDD-NOS	14	14.71 (2.87)	1; TD, 2; 22q11DS	1; 31, 2; 20	1; 16.55(3.3), 2; 16.75 (3.71)	CA	Labelling	<b>Static</b> , Photographs, 6s exposure time.	Happy, Sad, Surprised, Disgust, Fear, Anger, Neutral	ASD and 22q11DS # of fixations to face < TD. When IQ controlled for this effect was not significant. ASD fixation time on core features = TD.	<b>88% (21/24)</b> . ASD sample small. Participants matched only on CA but IQ controlled for. Stimuli not randomized.

Table 2. Continued

Citation	Sample						Matching procedure	Task Format	Stimuli	Emotions	Key Findings	Methodology Quality
	Clinical			Comparison								
	Diagnosis	N	Mean age (SD)	Diagnosis	N	Mean age (SD)						
White et al., 2015	ASD	15	14.88 (1.55)	TD	18	14.33 (1.52)	CA, Gender	Implicit	<b>Static</b> , photographs of single faces and face pairs. Both presented for 4s	Face pairs: Disgust, Anger, happy, calm (instead of neutral), Single face: Happy, Sad, Surprise, Anger, Disgust, fear. Analysis undertaken on Disgust, angry and happy only.	ASD fixation time on face and eyes = TD. After controlling for negative evaluation, ASD fixation time on eyes and face < TD. Fear of negative evaluation in ASD predicted fixation duration to face and trend for fixation duration to eyes in anger and disgust. When stimulus presentation divided into 500ms epochs, ASD fixation time on angry in 1 <sup>st</sup> 500ms < TD. Progressive disengagement to disgust more apparent in ASD versus TD. ASD attention to disgust in 1 <sup>st</sup> , 7 <sup>th</sup> and 8 <sup>th</sup> 500ms epoch < TD.	<b>83% (20/24)</b> . Sample size small. Stimuli not randomized. Participants matched on CA.
Dalton et al., 2005	Autism, AS	11	15.9 (4.7)	TD	12	17.1 (2.78)	CA	Labelling (neutral/emotion)	<b>Static</b> , photographs. Direct and Averted Gaze. 3s exposure time.	Neutral, Happy, Fear, Anger	ASD fixation time on eyes < TD. ASD fixation time on mouth and face = TD.	<b>75% (18/24)</b> . Sample size small. Participants matched on CA. Analytic method partially described. Stimuli not randomized. Partial discussion of limitations and confounders.

Table 2. Continued

Citation	Sample		Comparison				Matching procedure	Task Format	Stimuli	Emotions	Key Findings	Methodology Quality
	Diagnosis	N	Mean age (SD)	Diagnosis	N	Mean age (SD)						
Dalton et al., 2008	Autism, AS	14	15.9 (4.71)	1; FXS, 2; TD	1; 9, 2; 15	1; 20.7 (2.77) 2; 16.8 (2.57)	WRIT	Labelling (neutral/emotion)	As above.	Happy, Fear, Anger	ASD fixation pattern on eyes and mouth = FXS.	<b>75% (18/24).</b> Sample size small. IQ of TD group not assessed, although FXS and ASD group did not differ in IQ. Stimuli not randomized. ET results not reported in sufficient detail. Conclusions partially supported by results.
Wagner et al., 2013	ASD	17	17.0 (2.2)	TD	19	17.9 (2.5)	CA, KBIT-2	Implicit	<b>Static,</b> photographs, 5s exposure time.	Anger, Fear, Neutral	ASD fixation time on face, eyes and mouth = TD.	<b>100% (24/24)</b>
Tottenham et al., 2014	Autism, AS, PDD-NOS	26	17 (7)	TD	39	17 (9)	WASI, PPVT 3	Labelling and Implicit (ET behaviour obtained only during Implicit task)	<b>Static,</b> photographs, 300ms exposure time.	Anger, Neutral, Happy	Trend for ASD gaze towards eyes < TD. ASD gaze towards eyes < TD for neutral. ASD gaze towards eyes of angry = TD. ASD participants who gave higher threat ratings to neutral faces produced less eye movements towards eyes. This was not seen for angry faces or in TD.	<b>96% (23/24).</b> Fixed-random protocol.

Table 2. Continued

Citation	Sample						Matching procedure	Task Format	Stimuli	Emotions	Key Findings	Methodology Quality
	Clinical			Comparison								
	Diagnosis	N	Mean age (SD)	Diagnosis	N	Mean age (SD)						
Hanley et al., 2012	AS	14	20.5	TD	14	20.4	CA Gender, WASI	Implicit	<b>Static</b> , photographs, 5 conditions: isolated posed faces, isolated acted faces, isolated naturalistic faces, acted social scenes and naturalistic social scenes. 5s exposure time.	Happy, Fear, Sad, Excited, Disgusted, Angry, Romantic, Thinking, Bored	ASD Fixation time on posed and acted faces = TD. For naturalistic isolated faces, ASD fixation time on hair > TD. For acted social scenes, ASD fixation time on eyes < TD and fixation time on body > TD. For naturalistic scenes, ASD fixation time on eyes and face < TD.	<b>88% (21/24).</b> Sample size small. Participant characteristics limited in description. Partial description of limitations.
<i>EEG</i> Lerner et al., 2013	ASD	34	13.07 (2.07)	Age group Norms				Labelling	<b>Static</b> , photographs, stimuli presented until participant response, maximum 3s.	Happy, Sad, Anger, Fear	N170 latency associated with decrease accuracy. Larger N170 amplitudes had faster responses. Shorter N300 latencies associated with faster response times for adult faces.	<b>100% (24/24)</b>
Akechi et al., 2010	Autism, AS, PDD-NOS	14	13.7 (2.3)	TD	14	12.32 (2.1)	CA, Gender, WISC III (Japanese)	Labelling	<b>Static</b> , direct and averted gaze, Stimuli exposure time 1.2s	Anger, Fear	ASD P100 and VPP amplitude and latency = TD. ASD N170 latency = TD. ASD N170 amplitude to congruent (fearful with averted gaze, anger with direct) = incongruent stimuli. TD N170 amplitude to congruent > incongruent stimuli.	<b>92% (23/24).</b> Sample size small.

Table 2. Continued

Citation	Sample						Matching procedure	Task Format	Stimuli	Emotions	Key Findings	Methodology Quality
	Clinical			Comparison								
	Diagnosis	N	Mean age (SD)	Diagnosis	N	Mean age (SD)						
Gross et al., 2012	ASD	10	14.1 (2.7)	1; TD, 2; ADHD	1; 11, 2; 9	1; 14.8 (4.5) 2; 14.2 (3.9)	CA	Implicit and Labelling (anger, disgust)	<b>Static</b> , photographs, 300ms exposure time.	Anger, Disgust, Fear, Sad	ASD had a lower induced gamma in emotion recognition task versus gender recognition. ADHD higher induced gamma in emotion recognition versus gender recognition. ADHD higher induced gamma than ASD in emotion recognition.	<b>83% (20/24)</b> . Sample size small. Limited discussion of study limitations. Stimuli randomly selected. IQ measured however matching procedure unclear.
Wagner et al., 2013	ASD	17	17 (2.2)	TD	18	17.9 (2.5)	CA, KBIT-2	Implicit	<b>Static</b> , photographs, 5s exposure time.	Anger, Fear, Neutral	ASD P100 amplitude = TD. ASD no difference of N170 between fearful, angry, neutral. TD N170 amplitude to fear > angry.	<b>100% (24/24)</b>

Abbreviations: ASD; Autism Spectrum Disorder, TD; Typically Developing, CA; Chronological age, VR; Virtual reality, DAS; Differential Ability Scales SB; Stanford Binet, WISC; Wechsler Intelligence Scale for Children, WASI; Wechsler Abbreviated Scales of Intelligence, AS; Asperger Syndrome, PDD-NOS; Pervasive Developmental Disorder Not Otherwise Specified FXS; Fragile X Syndrome, WRIT; Wide Range Intelligence Test, KBIT-2; ; Kauffman Brief Intelligence Test PPVT; Peabody Picture Vocabulary Test ADHD; Attention Deficit Hyperactivity Disorder. N/A denotes areas where sufficient information were not provided by study.

*Table 3. Adult eye tracking and electrophysiological studies*

Citation	Sample						Matching procedure	Task Format	Stimuli	Emotions	Key Findings	
	Clinical			Comparison								
	Diagnosis	N	Mean age (SD)	Diagnosis	N	Mean age (SD)						
<i>Eye Tracking</i> Han et al., 2015	LFAS	12	19.5 (3.1)	1; TD child, 2; TD adult	1; 12, 2; 12	1; 8.1 (2.2), 2; 24.3 (5.3)	CA (1), RCPM (2)	Matching	<b>Dynamic</b> , (morphing) Human Face and mechanical Face). 4s exposure time.	Happy, Disgust, Fear, Surprise	ASD fixation time < TD. ASD fixation time on core features > non-core features. ASD fixation time on core features < TD for mechanical display. ASD fixation time on core features of mechanical face < human face. ASD fixation time to mechanical motion > TD. ASD fixation time on core features = mechanical motion. TD fixation time on core features > mechanical motion.	<b>88% (21/24)</b> . Stimuli not randomized. Limitations partially discussed.

Table 3. Continued

Citation	Sample		Comparison				Matching procedure	Task Format	Stimuli	Emotions	Key Findings	
	Diagnosis	N	Mean age (SD)	Diagnosis	N	Mean age (SD)						
Sawyer et al., 2012	AS	29	21.6 (9.8)	TD	24	24 (9.2)	CA, WASI	Implicit and Labelling (ET obtained only during full face and passive viewing)	<b>Static</b> , photographs, 5s exposure time.	Happy, Sad, Surprised, Fear, Anger, Disgust, Scheming, Guilt, Thoughtful, Admiring, Quizzical, Flirting, Bored, Interested, Arrogant, Embarrassed	ASD fixations on eyes and mouth = TD.	<b>92% (23/24)</b> . Partial discussion of limitations.
Neumann et al., 2006	Autism	10	23 (2)	TD	10	28 (3)	CA, WASI, Gender	Labelling	<b>Static</b> , Whole Face and Guassian Bubbles Upright and Inverted Faces. Whole face stimuli exposure time 1s. Bubbled stimuli presented until participant response or a maximum of 10s.	Fear, Happy	ASD viewing of upright whole faces = TD. When faces whole and inverted, ASD fixation time on mouth > TD. In bubbled condition, ASD fixation time on mouth > TD and ASD fixation time on eyes < TD.	<b>92% (22/24)</b> . Sample size small. Whole face stimuli viewed by 11 participants. Limited discussion of limitations.

Table 3. Continued

Citation	Sample		Comparison					Matching procedure	Task Format	Stimuli	Emotions	Key Findings
	Clinical											
	Diagnosis	N	Mean age (SD)	Diagnosis	N	Mean age (SD)						
Sasson et al., 2007	Autism	10	23 (5.27)	1;TD,2; Schizophrenia	1;10.2; 10	1; 22.4 (6.3) 2; 28.1 (5.07)	CA, WASI	Labelling	<b>Static</b> , face Digitally Erased Faces, exposure time 3s.	Happy, Surprise, Fear, Anger, Sad, Disgust, Neutral	In face present condition: ASD fixation time on face < TD and ASD fixation time = Schizophrenia. ASD oriented to faces at the same speed regardless of face condition. ASD showed negative correlation between fixation time on face and recognition accuracy. TD oriented faster to face in face present condition compared to face-absent.	<b>83% (20/24)</b> . Sample size small. Stimuli not randomized. Partial discussion of limitations.
Spezio et al., 2007a	Autism	9 (8 ET)	23 (6.75)	TD (5 whole face)	10	28 (8.15)	CA, WASI	Labelling	<b>Static</b> Whole Face and Gaussian Bubbles. Stimuli displayed until participant response with maximum of 10s. Whole face stimuli displayed for 1s.	Fear, Happy (Gaussian Bubbles), Happy, Fear, Anger, Surprise, Disgust (whole face)	In bubbled condition, ASD fixation time and # of fixations to mouth > TD and ASD fixation time to right eye < TD. ASD fixation time for whole face condition = TD.	<b>87% (21/24)</b> . Sample size small. Partial discussion of limitations

Table 3. Continued

Citation	Sample		Comparison		Matching procedure	Task Format	Stimuli	Emotions	Key Findings			
	Diagnosis	N	Mean age (SD)	Diagnosis	N	Mean age (SD)						
Spezio et al., 2007b	Autism	8	23 (7.11)	TD	10	28 (8.15)	CA, WASI	Labelling	<b>Static</b> , Gaussian Bubbles. Stimuli displayed until participant response with maximum of 10s.	Fear, Happy	When bubbles revealed more information in the left eye, ASD fixation time on mouth > TD. When bubbles revealed more information at the mouth, ASD fixation time on mouth < TD.	<b>83% (20/24)</b> Sample size small. Results not reported in sufficient detail. Partial discussion of limitations
Hernandez et al., 2009	Autism	11	24.09 (8.31)	TD	23	22.2 (3.6)	N/A	Implicit	<b>Static</b> , photographs, neutral faces with direct and averted gaze, emotional faces and avatar faces.4s exposure time.	Happy, Sad, Neutral	ASD fixation time on core features = fixation time on non-core/outside features. TD fixation time on core features > fixation time on non-core/outside features. ASD fixation time on eyes < TD for neutral, happy, sad, neutral with averted gaze and avatar stimuli. ASD fixation on nose < TD for neutral, happy, sad and neutral with averted gaze stimuli. ASD fixation time on mouth = TD. ASD fixation time on outside regions/off screen > TD for all stimuli. ASD started exploration of face on eyes < TD and started exploration on mouth > TD.	<b>79% (19/24)</b> . Sample size small. Participant matching procedure unclear. Participant source not described. Participant characteristics partially described. Limitations partially discussed.

Table 3. Continued

Citation	Sample						Matching procedure	Task Format	Stimuli	Emotions	Key Findings	
	Clinical			Comparison								
	Diagnosis	N	Mean age (SD)	Diagnosis	N	Mean age (SD)						
Pelphrey et al., 2002	HFA	5	25.2	TD	5	28.2	N/A	Implicit and Labelling	<b>Static</b> , photographs, 2s exposure time	Happy, Fear, Anger, Disgust, Surprise, Sad	ASD fixation time and # of fixations on core regions < TD. ASD fixation time on eyes and nose < TD, ASD fixation time on mouth = TD. ASD # fixations and fixation time on face = TD	<b>71% (17/24)</b> . Sample size small. Matching procedure unclear. Results not reported in sufficient detail. Stimuli not randomized.
Rutherford et al., 2008	autism, AS	11	25.8 (6.09)	TD	11	25.7 (8.87)	CA, Gender, WAIS, Education	Labelling	<b>Static</b> , photographs, stimuli exposure time 2.5s	Happy, Surprise, Anger, Disgust, Sad, Distress, Scheming, Thoughtful, Flirting, Admiring, Quizzical, Bored, Interested, Guilty, Arrogant.	Trend for ASD preference for eyes over mouth > TD. ASD fixation time on features of complex emotion < basic emotion. TD fixation time on features of complex emotion > basic emotion. Increased stimulus complexity resulted in greater eye preference for TD and decrease in eye preference for ASD.	<b>83% (20/24)</b> . Sample size small. Stimuli not randomized. Partial discussion of limitations.

Table 3. Continued

Citation	Sample		Comparison				Matching procedure	Task Format	Stimuli	Emotions	Key Findings	
	Diagnosis	N	Mean age (SD)	Diagnosis	N	Mean age (SD)						
Falkmer et al., 2011	AS	24	29 (10.8)	TD	24	28.9 (10.6)	CA, gender	Matching	<b>Static, Whole Face and Puzzled.</b> Puzzled stimuli exposure time 10s, whole face stimuli displayed until participant response.	Happy, Anger, Surprise	Puzzled stimuli: ASD # of fixations on eyes < TD. ASD # fixations on mouth > TD. ASD # fixations on non-core/outside face = TD. ASD fixation time on mouth < TD. Whole face stimuli: ASD # fixations on eyes < TD. ASD # fixations on non-core/other parts of face > TD. ASD # fixations on mouth = TD. ASD fixation time on non-core/other parts of face > TD. ASD with highest recognition accuracy made more fixations on the eyes of puzzled stimuli, made fewer fixations on non-core/outside regions of whole face stimuli, had shorter fixation times on the eyes of puzzled stimuli and shorter fixation times to the mouth of whole faces compared to ASD participants with lowest recognition accuracy.	<b>88% (21/24).</b> Participant IQ not accounted for. Stimuli not randomized.

Table 3. Continued

Citation	Sample		Comparison				Matching procedure	Task Format	Stimuli	Emotions	Key Findings	
	Clinical											
	Diagnosis	N	Mean age (SD)	Diagnosis	N	Mean age (SD)						
Kliemann et al., 2012	Autism AS	16	30.44 (6.34)	TD	17	30.47 (6.23)	CA, MWT Non-verbal strategic thinking (Leistungssystem)	Labelling	<b>Static</b> , photographs, 150ms exposure time.	Happy, Fear, Neutral	Trend for ASD to make more eye movements away from eyes than towards eyes and opposite for TD. Emotion effect on eye preference in TD but not ASD. Across emotions TD higher preference index for eyes, while ASD lower preference index for eyes – most pronounced in neutral faces. Eye movements away from eyes correlated with reduced recognition performance in ASD.	<b>96% (23/24)</b> . Partial discussion of limitations.
Kirchner et al., 2011	autism	20	31.9 (7.6)	TD	21	31.8 (7.4)	CA, Wortschatztest	Labelling	<b>Static</b> , photographs, naturalistic. 4.5s Exposure time.	Complex Negative emotion from MET (e.g., Sad, Anger)	ASD fixation time on eyes and mouth = TD. ASD fixation time on face < TD. Fixation time on eye predictor of performance in ASD group and fixation time on mouth negative predictor of performance in ASD.	<b>92% (22/24)</b> . Stimuli counterbalanced.

Table 3. Continued

Citation	Sample			Comparison			Matching procedure	Task Format	Stimuli	Emotions	Key Findings	
	Diagnosis	N	Mean age (SD)	Diagnosis	N	Mean age (SD)						
Kliemann et al., 2010	ASD	17 (12 ET)	32.7 (8.2)	TD	19 (11 ET)	30.4 (5.9)	Gender, MWT	Labelling	Static, photographs, 150ms exposure time.	Happy, Fear, Neutral	ASD preference for eyes < TD. ASD tendency to gaze away from eyes downward to mouth when initially fixating on eyes > TD. TD tendency to gaze upward to eyes than downward to mouth for neutral and fear. ASD trend to gaze downward to mouth than upward to eyes for all emotions. Trend ASD to make faster movements away from eyes/slower movements to eyes compared to TD – most prominent for fear. ASD gaze away from eyes faster than away from mouth, opposite for TD. ASD eye preference index positively correlated with performance, not seen in TD. Eye preference index negatively correlated with ADI-R social score. No correlation of ADI-R communication score, AQ or verbal IQ and gaze patterns.	96% (23/24). ET sample size small.

Table 3. Continued

Citation	Sample		Comparison				Matching procedure	Task Format	Stimuli	Emotions	Key Findings	
	Clinical											
	Diagnosis	N	Mean age (SD)	Diagnosis	N	Mean age (SD)						
Corden et al., 2008	AS	18	32.9 (13.35)	TD	17	31.9 (11.30)	CA, Gender, WASI, DTVP	Implicit and Labelling	Static, photographs. 2.5s stimuli exposure time.	Happy, Sad, Fear, Surprise, Anger, Disgust	ASD fixations on eyes < TD. Trend for ASD fixations on mouth > TD. ASD fixations on face = TD. Fixation time not associated with ASD symptom severity. Trend for association between mouth fixations and symptom severity in ASD. Reduced recognition of fear in ASD associated with fewer fixations on eyes. High social anxiety in ASD associated with reduced fixations on eyes.	<b>100% (24/24).</b>
Boraston et al., 2008	Autism, ASD,AS	11	34.6 (9.01)	TD	11	39.6 (11.1)	CA, WASI	Labelling	Static, photographs, 2.5s exposure time.	Neutral, Genuine Smile, Posed Smile	ASD spent less gaze time on eye region compared to TD and a trend for more gaze time towards the mouth. ASD made fewer fixations to the eye region compared to TD and a trend for more fixations to the mouth. No correlations found between gaze time or % fixations and performance.	<b>92% (22/24).</b> Sample size small. Partial discussion of limitations.

Table 3. Continued

Citation	Sample						Matching procedure	Task Format	Stimuli	Emotions	Key Findings	
	Clinical			Comparison								
	Diagnosis	N	Mean age (SD)	Diagnosis	N	Mean age (SD)						
<i>EEG</i>												
Yang et al., 2011	AS	5	19.2	TD	7	N/A	N/A	Labelling (sliding scale angry to happy)	<b>Static</b> , photograph, 4s exposure time.	Anger, Happy, Neutral	Theta synchronization weaker in ASD. Beta2 desynchronization strong in ASD	<b>71% (17/24)</b> . Sample size small. Limited discussion of participant source or participant characteristics and matching procedures. Control population not described. Limited estimate of variance.
Tseng et al., 2015	AS	10	19.6 (1.96)	TD	10	24.4 (3.24)	Gender, WAIS III	Labelling (sliding scale angry to happy)	<b>Static</b> , Photograph and line drawing of face. Exposure time 1s		ASD N170 amplitude and latency = TD. In line drawing task ASD N400 amplitude = TD. In photograph task N400 visible in TD not ASD. ASD weaker delta/theta synchronization than TD in early and late stages of emotion recognition. ASD fewer distant inter-hemispheric connections than TD in photograph task but similar to TD in line drawing task.	<b>95% (23/24)</b> . Sample size small.

Table 3. Continued

Citation	Sample		Comparison				Matching procedure	Task Format	Stimuli	Emotions	Key Findings		
	Clinical		Diagnosis	N	Mean age (SD)	Diagnosis						N	Mean age (SD)
Gayle et al., 2012	AQ traits	37			19.8 (1.67)				Implicit	<b>Static</b> , photographs exposure time 150ms.	Neutral, Sad, Happy	vMMN amplitudes to happy positively correlated with AQ score (smaller/more positive amplitude associated with higher AQ score).	<b>88% (21/24)</b> Limited discussion of participant characteristics. Method of participant comparison unclear. Stimuli pseudo-randomized.
Lassalle et al., 2015	High AQ	25		Low AQ	25	21.28 (2.54)	N/A	Implicit	<b>Static</b> , Direct and averted gaze and upright and inverted. Neutral face with direct gaze exposure time 500ms, neutral face with averted gaze exposure time 200ms, emotion face with averted gaze exposure time 300ms.	Fear, Happy	Effect of congruency on P100 significant in low but not high AQ group. EDAN in high AQ = EDAN in low AQ. Laterality effect of ADAN present in low AQ group only.	<b>92% (22/24)</b> , Participant matching procedure unclear, however, anxiety measured for all participants. Limited discussion of limitations.	

Table 3. Continued

Citation	Sample		Comparison				Matching procedure	Task Format	Stimuli	Emotions	Key Findings	
	Diagnosis	N	Mean age (SD)	Diagnosis	N	Mean age (SD)						
Magnee et al., 2008	Autism, AS	12	21.5 (4.0)	TD	13	23.0 (2.9)	CA, WAIS III	Implicit	<b>Static</b> , photographs with congruent and incongruent auditory pairs. Face stimuli presented for 900ms before auditory stimuli. Face stimuli remained until end of auditory presentation.	Fear, Happy	ASD N170 and P100 = TD. ASD N200 amplitude to fear voice < happy voice when presented with fear face. TD N200 amplitude to fear voice > happy voice when presented with fear faces.	<b>83% (20/24)</b> . Sample size small. Analytic method partially described. Limited discussion of source of participant and discussion of limitations.
Magnee et al., 2011	HFA	23	22.7 (3.8)	TD	24	22.7 (1.9)	CA, WAIS III (Dutch)	Implicit	<b>Static</b> , Congruent and Incongruent Visual and Auditory Pairs. Face stimuli exposure time 400ms, auditory stimuli presented for 500ms.	Fear, Happy	No differences in N170 to visual stimuli. TD had significant congruency effects for N170 amplitude for divided attention condition (both auditory and visual input) in left hemisphere but not ASD group.	<b>88% (21/24)</b> . Limited discussion of participant source. Analytic method partially described. Limitations partially described.

Table 3. Continued

Citation	Sample						Matching procedure	Task Format	Stimuli	Emotions	Key Findings	
	Clinical			Comparison								
	Diagnosis	N	Mean age (SD)	Diagnosis	N	Mean age (SD)						
O'Connor et al., 2007	AS	15	23.5(5.2)	TD	15	23.8 (4.4)	CA	Labelling	<b>Static</b> , photographs, familiar and unfamiliar faces, stimuli exposure time 600ms.	Neutral, Sad	ASD N170 latency to eyes and mouth > than TD. ASD latency to faces > TD. ASD N170 latency to faces = objects. TD N170 latency to faces shorter than to objects. ASD P100 = TD.	<b>92% (22/24)</b> . Sample size small. Participants matched on CA.
O'Connor et al., 2005	AS	15	24.6 (8.8)	TD	15	23.8 (8.7)	CA, Gender	Labelling	<b>Static</b> , photographs, Stimuli 1s exposure time.	Happy, Sad, Anger, Fear	ASD P100 amplitude = TD. ASD P100 and N170 latencies > than TD. ASD N170 amplitude < than TD.	<b>92% (22/24)</b> . Sample size small. Participants matched on CA.
Cooper et al., 2013	High AQ	10	25.4 (for both groups)	Low AQ	10	25.4 (for both groups)	N/A	Implicit	<b>Dynamic</b> , video of faces with hand movement. Stimuli exposure time 3s.	Happy, Anger, Neutral	High AQ greater low beta event related desynchronization to angry compared to happy. No group differences in alpha. Low AQ greater low beta event related desynchronization to happy compared to angry and neutral; low AQ had greater low beta event related desynchronization to happy compared to high AQ.	<b>83% (20/24)</b> . Sample size small. Limited discussion of participant source or participant characteristics. Group matching procedure unclear.

Table 3. Continued

Citation	Sample		Comparison				Matching procedure	Task Format	Stimuli	Emotions	Key Findings	
	Diagnosis	N	Mean age (SD)	Diagnosis	N	Mean age (SD)	CA					
Fujita et al., 2013	Autism, AS, PDD-NOS	9	31.5	TD	10	26.8	CA	Implicit	Static, upright and inverted. 20 ms exposure time.	Fear, Neutral	ASD N100 amplitude for upright and inverted faces = upright and inverted objects. TD N100 amplitude to fear in upright > objects in upright. TD N100 to inverted faces = inverted objects. No subliminal face effect in ASD (object – fear or neutral). TD subliminal face effect with N100 amplitude for upright fear > inverted fear. ASD N100 amplitude subliminal face effect < TD for upright condition.	88% (21/24). Sample size small. Participants matched on CA.

Abbreviations: LFAS Low functioning Autism; TD; Typically developing, CA; Chronological age, RCPM; Ravens Coloured Progressive Matrices, AS; Asperger Syndrome, WASI; Wechsler Abbreviated Scales of Intelligence, HFA; High Functioning Autism, WAIS; Wechsler Adult Intelligence Scales, MWT; Mehrfachwahl-Wortschatztest (Multiple Choice Vocabulary Test), DTVP; Developmental Test of Visual Perception, AQ; Autism Quotient. N/A denotes areas where sufficient information was not provided by study.

## **RESULTS**

### **Search Results**

The search resulted in a total of 744 articles with the following distribution: Cinahl (40), Embase (189), Medline (171), ProQuest (15), Psycinfo (118), and Scopus (211). Duplicate removal resulted in a total of 484 eligible articles. The titles and abstracts of these articles were reviewed by the first author (MB), resulting in 70 articles being forwarded to full text review. The secondary review excluded an additional 15 articles and included an additional four (two EEG and two ET) from the reference lists of the included articles, one article was also included following inter-rater review (described in section 3.2). In total, 54 articles were included in this review (31 ET, 22 EEG, 1 ET and EEG).

### **Inter-Rater Reliability**

A random selection of fifty articles identified from the electronic database search were reviewed by two researchers with a background in ASD and FER according to the inclusion and exclusion criteria in order to assess the inter-rater reliability of article assessment. The two reviewers reached consensus on 48 of the 50 articles (96%) and following discussion the reviewers reached agreement on all 50 articles (100%) with one additional article being included in the review (Figure 2).

### **Study Type**

Fifty-two studies were case-control in nature whereby a sample of individuals with ASD was compared to a comparison group. Two studies did not have a comparison sample (Gayle, Gal, & Kieffaber, 2012; Lerner, McPartland, & Morris, 2013).

## **Methodological Quality**

The majority of included studies (k=46) were of strong methodological quality (score of 80% or greater) and six were of good methodological quality (70–80%) as assessed by the Kmet form for quantitative analysis. Tables 1, 2 and 3 outline the assessed methodical quality of the studies. Limitations primarily existed in the description of participant characteristics, process of matching or sample size (Tables 1, 2 and 3).

## **Participant Characteristics**

As shown in Tables 1, 2 and 3, Autism, HFA, AS and ASD were the most common clinical samples in this review. Some studies reported including participants with a PDD-NOS diagnosis (Akechi et al., 2010; Bal et al., 2010; Crawford, Moss, Anderson, Oliver, & McCleery, 2015; Dawson, Webb, Carver, Panagiotides, & McPartland, 2004; de Wit, Falck-Ytter, & von Hofsten, 2008; Falck-Ytter, Fernell, Gillberg, & von Hofsten, 2010; Fujita et al., 2013; McCabe et al., 2013; Tottenham et al., 2014; Van der Geest, Kemner, Verbaten, & Van Engeland, 2002). Primarily, ASD participants were high functioning (at least average IQ) however, one study reported including a sample of individuals with LFA (Han, Tijus, Le Barillier, & Nadel, 2015).

In the majority of studies, comparison groups consisted of TD individuals. A subset of studies compared the ASD sample to groups of participants with other disabilities or conditions such as ADHD (Gross et al., 2012; Tye et al., 2014), developmental delay (Vlamings, Jonkman, van Daalen, van der Gaag, & Kemner, 2010), Fragile X syndrome (FXS) (Crawford et al., 2015; Dalton, Holsen, Abbeduto, & Davidson, 2008), 22q11 Deletion Syndrome (22q11DS) (McCabe et al., 2013) and Schizophrenia (Sasson et al., 2007) while two studies included in this review did not include a comparison sample

(Gayle et al., 2012; Lerner et al., 2013). Participant groups were primarily matched on chronological age and verbal or non-verbal intelligence (Tables 1, 2 and 3).

### **Task format**

Procedures requiring participants to overtly determine the presented emotion via labelling or matching tasks were employed in 31 studies. Implicit tasks, that is, those that did not require the explicit recognition of emotion or required only the passive viewing of stimuli, were used in 31 EEG and ET studies, with a number of studies employing both.

Stimuli consisted primarily of static photographs. Eight studies presented dynamic stimuli of facially expressed emotions (Bal et al., 2010; Bekele et al., 2014; Bekele et al., 2013; Cooper, Simpson, Till, Simmons, & Puzzo, 2013; de Jong, van Engeland, & Kemner, 2008; Falck-Ytter et al., 2010; Han et al., 2015; Nuske, Vivanti, & Dissanayake, 2014). While whole face stimuli were presented in the majority of studies, some studies utilised experimentally manipulated stimuli including; revealing only certain features of the face via bubbles (Spezio, Adolphs, Hurley, & Piven, 2007a, 2007b) or puzzle pieces (Falkmer, Bjallmark, Larsson, & Falkmer, 2011; Leung, Ordqvist, Falkmer, Parsons, & Falkmer, 2013), presenting upright and inverted stimulus orientation (Falck-Ytter et al., 2010; Fujita et al., 2013; Lassalle & Itier, 2015; Neumann, Spezio, Piven, & Adolphs, 2006), manipulating spatial frequencies (de Jong et al., 2008; Vlamings et al., 2010) or line drawings (Tseng, Yang, Savostyanov, Chien, & Liou, 2015), direct and averted gaze (Akechi et al., 2010; Hernandez et al., 2009; Lassalle & Itier, 2015; Van der Geest et al., 2002), familiar and unfamiliar faces (Nuske, Vivanti, & Dissanayake, 2014), and digitally erased faces (Sasson et al., 2007).

The six basic emotions (happiness, anger, sadness, disgust, fear, surprise) or a subset of these six were presented in the vast majority of studies. For the purposes of this review ‘neutral’ was also considered a basic expression due to its potential in controlling for effect of emotional content on the outcomes. Complex emotions such as calm (de Wit et al., 2008), contempt (Bekele et al., 2014; Bekele et al., 2013), flirting, admiring, quizzical (Rutherford & Towns, 2008; Sawyer, Williamson, & Young, 2012) and others were presented in a limited number of studies (Bekele et al., 2014; Bekele et al., 2013; Kirchner, Hatri, Heekeren, & Dziobek, 2011; Rutherford & Towns, 2008; Sawyer et al., 2012). Two studies used stimuli that consisted of posed and Duchenne smiles to determine differences in the eye gaze patterns when differentiating genuine and posed smiles in ASD (Boraston, Corden, Miles, Skuse, & Blakemore, 2008; Key et al., 2015).

## **Eye Tracking**

### **Children**

#### ***Static Basic Emotions (k=6)***

Findings of studies comparing children with ASD to TD samples were mixed in regard to eye gaze patterns to the core facial features. Van der Geest et al. (2002) not only reported a similar number of fixations to the eyes and mouth, but also found that children with ASD made the majority of their first fixations to the eyes, similar to TD populations, when completing a free viewing task of angry, happy, neutral and surprised expressions. de Wit et al. (2008) also failed to find reduced gaze to eyes in children with ASD during the viewing of happy, anger and fearful expressions. Similar findings were reported by Falck-Ytter et al. (2010) when examining the ratio of looking time to happy, angry, disgusted, fearful, neutral and unlabelled grimace emotions, with children with ASD having similar looking times to both the eyes and mouth. Leung et al. (2013) reported comparable results

in response to angry, happy, and surprised emotions. They presented children with ASD with whole face stimuli and puzzle pieces with eyes either bisected or whole. They postulated that the eyes bisected condition would not affect the recognition accuracy of children with ASD due to their purported lower reliance on the eyes in face and emotion processing. However, not only did the children with ASD make a similar number of fixations to the eyes as their TD counterparts, their accuracy in recognition was also impaired in the eyes bisected condition to a similar extent as in the control sample (Leung et al., 2013).

Nuske, Vivanti, Hudry, and Dissanayake (2014) hypothesised that children with ASD would display differences in gaze behaviour in response to emotional faces, presented for either 30msec, 300msec, or 2sec. Consistent with this, children with ASD had shorter fixation durations to the eyes of fearful expressions and neutral faces across all stimuli exposure conditions (30 msec, 300 msec, 2 sec) driven by differences in the longest exposure time (2 sec). Children with ASD also made shorter fixations not only to neutral faces when presented for the longest exposure period (2 sec), but also to fearful expressions when presented for 30 msec and 2 sec (Nuske, Vivanti, Hudry, et al., 2014). Furthermore, children with ASD made shorter fixations to the mouths of neutral, but not fearful faces across display conditions (driven by differences in the 2 sec conditions). Van der Geest et al. (2002), reported no differences between children with ASD and TD children in either the number of fixations or the time spent on the face or non-core face areas. Nevertheless, de Wit et al. (2008) found that children with ASD had a shorter overall looking time compared to TD children. Similar to the findings in regard to the core features of the face, Leung et al. (2013) reported no differences in the number of fixations but reported longer fixation durations for children with ASD regardless of stimuli type, emotion or area of interest.

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When examining correlations between social and communication abilities as measured by the Autism Diagnostic Interview-Revised (ADI-R), de Wit et al. (2008) found a negative correlation between these scores and looking time to the screen and percentage of looking time to the mouth. Similarly, when examining children with and without ASD, Falck-Ytter et al. (2010) found a positive correlation between social impairment and looking time to the mouth and a negative correlation between social impairment and looking time to the eyes, while the inverse was true for communication impairment.

When compared to children with FXS, children with ASD looked significantly more to the eyes of neutral expressions. However, dwell time on faces with happy, disgusted, and neutral expressions was similar in both groups, suggesting that attention to emotional faces is allocated similarly in these groups (Crawford et al., 2015).

### ***Static Complex Emotions (k=1)***

The complex emotion of calm was included in one free viewing task (de Wit et al., 2008). While this study did not conduct separate eye gaze analysis comparing basic and complex emotions, it was found that children with ASD had a shorter overall looking time to emotional faces compared to TD children, however no differences were reported in regard to fixation time on the eyes.

### ***Dynamic Basic Emotions (k=3)***

Reduced fixations to the eyes were reported for children with ASD in one study (Nuske, Vivanti, & Dissanayake, 2014) that explored the effect of face familiarity on emotion perception. While children with ASD had divergent gaze to the eyes, these differences were present only in response to neutral, but not to fearful faces, with children with ASD making fewer fixations to the eyes regardless of familiarity of the face. In contrast to these

findings, Falck-Ytter et al. (2010) reported no differences in the number of fixations children with ASD made to the eye regions of angry, happy, disgusted, fearful, neutral, and grimace facial expressions.

In regard to the other core facial features, ASD-linked differences have been found, most notably in relation to gaze time towards the mouth. In Nuske, Vivanti, and Dissanayake (2014), TD children fixated more to the mouths of neutral expressions than children with ASD when viewing familiar and unfamiliar faces displaying expressions. However, Falck-Ytter et al. (2010) reported no group differences in time spent fixating on the mouth.

Children with ASD have also been found to spend less time looking at faces overall in comparison to their TD counterparts in two studies when viewing dynamic stimuli (Bal et al., 2010; Nuske, Vivanti, & Dissanayake, 2014). Children with ASD had smaller fixation duration percentages to regions other than the face when presented with fearful faces, but not other emotions (Bal et al., 2010). Nuske, Vivanti, and Dissanayake (2014) found a reduction in the number of fixations to neutral faces but not fearful faces in children with ASD. Correlations between the ADI-R and gaze behaviour to faces were reported in one study (Falck-Ytter et al., 2010). Similar to the findings with static faces, children with ASD showing high social impairment scores spent more time fixating on the mouth and less on the eyes when viewing dynamic stimuli compared to those with low social impairments. Higher communication impairment scores were associated with less looking time to the mouth, however, there were no correlations between gaze to the eyes and communication impairment. When using the Social Communication Questionnaire (SCQ), a measure of autism symptoms derived from the ADI-R, these findings relating to social impairment and the mouth were replicated. When examining dynamic stimuli presenting an action, those children with ASD who had increased looking time to the face

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as opposed to the action, had lower social impairment scores but higher communication impairment scores.

## **Adolescents**

### ***Static Basic Emotions (k=6)***

Adolescents with ASD were found to spend less time looking at faces expressing emotion compared to the TD counterparts (McCabe et al., 2013; White, Maddox, & Panneton, 2015). McCabe et al. (2013) reported a lower number of fixations in adolescents with ASD across the six basic emotions compared to TD adolescents. However, when controlling for IQ, this difference was no longer significant. White et al. (2015) found no differences between their sample of adolescents with ASD and matched controls to disgust and angry expressions, however, when accounting for self-reported ratings on the fear of negative evaluation, the adolescents with ASD had shorter fixation durations on the face. When fixation durations were assessed in 500msec bins, adolescents with ASD reduced their fixation durations to disgust expressions more so than TD adolescents and had reduced fixation durations to angry expressions compared to TD adolescents during the first 500msec, suggesting differences in disengagement from disgust and angry expressions in ASD populations. In contrast however, Wagner, Hirsch, Vogel-Farley, Redcay, and Nelson (2013) reported no differences in the time adolescents with ASD spent viewing emotionally expressive faces.

In addition to a decrease in time spent fixating on the face, adolescents with ASD were also reported to spend less time fixating on the eyes of emotionally expressive faces (Dalton et al., 2005; Tottenham et al., 2014; White et al., 2015) with two studies reporting similar ET patterns to the eye region in adolescents with and without ASD (McCabe et al., 2013; Wagner et al., 2013). Tottenham et al. (2014) reported that adolescents with

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ASD made fewer eye movements towards the eyes of neutral but not angry expressions. Dalton et al. (2005) reported fewer fixations to the eyes for happy, fear, angry and neutral expressions. White et al. (2015) reported no differences in fixations to the eyes, however, when accounting for self-report scores of fear of negative evaluation, adolescents with ASD presented with shorter fixation durations to the eye region. In a similar vein, Tottenham et al. (2014) examined the correlations between how threatening adolescents perceived an emotion to be and their gaze patterns. Adolescents with ASD who perceived neutral faces as more threatening had a higher tendency to look away from the eyes, however, this was not seen in response to angry faces or in the TD adolescents.

None of the static simple emotion recognition studies in adolescents reported differences in the eye gaze patterns to the mouth between adolescents with and without ASD, a finding apparent across task formats, participant matching procedures and emotions (Dalton et al., 2008; Dalton et al., 2005; McCabe et al., 2013; Wagner et al., 2013).

### ***Static Complex Emotions (k=1)***

Hanley, McPhillips, Mulhern, and Riby (2012) sought to understand how adolescents process static stimuli with varying levels of social content, presenting adolescents with and without ASD with static images of posed, acted and naturalistic expressions as well as images taken from acted and naturalist social scenes. Hanley et al. (2012) found no differences for posed or acted isolated expressions, however, adolescents with ASD spent significantly more gaze time viewing the hair of naturalistic isolated faces. When viewing items taken from social scenes, adolescents with ASD spent less time fixating on the eyes and more time on the body in acted social scenes and less time on the eyes and face in naturalistic social scenes (Hanley et al., 2012).

***Dynamic Complex Emotions (k=2)***

Dynamic complex emotions were used by two studies presented by the same authors (Bekele et al., 2014; Bekele et al., 2013). These studies attempted to evaluate the effect of immersive stimuli on emotion recognition in ASD using animated avatar faces expressing facial emotions. Both studies, examined emotion recognition as well as eye gaze patterns while the avatar was telling a story or talking with a neutral expression. Adolescents with ASD had a greater proportion of gaze time to the forehead and less to the mouth than TD adolescents in both studies (Bekele et al., 2014; Bekele et al., 2013). While there was agreement between the two studies in gaze time to the mouth and forehead, differences arose in other features. In Bekele et al. (2013) adolescents with ASD had a smaller gaze time on the face and a greater gaze time on non-face areas when both groups correctly identified the emotion along with shorter gaze time towards the mouth and longer gaze time towards the forehead. When adolescents with ASD were incorrect, only the difference in gaze time towards the forehead and mouth was significant (Bekele et al., 2013).

**Adults*****Static Basic Emotions (k=11)***

In regard to ET patterns to the core facial features, the most apparent difference between adults with ASD and TD controls related to fixations to the eyes. The majority of studies found that adults with ASD allocated a smaller proportion of time to the eyes, fixated less to the eyes or gazed away from the eyes of emotionally expressive faces more often compared to their TD counterparts (Boraston et al., 2008; Corden, Chilvers, & Skuse, 2008; Falkmer et al., 2011; Hernandez et al., 2009; Kliemann, Dziobek, Hatri, Baudewig, & Heekeren, 2012; Kliemann, Dziobek, Hatri, Steimke, & Heekeren, 2010; Pelphrey et

al., 2002). This difference was apparent regardless of emotion (Boraston et al., 2008; Corden et al., 2008; Hernandez et al., 2009; Pelphrey et al., 2002) or whether the task was free viewing (Corden et al., 2008; Hernandez et al., 2009; Pelphrey et al., 2002) or required active recognition (Boraston et al., 2008; Corden et al., 2008; Falkmer et al., 2011; Kliemann et al., 2012; Kliemann et al., 2010; Pelphrey et al., 2002).

When considering the relationship between gaze to facial features and FER, Boraston et al. (2008) aimed to examine whether adults with ASD were able to differentiate natural from posed smiles, finding that adults with ASD had both a reduced gaze time and made fewer fixations to the eyes of the expressive faces. Corden et al. (2008) found that in both free viewing and active recognition of the six basic emotions, adults with ASD had a smaller proportion of fixations to the eyes, despite both ASD and TD scanning different emotions in a similar manner.

Adults with ASD demonstrated no differentiation in eye gaze in relation to emotional expression, unlike TD adults who altered their eye gaze in response to the emotion presented (Kliemann et al., 2012; Kliemann et al., 2010). Adults with ASD looked downward to the mouth from the eyes more often than TD adults (Kliemann et al., 2010), showing a decreased preference for the eyes of fearful and neutral expressions. This was consistent with Spezio et al. (2007b) who found that adults with ASD made more saccades away from the eye region than TD controls.

Three studies found that individuals with ASD who made more fixations to the eyes had higher proficiency at emotion recognition than those who did not or looked more at other areas of the face (Falkmer et al., 2011; Kliemann et al., 2012; Kliemann et al., 2010). Hernandez et al. (2009) found that when beginning the exploration of emotional faces, TD adults began their search in the eyes more often than adults with ASD. Corden et al.

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(2008) found that those with ASD who looked less at the eyes had poorer recognition of fear and those who had higher scores of social anxiety fixated less on the eyes.

In regard to looking time to other core facial features findings are more mixed. Studies reporting on fixations to the nose, found that participants with ASD spent less time on the nose than TD adults (Hernandez et al., 2009; Pelphrey et al., 2002).

Falkmer et al. (2011) found that adults with ASD made a similar number of fixations and had similar duration of fixations on the mouth as TD adults when viewing whole faces. Similarly, despite adults with ASD having a smaller percentage of fixation time to the core features, Pelphrey et al. (2002) found no differences between groups in the proportion of time spent on the mouth. Hernandez et al. (2009) found similar results in their free-viewing task of happy, sad, neutral, neutral faces with averted gaze and avatars with no differences in looking time between groups. However, Hernandez et al. (2009) reported that adults with ASD were more likely to begin their exploration of emotional faces on the mouth compared to TD adults.

While some studies reported that adults with ASD fixated less to whole faces than their TD counterparts (Hernandez et al., 2009), others reported no differences between groups (Corden et al., 2008; Neumann et al., 2006; Pelphrey et al., 2002). Hernandez et al. (2009) found that adults with ASD spent more time on regions peripheral to the face than TD adults and while TD spent more time on the core facial features than peripheral regions.

A number of studies used other experimental paradigms involving the manipulation of facial stimuli in order to investigate the differential effect of top down and bottom up visual processing strategies (Falkmer et al., 2011; Neumann et al., 2006; Sasson et al., 2007; Spezio et al., 2007a, 2007b). Manipulations included examining the effect of

Gaussian bubbles (Neumann et al., 2006; Spezio et al., 2007a, 2007b) or puzzle pieces (Falkmer et al., 2011), inverted faces (Neumann et al., 2006) and digitally erased faces (Sasson et al., 2007). When viewing inverted stimuli, Neumann et al. (2006) found that adults with ASD had longer fixation times to the mouth compared to the TD group. When examining bubbled or puzzled stimuli, adults with ASD looked more at the mouth and less at the eyes than TD adults in four studies (Falkmer et al., 2011; Neumann et al., 2006; Spezio et al., 2007a, 2007b). Spezio et al. (2007b) found that when information was available in the eyes that could assist in the recognition of emotion, adults with ASD looked more towards the mouth than TD adults. Sasson et al. (2007) presented adults with and without ASD and schizophrenia with static images of social scenes with the faces present or digitally erased, hypothesising that the performance of the clinical populations would be more impacted by the face-present condition. The adults with ASD had a shorter fixation duration to faces in the face present condition in comparison to TD adults with TD adults orientating to the face faster when the face was present versus absent while ASD did not differentiate in orientation speed (Sasson et al., 2007). In contrast to the findings of increased eye fixations and performance (Falkmer et al., 2011; Kliemann et al., 2012; Kliemann et al., 2010), Sasson et al. (2007) found the opposite effect, with adults with ASD having a negative correlation between recognition accuracy and fixation duration to the face.

#### Static Complex Emotions (k=3)

When viewing static complex emotions, a single study reported that adults with ASD looked less at the face and made fewer fixations to faces expressing complex emotions (Kirchner et al., 2011). However, a decrease in looking time to the eyes (Kirchner et al., 2011; Rutherford & Towns, 2008) or divergent eye gaze patterns to other core features of

the face, including the mouth (Kirchner et al., 2011; Sawyer et al., 2012) was not found. Rutherford and Towns (2008) reported that even though no group differences emerged in regard to fixations to the eyes or mouth. Similar to the findings with static basic emotions (Falkmer et al., 2011; Kliemann et al., 2012; 2010), Kirchner et al. (2011) found a positive association with looking time to the eyes and a negative association with looking time to the mouth for recognition performance of complex negative stimuli in their ASD populations.

Two studies compared the time spent viewing the features of complex emotions in comparison with basic emotions. One study reported no differences in time spent examining the eyes and mouth of complex compared to basic emotions in their ASD and TD groups (Sawyer et al., 2012), while Rutherford and Towns (2008) found that adults with ASD spent more time on the eyes and mouth of faces expressing basic emotions compared to complex emotions, while the opposite was true for TD adults.

### ***Dynamic Basic Emotions (k=1)***

Dynamic representations of simple emotions were presented to adults in one study. Han et al. (2015) examined a sample of adults with ASD who presented with a comorbid intellectual disability. This study used morphing facial expressions as well as mechanical displays representing emotional expressions with the aim of determining whether motion processing was more enhanced in ASD as opposed to the processing of emotion. Adults with ASD had a lower percentage of fixation time; however fixations to the eyes and mouth of emotional stimuli were similar to that of their TD control groups. To the mechanical display, adults with ASD made fewer fixations to the core features of the face, differentiating their gaze to the robotic setup from that to the emotional display, a

difference not seen in the TD control groups. This suggests that adults with ASD may process motion rather than emotion when viewing dynamic facial expressions.

## **EEG Evoked Potentials**

EEG evoked potentials were examined by 18 of the studies included. Of these studies, the most reported components were N170 and P100.

### **Children**

#### ***N170 (k=6)***

Children with ASD were found to be atypical in both the latency and amplitude of the N170 component in three studies (Batty, Meaux, Wittemeyer, Roge, & Taylor, 2011; de Jong et al., 2008; Tye et al., 2014). Delayed N170 latencies in children with ASD were found in one study (Batty et al., 2011) with another study finding differences in the latencies between children with ASD and ASD with comorbid ADHD (Tye et al., 2014). Batty et al. (2011) found that across basic emotions, children with ASD had slower N170 latencies compared to children matched for chronological age. In regard to the amplitude of the N170, de Jong et al. (2008) reported reduced amplitude of the N170 in children with ASD compared to TD children in response to fearful expressions. Furthermore, fearful expressions elicited larger N170 responses in TD children when compared to neutral with no modulation effect seen in children with ASD.

ADHD comorbidity has also been associated with divergent N170 latencies and amplitudes in ASD populations. Tye et al. (2014) found that children with ASD had slower N170 latencies to neutral faces compared to angry faces and longer latencies to fearful expressions in comparison to happy faces while children with co-occurring ASD and ADHD had the opposite response to these emotions. In addition, children with ASD and

ASD/ADHD comorbidity had decreased N170 amplitude across happy, angry, fearful and disgusted expressions in comparison to TD controls. In contrast to the findings of de Jong et al. (2008), the amplitude of the N170 was modulated by emotion in the ASD group with fear eliciting larger amplitudes compared to neutral. This same modulation effect was not seen in TD children or children with ADHD.

### ***P100 (k=4)***

Two child studies reported that children with ASD and TD matched controls had similar P100 ERPs in response to emotional faces (O'Connor, Hamm, & Kirk, 2005; Wong, Fung, Chua, & McAlonan, 2008). In contrast, two free-viewing studies reported differences in both latency and amplitude of the P100 ERP (Batty et al., 2011; Vlamings et al., 2010). Batty et al. (2011) compared children with ASD to two groups of TD children, one matched for chronological age and one matched on verbal equivalent age, and compared to both children with ASD had smaller P100 amplitudes in response to the six basic emotions, but slower latencies only in comparison to chronologically age matched controls.

The effect of spatial processing bias in ASD was examined in one study using neutral and fearful faces presented in high and low spatial frequencies. Vlamings et al. (2010) postulated that high spatial frequencies represented more detail supporting local orientated processing and low spatial frequency related to global pattern processing. Fear faces presented in high spatial frequency elicited larger P100 amplitudes compared to neutral faces in children with ASD aged 3-4 years. Conversely, IQ matched TD control children were found to show larger P100 amplitudes to neutral faces compared to fear faces presented in low spatial frequency (Vlamings et al., 2010).

### ***Other ERPs***

The P200 ERP was examined in three child studies (Dawson et al., 2004; O'Connor et al., 2005; Wong et al., 2008). Of these, one reported differences, with children with ASD having smaller and slower P200 responses to neutral faces during an implicit recognition task compared to chronologically age matched children. When matched on verbal equivalent age, however, children with ASD had larger P200 amplitudes than TD children in the midline and central regions only (Dawson et al., 2004).

Within the child ERP studies, other not as commonly explored components included the N300 (Dawson et al., 2004), P300 and P500 (Dawson et al., 2004), N400 (Key et al., 2015), P400 (Key et al., 2015), Negative Slow Wave (NSW) (Dawson et al., 2004), N290 (Key et al., 2015) and Nc (Dawson et al., 2004; Key et al., 2015).

Children with ASD were found to have no differentiation in the amplitude of the N300 and NSW while TD children showed larger amplitudes to fear compared to neutral faces (Dawson et al., 2004). Differences in P300 emerged with ASD children having larger amplitudes to neutral compared to fear expressions while verbally equivalent aged children showed the opposite (Dawson et al., 2004). Infants at a high risk of developing ASD showed altered differentiation of P400 and Nc ERPs in response to neutral, small and large smiles compared to low risk infants (Key et al., 2015).

### **Adolescents**

#### ***N170 (k=3)***

The amplitude and latency of the N170 component may not be modulated by emotion in adolescents with ASD. Adolescents with ASD were found to show no modulation of the N170 amplitude in response to fear and angry faces while TD adolescents showed

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different N170 amplitudes as a function of emotion (Wagner et al., 2013). A similar effect was seen when Akechi et al. (2010) examined the effect of eye gaze on emotion processing. It was proposed that the processing of gaze and emotion are not independent and gaze direction may facilitate the processing of emotion whereby approach orientated emotions such as happiness are processed faster with direct gaze while avoidant orientated emotions are processed faster with indirect gaze. It was found that TD adolescents displayed larger N170 amplitudes to stimuli showing congruent emotions and gaze direction (fear faces with indirect gaze, angry with direct gaze) compared to incongruent emotions and gaze direction while the adolescents with ASD did not show this difference, indicating that adolescents with ASD may experience difficulty integrating gaze and expression cues.

A single group experimental study examined the correlation between N170 and the accuracy of adolescents with ASD at recognising emotions. This study found that adolescents diagnosed with ASD who had longer latencies and smaller amplitudes of the N170 were less likely to correctly identify emotion accurately and had longer response times (Lerner et al., 2013).

### ***P100 (k=2)***

Two studies examined the P100 component in adolescents with ASD (Akechi et al., 2010; Wagner et al., 2013). One of these studies reported negligible differences in both the latency and the amplitude of the P100 in adolescents with and without ASD in response to the six basic emotions (Wagner et al., 2013). The sole difference between ASD and TD adolescents was found in response to angry and fear expressions. The P100 latency differed between O1 and O2 electrodes in TD participants but not ASD participants (Akechi et al., 2010).

## **Adults**

### ***N170 (k=5)***

Three studies reported differences between adults with ASD and controls while two studies did not find between group differences (Magnée, de Gelder, van Engeland, & Kemner, 2008; Tseng et al., 2015). O'Connor et al. (2005) found that adults with ASD had smaller and delayed N170 ERPs to happy, sad, angry and scared expressions compared to controls. In a later study, O'Connor, Hamm, and Kirk (2007) found that when examining emotional faces in comparison to objects, N170 in adults with ASD did not differentiate face from object processing while TD controls had earlier N170 responses to faces when compared to objects. Furthermore, TD individuals had earlier N170 responses to faces and the eye and mouth regions of emotionally expressive faces compared to adults with ASD.

Difficulty with the integration of multisensory information was evident in two studies (Magnée et al., 2008; Magnée, de Gelder, van Engeland, & Kemner, 2011). When presented with only visual input, the ASD groups did not differ from TD adults in regard to the N170 (Magnée et al., 2008, 2011), however, when required to divide attention, adults with ASD did not show differentiation based on the congruency of auditory and visual stimuli as seen in TD adults (Magnée et al., 2011).

### ***P100 (k=4)***

The P100 component was examined in four ERP studies in adults (Lassalle & Itier, 2015; Magnée et al., 2008; O'Connor et al., 2005, 2007). Adults with ASD were found to have longer latencies to happy, sad and angry expressions in one study (O'Connor et al., 2005). TD individuals with high autistic traits were also found to differ in P100 with gaze and

emotion having a congruency effect on the P100 of TD adults with low autistic symptomology, but not in adults with high autistic symptomology (Lassalle & Itier, 2015).

### ***Other ERPs***

Other ERPs examined in adult populations were the N100 (Fujita et al., 2013), P300 (Fujita et al., 2013), N200 (Magnée et al., 2008), N400 (Tseng et al., 2015), Visual Mismatch Negativity (vMMN) (Gayle et al., 2012), Early Directing Attention Negativity (EDAN) and Anterior Directing Attention Negativity (ADAN) (Lassalle & Itier, 2015). N100 amplitudes were not modulated by emotional faces or objects in adults with ASD while TD adults showed larger N100 ERPs in response to emotional faces compared to objects (Fujita et al., 2013). Similarly, the N400 ERP was similar in TD and ASD adults when shown line drawings of expressions, however the N400 was not apparent in adults with ASD when shown photographs of expressions (Tseng et al., 2015). In regard to vMMN, TD adults with high autistic traits showed smaller vMMN amplitudes to happy faces compared to TD adults with low autistic traits (Gayle et al., 2012). Lassalle and Itier (2015) examined both EDAN and ADAN, EDAN occurring 200ms–300ms after stimulus presentation and ADAN, occurring 300-500ms after stimulus presentation have previously been associated with the orientation of attention and the maintenance of attention, respectively. These authors examined the effect of stimulus inversion and gaze direction on the processing of emotional stimuli, finding an effect of gaze direction on ADAN in individuals with low but not high autistic traits on the Autism Spectrum Quotient (AQ).

### ***Quantitative EEG (k=6)***

Quantitative methods of examining EEG were used in six studies. Alpha, theta and beta frequencies were the most explored followed by delta and gamma. The particular methods

used varied across studies and included dipole source analysis, phase synchronization, desynchronization, coherence, mu suppression and oscillations. All studies reported atypical cortical activation in ASD populations with differences being reported across the frequency spectrum.

The theta wave occurring between 4 and 7.5 Hertz has been previously associated with the processing of affect, and was examined in three studies (Tseng et al., 2015; Yang, Savostyanov, Tsai, & Liou, 2011; Yeung, Han, Sze, & Chan, 2014). Children with ASD were found to have lower right frontal theta coherence compared to TD children and did not show the same increase in theta coherence observed in TD children in response to emotional faces compared to neutral faces (Yeung et al., 2014). In addition, children with higher theta coherence appeared to have lower autistic symptomology (Yeung et al., 2014). Tseng et al. (2015) found similar results with adolescents and adults with ASD displaying weaker delta/theta synchronization than typically developing controls in both early and late stages of emotion recognition. Weaker theta synchronization in ASD was also reported by Yang et al. (2011).

ASD populations were found to have greater beta 2 synchronization and alpha desynchronization in posterior regions compared to TD populations (Yang et al., 2011), however, these findings were not consistent across studies (Cooper et al., 2013; Tseng et al., 2015).

Mu rhythm activity, the suppression of which is believed to be associated with mirror neuron function (Pineda, 2005), was investigated in one study. Cooper et al. (2013) examined event related desynchronization in the low beta and alpha bands mu activity, postulated to reflect mirror neuron activity in the motor cortex and somatosensory cortex respectively. TD adults with low autistic traits presented with greater low beta

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desynchronization compared to adults with high autistic traits when examining happy faces, reflecting reduced activation of the mirror neuron system to happy faces in individuals with high autistic traits on the AQ. Furthermore, while low trait autism individuals showed greater low beta desynchronization to happy as compared to angry faces, the inverse was true for the high autism trait group, also suggesting divergent mirror neuron activity. No group differences emerged in the alpha mu component, indicating divergent mu rhythm activity may arise in the motor cortex (Cooper et al., 2013).

Gamma oscillations were explored in one study of children with ASD compared to a group of children with ADHD and a group of TD children in emotion and gender recognition tasks. Children with ASD were shown to have lower gamma power to anger and disgust emotions when compared to gender recognition tasks while TD children showed a smaller differentiation of gamma power between these two tasks (Gross et al., 2012).

## **GENERAL DISCUSSION**

Evidence from both ET and EEG studies included in this review suggests that the attentional and cognitive processes involved in FER are atypical in ASD populations. Eye tracking studies reported atypical gaze to the emotional faces and core facial features in individuals with ASD during FER while EEG studies most consistently reported atypical modulation of the N170 ERP. In addition, while less examined, findings in the frequency domain also indicate atypical cortical activity during FER in ASD samples.

It seems somewhat surprising that the pattern of ET results was not more consistent across studies. Reduced gaze to the eyes is frequently cited as observed in ASD and is generally considered a key characteristic of the diagnosis (American Psychiatric Association, 2013; Baron-Cohen et al., 2000). However, a number of studies in this review failed to find any

significant difference in the gaze behaviour of individuals with ASD in comparison to TD controls and there appeared to be a clear effect of age on between group differences in gaze behaviour. Only two of the nine child studies that compared children with ASD to TD children, reported a reduced number of fixations or duration of time spent looking at the eyes (Nuske, Vivanti, & Dissanayake, 2014; Nuske, Vivanti, Hudry, et al., 2014). Similarly, of the eight adolescent studies, only three reported reduced gaze to the eyes in individuals with ASD (Dalton et al., 2005; Tottenham et al., 2014; White et al., 2015). When examining the adult studies, results were more consistent with 11 of the 16 studies reporting reduced use of information presented in the eyes by persons with ASD (Boraston et al., 2008; Corden et al., 2008; Falkmer et al., 2011; Han et al., 2015; Hanley et al., 2012; Hernandez et al., 2009; Kliemann et al., 2010; Neumann et al., 2006; Pelphrey et al., 2002; Spezio et al., 2007a, 2007b). This apparent change of gaze behaviour across the developmental trajectory may have several potential origins. The failure to find stable, significant differences between ASD and TD children, may in part be explained by the stimuli or tasks used and their inability to adequately capture attention in either group. It is possible that the stimuli presented do not engage children sufficiently, and thus were not capable of eliciting divergent gaze behaviour. Those child studies which did find reduced gaze in children with ASD varied exposure time (30ms, 300ms, 2secs) (Nuske, Vivanti, Hudry, et al., 2014) or used familiar and unfamiliar faces (Nuske, Vivanti, & Dissanayake, 2014) whereas the study reporting increased gaze to the eyes in ASD children used very unusual puzzle piece stimuli (Leung et al., 2013). The remaining child studies typically examined gaze to stimuli that were presented for longer durations (4 – 10 secs) and utilised prototypical static and dynamic faces. It is possible that the additional complexity offered by the varied exposure times, face familiarity or puzzled stimuli required greater cognitive processing, resulting in altered eye gaze.

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Adult studies reported reduced gaze in response to not only complex emotions (Hanley et al., 2012) but also in response to basic emotions (Corden et al., 2008; Falkmer et al., 2011; Han et al., 2015; Hernandez et al., 2009; Kliemann et al., 2010; Neumann et al., 2006; Pelphrey et al., 2002; Spezio et al., 2007a, 2007b), with significantly reduced gaze to the eyes being found with prototypical static faces (Corden et al., 2008; Kliemann et al., 2010; Pelphrey et al., 2002), dynamic faces (Han et al., 2015) and experimentally manipulated stimuli (Hernandez et al., 2009; Neumann et al., 2006; Spezio et al., 2007a, 2007b). Given that the development of basic emotion recognition typically reaches maturity in late childhood (Tonks et al., 2006), it appears unlikely that the increased consistency in documents of reduced eye gaze in adults with ASD was due to the increased complexity of the stimuli used in adult populations. It is possible that this difference in gaze behaviour becomes more apparent in adult populations as a result of divergent development of facial emotion processing in late childhood or adolescence.

Two accounts have been offered to explain divergent eye gaze patterns in ASD, the social salience and the eye avoidance accounts. The social salience account proposes that the eye region may provide particularly salient information assisting in the decoding of facial information and emotional expressions (Baron-Cohen, Jolliffe, Mortimore, & Robertson, 1997; Langton, Watt, & Bruce, 2000). A lack of orientation or focus on the eyes in ASD populations may therefore suggest that individuals with ASD do not perceive the eyes as being socially salient or meaningful (Baron-Cohen et al., 1997; Baron-Cohen, Wheelwright, Hill, Raste, & Plumb, 2001). As a result, individuals with ASD may select to look at more physically salient features, such as the mouth which has greater variability and motion than the eye region, perhaps capturing the attention of individuals with ASD to a greater degree. Reduced saliency of social information for individuals with ASD, may be indicative of possible altered function of a number of structures within the social brain

such as the fusiform face area (FFA) (Kanwisher, McDermott, & Chun, 1997), amygdala (Rudrauf et al., 2008; Santos, Mier, Kirsch, & Meyer-Lindenberg, 2011), orbitofrontal cortex and temporal poles (Rudrauf et al., 2008). These structures have been shown to engage in feedback processes with visual processing streams, influencing visual attention during emotion processing (Rudrauf et al., 2008). Atypical eye gaze in ASD individuals, particularly to the eye regions may suggest that the pathways involved in the rapid evaluation and processing of emotional stimuli are altered in ASD. The eye avoidance hypothesis (Tanaka & Sung, 2016) postulates that individuals with ASD may present with over-arousal of the amygdala and hyper-physiological arousal in response to social stimuli. As a result, reduced gaze to the eyes in individuals with ASD may be an attempt to self-regulate and mediate the level of threat perceived from the eyes (Dalton et al., 2005; Tanaka & Sung, 2016).

On a related note, anxiety or fear of negative evaluation appeared to have an effect on gaze towards the eyes in a number of ET studies included in this review. Comorbid anxiety is common within ASD populations (Maddox & White, 2015) and atypical gaze to faces, particularly resulting in a reduction in fixation towards the eyes has been reported in anxiety disorders (Daly, 1978; Wang, Hu, Short, & Fu, 2012). Moreover, anxiety disorders when combined with ASD, have been shown to exacerbate ASD symptoms (Farrugia & Hudson, 2006). Few studies have examined the impact of co-occurring anxiety in ASD populations and most have failed to control for anxiety in their clinical and control populations. Those that have included a measure of social anxiety or threat rating found that those with ASD who had higher anxiety scores, or who rated emotions as more threatening, looked at the eyes significantly less than their TD counterparts (Corden et al., 2008; Tottenham et al., 2014; White et al., 2015).

Atypical gaze to other core facial features such as the mouth, was also observed in some studies (Bal et al., 2010; Bekele et al., 2014; Corden et al., 2008; Leung et al., 2013; Nuske, Vivanti, & Dissanayake, 2014; Nuske, Vivanti, Hudry, et al., 2014). As a result, atypical gaze to faces during FER may also indicate atypical processing of information from the mouth region, however, findings overall remain inconclusive.

There was also a clear tendency in the ET literature towards the report of non-significant trends, with the majority of these trends reporting results consistent with the significant findings (Bal et al., 2010; Bekele et al., 2013; Boraston et al., 2008; Corden et al., 2008; de Wit et al., 2008; Kliemann et al., 2012; Kliemann et al., 2010; Rutherford & Towns, 2008; Tottenham et al., 2014). This tendency for reports of trends to corroborate significant findings may be seen to provide additional, although weak, support for the notion of reduced gaze towards the eyes during FER. While it is noted that these findings are not statistically significant, the tendency for these trends to be reported and for conclusions to be based on them can make the interpretation and integration of the results reported in the literature problematic. It is, for instance, not clear whether the report of trends is selective, i.e., whether trends are reported only if they are seen to be consistent with an expected pattern of results. Such a bias may help to strengthen a presumed pattern of results that has a less solid empirical base as originally thought. Methodological issues associated with some studies, such as small sample size, may have contributed to this tendency to find and report statistical trends. Future research may benefit from larger scale studies to more accurately determine the gaze behaviour of individuals with ASD.

It should also be noted that across ET studies a number of different outcome measures are reported. For example, studies may examine the duration of the first fixation, the total fixation time, number of fixations, scan paths or location of first fixations and the rationale

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for choosing one over the other is not always clear. The range of outcome measures examined may impact the resultant findings. For example, it was found that adults with ASD may differentiate their gaze depending on the location of their first fixation, indicating a reduced preference for the eyes compared to TD adults (Kliemann et al., 2012; Kliemann et al., 2010).

Across studies reporting ERPs, the N170 was consistently smaller, delayed and slower in ASD populations. The N170 ERP has been shown to be largest in response to faces (Blau, Maurer, Tottenham, & McCandliss, 2007), suggesting its involvement in the processing of facial information. While the face-specific nature of the N170 ERP is well accepted (Eimer, 2000, 2011; Eimer et al., 2011), the precise function of the N170 ERP continues to be debated. The N170 ERP has been suggested to reflect the early encoding of facial stimuli (Eimer, 2000), whereas other studies have indicated that the N170 can also be modulated by the emotional content of the faces (Batty & Taylor, 2003; Blau et al., 2007). Given the debate in the current literature regarding the processes reflected in the N170 ERP, it is unclear whether FER impairment in ASD reflects altered encoding of facial information, resulting in difficulty processing facial configurations (O'Connor et al., 2007) or altered function in a possible parallel system specific for emotion processing (Blau et al., 2007). Nevertheless, consistently smaller and slower N170 ERPs in the ASD populations indicate altered function of early visual processing during FER.

An important caveat is that differences in ERPs in ASD populations may also be indicative of heterogeneity in the ASD population. It could be the case that only a subset of individuals with ASD are impacted by FER deficits (Nuske et al., 2013) or that there is more universal disorganisation and variability in neural pathways involved in FER in ASD.

Studies of frequency domain measures of EEG provide further evidence for atypical activation of cortical regions during FER in ASD. Increased theta synchronization has been demonstrated to reflect information encoding and episodic memory (Klimesch, 1999), and a reduction in theta synchronization and reduced right frontal theta coherence in ASD populations (Tseng et al., 2015; Yang et al., 2011) may reflect poor encoding of facial emotion. The hippocampus and amygdala have been shown to be involved in the encoding of emotional memory (Richardson, Strange, & Dolan, 2004) and the amygdala has been found to have atypical structure and function in ASD (Baron-Cohen et al., 2000; Bölte et al., 2015; Dalton et al., 2005). Reduced theta synchronization may be indicative of atypical connectivity between neural networks involving the amygdala and hippocampus resulting in less efficient encoding and memory retrieval of facial expression. A phasic suppression of alpha during task performance has been shown to reflect increasing attention demands (Klimesch, 1999; Klimesch, Doppelmayr, Russegger, Pachinger, & Schwaiger, 1998), thus, greater alpha de-synchronization in ASD may suggest increased concentration or attention to the task, possibly reflecting decreased efficiency of structures involved in FER (Yang et al., 2011). Changes in the frequency domain can be reflective of a number of different cognitive processes (Başar, Başar-Eroglu, Karakaş, & Schürmann, 2001), therefore, caution must be observed when inferring the particular cognitive processes involved in FER.

Yang et al. (2011) and Tseng et al. (2015) both postulated that the observed reduction in the lower frequency bands in people with ASD may be indicative of impaired automatic processing of emotion while increased alpha desynchronization and beta may be reflective of increased conscious control of visual processing. This is possibly indicative of the use of compensatory strategies accounting for weaknesses in the typical automatic processes involved in emotion recognition (Tseng et al., 2015).

While only examined in one study, the role of the mirror neuron system in FER is important to note (Cooper et al., 2013). The mirror neuron network is postulated to be involved in the understanding of movement and imitation (Rizzolatti & Craighero, 2004). For this reason, the function of this system in understanding the movement of others has been proposed to be linked to the understanding of social situations, theory of mind (Gallese, 2007; Schulte-Rüther, Markowitsch, Fink, & Piefke, 2007; Williams, Whiten, Suddendorf, & Perrett, 2001) and facial expressions (Enticott, Johnston, Herring, Hoy, & Fitzgerald, 2008). Suppression of mu rhythm has been suggested to reflect mirror neuron activity (Pineda, 2005; Rizzolatti & Craighero, 2004). Atypical patterns of mu activity found in individuals with high autistic symptomology (Cooper et al., 2013) suggest that the mirror neuron system involved in the understanding of actions may contribute to an FER impairment in ASD and warrants further investigation (Hickok, 2009).

The effect of emotion per se as well as of specific emotions on the differences reported between groups was difficult to elucidate from the extant literature. A number of studies reported differences in ET and ERP responses to neutral faces in addition to differences in response to emotional expressions. Therefore, it is unknown whether impairments in face recognition in general result in a FER deficit, or whether there are additional impairments in ASD related specifically to the processing of facially expressed emotion. Previous reviews have suggested that individuals with ASD have a deficit in face processing (Tang et al., 2015; Weigelt, Koldewyn, & Kanwisher, 2012), and diminished fixations to the eyes during tasks such as face recognition have been identified in ASD (Harms et al., 2010; Senju & Johnson, 2009; Tanaka & Sung, 2016). Certainly, atypical gaze to faces would also manifest in FER tasks. A number of studies across the developmental trajectory reported that while ERPs were modulated by emotion in TD samples, this modulation was absent in ASD samples. This suggests that whereas TD

display differentiated neural activity based on the emotional content of faces, persons with ASD may not display this same differentiation, suggesting that while general face processing in ASD is impaired, there may be an additional or compounding impairment in the processing of emotion.

## **FUTURE DIRECTIONS AND CHALLENGES**

Facial emotion recognition is a complex task drawing on a number of neural networks (Adolphs, 2002). Given the complexity of these processes, a significant body of research has emerged across diverse areas to elucidate the nature of FER impairment in ASD. However, the large degree of heterogeneity in the studies included in this review owing to differences in experimental paradigms and tasks makes synthesising results difficult. The methodological differences across studies may affect the findings. Participant factors, for example sample size, ASD population characteristics or matching procedure may also result in differing outcomes. ERPs have been shown to be influenced by the experimental paradigm selected. For example, a P100 elicited by a target following an emotional face (Lassalle & Itier, 2015) may reflect a different process as does a P100 elicited by the emotional face (O'Connor et al., 2005). Thus, caution must be used when interpreting the available results. The complexity of this field renders the synthesis of results across studies difficult and will continue to challenge researchers.

One option to generate more clarity to the pattern of FER results in ASD might be subgroup analyses. While attempts have been made to determine subtypes of ASD (Beglinger & Smith, 2001; Georgiades et al., 2013; Ousley & Cermak, 2015), the phenotype of ASD remains heterogeneous (Georgiades et al., 2013) changing across the developmental trajectory and in response to intervention or treatment. Comparison of different samples and different individuals with ASD may not provide an accurate

representation of FER in ASD. Falck-Ytter et al. (2010) found differences in the way in which social impairment and communication impairment scores on the ADI-R correlated with gaze behaviour, possibly providing some evidence to suggest that the individual profiles of individuals with ASD may inform the gaze behaviour elicited by FER. Future research may take into account the individual developmental profile of ASD participants and conduct longitudinal studies to determine how the attentional and neurological processes involved in FER may develop across the lifespan.

In addition to the variable diagnosis of ASD itself, ASD often presents with co-occurring diagnoses (Joshi et al., 2010). Social anxiety and ASD can present with similar symptomology, particularly in high functioning individuals (Tyson & Cruess, 2012) and anxiety may present with atypical gaze to faces (Daly, 1978; Wang et al., 2012). Approximately 30 percent of the ASD population have an ADHD diagnosis (Simonoff et al., 2008). Behavioural studies have shown that ASD with comorbid ADHD results in reduced recognition of facial emotion (Sinzig, Morsch, & Lehmkuhl, 2008). A recent study suggests that variability in FER performance may be explained in part by the attentional distractibility profile of the individuals with ASD (Berggren et al., 2016). To date, few studies have accounted for comorbid diagnoses when examining FER performance in ASD. Subsequently, it is difficult to conclude if FER impairment is resultant of ASD itself, or can be explained by co-occurring conditions, such as social anxiety or ADHD. Future research may be able to extricate to what extent atypical gaze and brain activity are due to co-occurring diagnoses or cognitive profiles.

A number of outcome related questions arose from this review. Firstly, the P100 and N170 were the most commonly explored ERPs in both child and adult studies with the majority of studies reporting both slower latencies and smaller amplitudes of the N170 in ASD

populations. The P100 and N170 represent both the early processing of visual information and the intermediate stages whereby configural and emotional encoding of faces occurs (Zhu et al., 2015). There was limited research investigating later components including N300 (Dawson et al., 2004), N400 (Tseng et al., 2015), P400 (Key et al., 2015), N250 and Late Stage Positive Potential (LPP). As these later occurring components are reflective of more cognitive processing (Sur & Sinha, 2009), future research may benefit from examining these later components in ASD to determine the extent and nature of the emotion processing differences.

Secondly, while the EEG and ET studies in isolation provide valuable insights into the neurophysiological and attentional processes underlying emotional face processing in ASD only one study examined them together (Wagner et al., 2013). However, this study only examined the two measures in parallel and did not integrate them. The integration of ET with other neuroimaging measures such as fMRI is more common, and contributes to advances in knowledge, such as the finding that the amygdala activity is moderated by fixations to the eyes (Dalton et al., 2005). EEG provides superior temporal resolution to fMRI, therefore combining EEG and ET may provide greater insights in to the very precise electrophysiological mechanisms which may be moderated by specific gaze behaviours.

The findings of this review also have potential clinical utility. ET patterns and specific electrocortical activity related to the processing of emotionally expressive faces may prove valuable as markers from both a diagnostic or predictive standpoint as well as a potential target for treatment. ET and EEG markers when used in combination may prove clinically significant as markers for diagnosing ASD, treatment outcome or predicting emotion recognition or social skills.

These EEG and ET markers may also lead to effective intervention methods in themselves. The findings that fixations to the eyes was associated with greater proficiency in FER in ASD populations may indicate that if these patterns are modified, proficiency in these tasks may improve. Biofeedback is an intervention which involves the training of the self-regulation of certain physiological processes with the aim of modifying behaviour. EEG and ET biofeedback has proved effective in increasing attention in children with ADHD and ASD, therefore, if biomarkers exist for FER, biofeedback may assist individuals with ASD to enhance their ability to detect and recognize facially expressed emotion (Bölte et al., 2015; Holtmann et al., 2011; Kouijzer, van Schie, Gerrits, Buitelaar, & de Moor, 2013).

## **CONCLUSION**

The ET and EEG results summarized in this review suggest that the attentional and cognitive processing of emotional faces is atypical in ASD across the developmental trajectory. Atypicalities in eye gaze, while not conclusive, indicate altered visual attention to facial emotions in individuals with ASD. A clear developmental effect was evident in the ET findings, indicating altered gaze to the eyes during FER is more apparent in adult populations. Atypical activation of cortical areas associated with the processing of facially expressed emotion is supported by the findings of EEG studies reporting differences in the elicitation of ERPs across the developmental trajectory.

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## CHAPTER THREE

### MORE THAN VALENCE? USING A DIMENSIONAL AND DISCRETE APPROACH TO INVESTIGATE COMPLEX FACIAL EMOTION PROCESSING

This chapter presents a manuscript pending publication.

**Black, M. H.**, Chen, N. T., Lipp, O. V., Maybery, M., Bölte, S., Falkmer, M., & Girdler, S. (pending publication). More than valence? Using a dimensional and discrete approach to investigate complex facial emotion processing.

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## **PREFACE**

As shown in Chapter Two, the majority of studies investigating FER in autistic individuals has used basic emotional concepts. While there is increasing interest in the use of complex emotions, there is currently little understanding of the underlying dimensions, or basic emotion components that comprise these complex concepts. The inherent complexity associated with use of complex emotions can make constructing experimental paradigms capable of capturing the full extent of complex emotion processing difficult. This is indeed evidenced by the few studies in Chapter Two which included complex emotional concepts.

This chapter examines the facial stimuli presented in the Cambridge Mind Reading Face-Voice battery. This battery presents dynamic videos of adult actors expressing a range of complex emotions. Here these emotions are reduced to their underlying discrete and dimensional components in order to provide a means for researches to better construct paradigms seeking to understand complex emotion perception and to exert greater experimental control over their experiments.

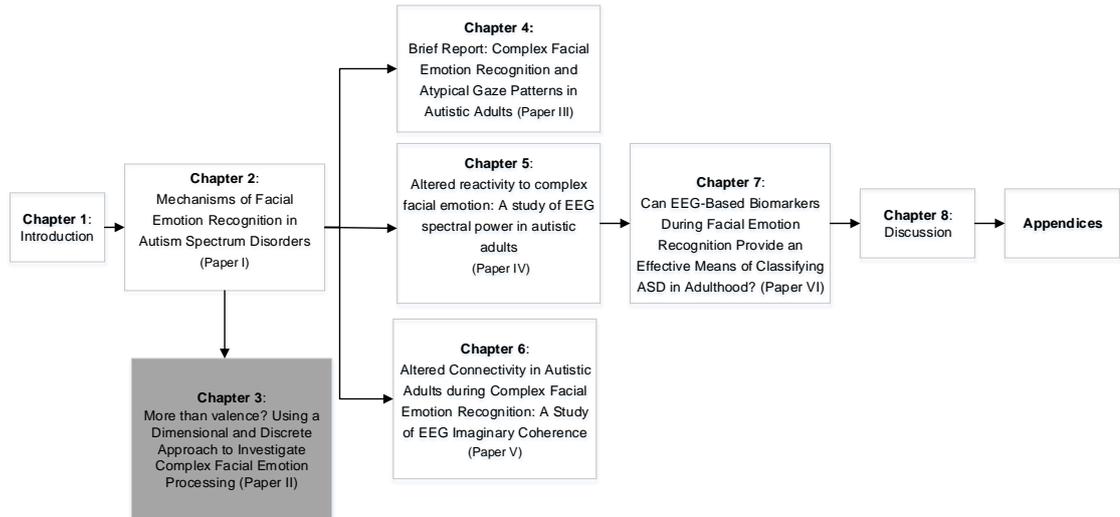


Figure 1. Thesis outline chapter three

**ABSTRACT**

Emotion perception provides a critical foundation for human interaction, with impairments in this domain associated with a number of clinical conditions. While investigation of facial emotion perception has been largely restricted to the basic emotions, there is increasing interest in the use of complex emotional concepts to provide insights more commensurable to everyday social functioning. The use of complex emotions is however hindered by an inadequate understanding of the characteristics and nature of these stimuli. The Cambridge Mind Reading Face-Voice Battery (CAMs) provides an ecologically valid assessment of emotion processing. The complex, dynamic facial emotion stimuli presented in this battery were examined using both a dimensional and discrete approach. Facial emotion stimuli were reduced to their underlying basic emotion components and normative data on the four dimensions of valence, arousal, dominance and approach is provided for a typically developed sample.

## INTRODUCTION

The ability to perceive emotions expressed by others provides a key foundation to the human experience. Social functioning difficulties in a number of clinical conditions including Autism Spectrum Disorder (Uljarevic & Hamilton, 2013), Schizophrenia (Kohler, Walker, Martin, & Healey, 2010), Borderline Personality Disorder (Fenske et al., 2015), Anxiety (Attwood et al., 2017) and Depression (Bourke, Douglas, & Porter, 2010) are purported to include, and perhaps be resultant of, emotion perception impairment. For this reason, significant research attention has focused on understanding the nature of emotion perception in typically developing and clinical populations.

Research examining emotion perception in typical and clinical populations has historically been grounded in discrete emotion theories, which propose that emotions are distinct, categorical entities (Colembetti, 2009; Ekman, 1992; Ekman & Friesen, 1971; Izard, 2011). Perhaps the most prominently recognised discrete emotion theory is that of basic emotions. Originally proposed by Ekman and Friesen (1971), the basic emotions (happiness, anger, fear, disgust, sadness, surprise) are foundational emotions, purported to be universally experienced, and easily distinguishable (Ekman, 1992; Ekman & Cordaro, 2011). It has been hypothesised that these basic emotions may arise from unshared neural pathways or have distinct neural signatures (Saarimäki et al., 2015). Popular stimulus sets such as the Pictures of Facial Affect (Ekman & Friesen, 1976), NimStim Set of Facial Expressions (Tottenham et al., 2012), Karolinska Directed Emotional Faces stimulus set (Goeleven, Raedt, Leyman, & Verschuere, 2008) and the Montreal Set of Facial Displays of Emotion (Beaupré, Cheung, & Hess, 2000) are all largely constructed using a basic emotion paradigm.

A significant proportion, and arguably a majority, of our collective understanding of emotion perception to date, is built upon these six basic emotions alone. Recently however, research attempting to understand the nature of emotion perception in typically developing and clinical populations has recognised limitations in investigations that are restricted to the six basic emotions. Given the complex nature of emotion and the contextual dynamics present in day to day social interaction, it is unlikely that investigation based on the six basic emotions alone can capture the full extent of emotion perception (Golan, Baron-Cohen, & Hill, 2006; O'Reilly et al., 2016). Some stimulus sets expanding beyond the six basic emotions, including more complex emotions (such as jealousy, guilt, intimacy or vibrancy) have emerged including the EU-Stimulus set (O'Reilly et al., 2016), the Multi-faceted Empathy Test (Dziobek et al., 2008), and the Cambridge Mind Reading Face-Voice Battery (Golan et al., 2006) in attempts to provide researchers with a greater array of stimuli through which to examine emotion perception.

Though there is a growing interest in the use of complex emotional concepts, the investigation of complex emotion processing is limited in a number of ways. Unlike the basic emotions, which are usually limited to six base emotions (Ekman, 1992; Ekman & Cordaro, 2011), there exists a multitude of complex emotional concepts. It is not feasible to suggest that researchers seeking to understand complex emotion processing should include all possible complex emotions in their investigations. Thus, questions arise in regard to constructing experimental paradigms which are adequately able to capture complex emotion perception.

As the use of ecologically and socially valid stimuli is of increasing interest, there is a need to understand the underlying characteristics of complex emotions to facilitate improved and more rigorous investigation of these concepts. Discrete emotion theorists

hypothesise that complex emotions arise from the basic or foundational emotions (Ekman, 1992; Ekman & Cordaro, 2011; Izard, 2011). Based on a distinct conceptualisation of emotion, it may be possible to reduce complex emotions to their underlying emotional families, or to a combination of the basic emotions.

It may also be possible to reduce emotions to their underlying dimensions. Dimensional theories of emotion, theorise that emotions arise from the intersection of independent neural systems (Posner, Russell, & Peterson, 2005 ; Russell, 1980). Typically, dimensional approaches purport that emotional experiences arise from the two dimensions of valence, or how pleasant an experience is, and arousal, such as how intense the experience is (Posner et al., 2005 ; Russell, 1980). Some dimensional models have proposed the inclusion of dominance as a third dimension contributing to the conceptualisation of emotion (Bakker, Van der Voordt, Boon, & Vink, 2014; Osgood, 1952; Osgood, Succi, & Tannenbaum, 1957), whereas other dimensional approaches have included other dimensions such as approach and avoidance (Lang, Bradley, & Cuthbert, 1998), reflecting motivational systems. The use of a dimensional approach may provide a means to capture the full complexity of emotion. To date only one complex, dynamic emotion battery is available which provides normative data on valence and arousal ratings (O'Reilly et al., 2016). However, the possible influence of other dimensions, and the underlying combination of basic emotions has not yet been examined.

The Cambridge Mind Reading Face-Voice battery (CAMs) is a battery designed to examine complex emotion processing and has been used to investigate emotion perception impairment in adults with Autism Spectrum Disorder (Golan et al., 2006). The CAMs battery presents both audio and visual stimulus sets to investigate vocal and facial emotion perception (Golan et al., 2006). The CAMs face-battery includes 52 video stimuli of adult

actors expressing a range of complex emotional concepts and was the focus of this study. While the CAMs has been argued to provide an ecologically valid measure of complex emotion processing, the underlying dimensions of these stimuli have not been investigated (Golan et al., 2006).

To address limitations in current stimulus batteries available to examine complex facial emotion perception, the current study sought to provide normative data on the CAMs to facilitate investigation using more complex emotional concepts and to provide researchers with the ability to exert greater experimental control over their paradigms.

## **METHOD**

### **Participants**

Typically developing adults aged 18 and over were eligible to participate in this study. Adults who reported intellectual or psychological conditions, such as intellectual disability, anxiety, depression and bipolar disorder were excluded. Analysis is based on total sample 141 adults, consisting of 50 males and 91 females. The mean age of the total sample was 26.4 (SD= 13.4) years and the mean AQ score of the total group was 17.8 (SD= 6.2). Participants primarily originated from Australia (n=78), United Kingdom (n=10), South Africa (n=8), Malaysia (n=8) and the United States (n=7) and were primarily university students from the disciplines of psychology and engineering.

### **Measures**

#### ***Cambridge Mind-Reading Face-Voice Battery (Face stimuli)***

Stimuli consisted of the face-stimuli from the Cambridge Face-Voice Battery (Golan et al., 2006). The 'face' stimuli consisted of 52 videos (50 test and 2 practice items) of males

and females expressing complex emotions from 20 emotion categories. Videos range from three – five seconds in length and are portrayed by multi-ethnic actors. The 20 emotion categories of the CAMs battery include 5 positive concepts (vibrant, empathic, exonerated, intimate, reassured), 12 negative concepts (appalled, confronted, distaste, grave, guarded, insincere, mortified, resentful, stern, subdued, subservient, uneasy) and 3 neutral concepts (appealing, lured, nostalgic).

### ***Dimensional Rating Scales***

Rating scales used in this survey were based on the Self-Assessment Manikin (SAM) (Bradley & Lang, 1994). The Self-Assessment Manikin is an assessment used to rate an individual's affective response to situations or objects (Bradley & Lang, 1994). Participants were required to rate “how you think the person in the video is feeling” in accordance with the SAM. The valence scale asked participants to rate on a 9-point Likert scale how unpleasant/pleasant the individual in the video felt, with a rating of 1 indicating “extremely unhappy, unpleasant or discontented” and a score of 9 indicating “extremely pleasant, happy or contented”. The arousal scale asked participants to rate how calm/excited they thought the person in the video was feeling with ‘1’ indicating “calm, relaxed or unaroused” and ‘9’ indicating “excited, stimulated and aroused”. The dominance scale related to how un-dominant/dominant they thought the individual in the video was with ‘1’ indicating “controlled, awed and submissive” and ‘9’ indicating “in-control, important and dominant”. Finally, the approach scale was rated on a scale of ‘1’ indicating that the person felt “avoidant, unfriendly, unhelpful and not sociable”, with ‘9’ indicating that the person felt “approachable, friendly, sociable or helpful”.

***Basic Emotion Rating Scales***

Similar to the rating scales designed to examine the underlying dimensions of each emotion, for each video, participants were also asked to rate the emotions on a 9-point Likert scale according to the six basic emotions (happiness, anger, sadness, fear, disgust, surprise). For example, “How angry is the emotion?”

***Autism Spectrum Quotient***

The Autism Spectrum Quotient (AQ) (Woodbury-Smith, Robinson, Wheelwright, & Baron-Cohen, 2005) was used to account for autistic-like traits within the sample. The AQ consists of 50 statements which respondents rate on a four-point Likert scale (1=definitely agree; 4= definitely disagree). With a score of 26, the AQ has sensitivity of 94.5% and specificity of 51.85%.

**Procedure**

An online survey tool, Qualtrics, controlled stimulus presentation and data acquisition. Participants viewed each stimulus video and were presented with the series of rating scales. Prior to beginning the survey, participants were first presented with a description of the questions and two practice items which they were required to complete before continuing on to the remainder of the survey. Participants then viewed the stimulus videos and rating scales for the 52 CAMs items. Following ratings of the CAMs battery, participants were required to complete the AQ questionnaire.

## **Ethical Considerations**

This study was approved by the Human Research Ethics Committee at Curtin University (HR52/2012), Perth, Australia. Participants provided informed consent prior to participation by indicating their agreement on the survey platform.

## **Data Treatment and Analysis**

For dimensional data, analysis was first conducted to determine the mean and standard deviation of ratings on each of the 52 face stimuli presented in the CAMS face-stimuli on four dimensions of valence, arousal, dominance and approach. As the CAMs battery presents participants with multiple representations of the same emotion, the mean and standard deviation of each stimulus within an emotion category were also obtained in order to reduce the stimuli to the 20 emotion concepts.

The combination of basic emotions contributing to each of the 20 emotional concepts was also of interest. The mean and standard deviation for each basic emotion rating of the 20 emotional concepts were calculated. A cut-off score of 4.5 was used to determine the basic emotions which had the greatest contribution to the complex concepts. Gephi network analysis software (Bastian, Heymann, & Jacomy, 2009) was also used to visualize and explore the combination of basic emotions contributing to each complex emotion concept presented in the CAMs.

## RESULTS

### Dimensions

Table 1 presents the mean and standard deviation ratings for the 52 (50 test and 2 practice) face stimuli presented in the CAMs, while means and standard deviations for the 20 emotional concepts are provided in Table 2.

*Table 1. Mean and standard deviations (SD) for 52 complex emotional stimuli presented in the Cambridge Mind Reading Face-Voice Battery*

Emotion	Valence		Arousal		Dominance		Approach	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
M4Vadmiring <sup>a</sup>	6.51	1.57	4.49	1.73	5.96	1.47	6.36	1.47
M6Vappalled	2.40	1.57	7.06	1.61	5.38	1.92	3.21	1.92
S5Vappalled	2.97	1.45	6.68	1.42	4.49	1.65	3.86	1.65
Y5Vappalled	2.44	1.22	6.68	1.63	5.23	1.78	3.47	1.78
M1Vappealling	2.87	1.21	5.18	1.50	4.01	1.73	3.93	1.73
M6Vappealling	5.57	1.47	5.16	1.48	5.02	1.22	5.58	1.22
M2Vconfronted	3.14	1.25	5.93	1.45	4.07	1.43	3.64	1.43
M8Vconfronted	3.01	1.25	5.23	1.53	4.75	1.60	3.35	1.60
Y2Vconfronted	5.13	1.37	6.49	1.23	5.03	1.20	5.45	1.20
M6Vdistaste	2.62	1.14	5.17	1.45	5.17	1.50	3.21	1.50

*Table 1. Continued*

Emotion	Valence		Arousal		Dominance		Approach	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
M7Vdistaste	2.69	1.12	5.18	1.33	4.72	1.51	3.44	1.51
Y4Vdistaste	2.48	1.33	4.89	1.59	4.75	1.72	3.23	1.72
S5Vempathic	4.80	1.26	3.97	1.58	5.52	1.54	5.25	1.54
M4Vempathic	3.69	1.34	3.84	1.43	4.35	1.41	5.18	1.41
Y2Vempathic	5.06	1.63	4.16	1.61	4.45	1.44	5.83	1.44
M2Vexonerated	5.04	1.70	4.72	1.39	6.33	1.44	4.71	1.44
S4Vexonerated	4.73	1.59	4.21	1.65	5.33	1.40	4.72	1.40
Y7Vexonerated	7.10	1.19	5.29	2.07	5.45	1.35	6.83	1.35
S1Vgrave	3.34	1.17	4.77	1.36	5.57	1.60	3.89	1.60
S6Vgrave	2.99	1.42	3.94	1.62	3.52	1.54	4.38	1.54
Y3Vguarded	3.29	1.19	5.10	1.60	6.11	1.73	3.44	1.73
Y8Vguarded	3.72	1.14	4.68	1.25	5.52	1.54	3.94	1.54
M4Vinsincere	6.44	1.89	4.71	1.74	5.45	1.37	6.23	1.37
Y7Vinsincere	4.96	1.70	4.65	1.44	5.06	1.56	4.98	1.56
M2Vintimate	6.18	1.48	4.65	1.75	5.80	1.64	5.84	1.64

*Table 1. Continued*

Emotion	Valence		Arousal		Dominance		Approach	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Y2Vintimate	7.00	1.16	4.40	1.93	5.48	1.39	6.87	1.39
M1Vlured	5.48	1.40	4.82	1.57	5.90	1.43	5.18	1.43
M2Vlured	5.39	1.21	4.21	1.38	4.61	1.36	5.43	1.36
S2Vlured	5.20	1.51	5.70	1.63	4.48	1.38	5.20	1.38
Y7Vmortified	2.13	1.46	6.87	1.66	3.59	1.75	2.87	1.75
Y8Vmortified	2.50	1.22	6.33	1.57	3.48	1.47	3.53	1.47
S2Vnostalgic	7.34	1.54	4.41	2.27	5.11	1.50	7.02	1.50
S5Vnostalgic	6.39	1.66	4.46	1.82	5.38	1.47	6.24	1.47
Y5Vnostalgic	7.38	1.09	4.16	1.93	5.68	1.41	6.90	1.41
M1Vreassured	5.23	1.73	5.35	1.51	5.60	1.21	5.21	1.21
M8Vreassured	7.08	1.42	5.18	2.10	5.18	1.34	6.96	1.34
S1Vreassured	6.58	1.24	4.09	1.70	5.55	1.26	6.43	1.26
M2Vresentful	2.87	1.32	4.67	1.52	4.96	1.71	3.48	1.71
M3Vresentful	2.60	1.34	5.48	1.55	6.81	1.40	3.13	1.40
M8Vresentful	2.97	1.06	5.15	1.39	4.88	1.59	3.44	1.59

*Table 1. Continued*

Emotion	Valence		Arousal		Dominance		Approach	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Y7Vrestless	2.42	1.34	6.76	1.56	2.74	1.36	2.84	1.36
M4Vsubdued	2.93	1.27	3.60	1.44	3.05	1.37	3.73	1.37
Y2Vsubdued	3.11	1.14	4.22	1.64	2.81	1.40	3.73	1.40
M3Vsubservient	3.07	1.13	4.42	1.57	2.84	1.73	3.14	1.73
Y1Vsubservient	3.69	1.28	5.13	1.56	2.75	1.47	3.40	1.47
M1Vstern	2.91	1.32	5.32	1.56	6.67	1.39	3.26	1.39
M2Vstern	3.47	1.36	4.65	1.45	6.32	1.58	3.86	1.58
S5Vstern	3.29	1.44	4.49	1.68	6.77	1.36	3.51	1.36
S2Vuneasy	2.99	1.13	5.31	1.53	3.21	1.39	3.50	1.39
S5Vuneasy	3.48	1.20	5.11	1.45	5.70	1.49	3.87	1.49
M8Vvibrant	8.43	1.06	7.04	1.97	5.96	1.80	8.01	1.80
Y4Vvibrant	8.52	0.88	6.69	2.12	6.10	1.66	7.89	1.66

<sup>a</sup> Stimulus coding system provided for stimuli from Cambridge Mind Reading Face-Voice Battery. Each code corresponds to a different stimulus video.

*Table 2. Means and standard deviations (SD) for each emotion concept*

Emotion	Valence		Arousal		Dominance		Approach	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Appalled	2.61	1.44	6.81	1.56	5.04	1.82	3.51	1.69
Appealing	4.22	1.91	5.17	1.49	4.52	1.57	4.76	1.70
Confronted	3.76	1.61	5.88	1.50	4.62	1.47	4.15	1.64
Distaste	2.60	1.20	5.08	1.47	4.88	1.59	3.29	1.41
Empathic	4.52	1.54	3.99	1.54	4.78	1.55	5.42	1.68
Exonerated	5.62	1.84	4.74	1.78	5.70	1.46	5.42	1.80
Grave	3.17	1.31	4.36	1.55	4.55	1.88	4.13	1.58
Guarded	3.50	1.18	4.89	1.45	5.81	1.66	3.69	1.62
Insincere	5.70	1.94	4.68	1.60	5.26	1.48	5.60	1.96
Intimate	6.59	1.39	4.52	1.85	5.64	1.53	6.35	1.65
Lured	5.35	1.38	4.91	1.65	5.00	1.53	5.27	1.65
Mortified	2.31	1.36	6.60	1.64	3.54	1.61	3.20	1.52
Nostalgic	7.04	1.52	4.35	2.02	5.39	1.47	6.72	1.42
Reassured	6.30	1.67	4.87	1.87	5.44	1.28	6.20	1.65

*Table 2. Continued*

Emotion	Valence		Arousal		Dominance		Approach	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Resentful	2.81	1.25	5.10	1.52	5.55	1.81	3.35	1.51
Stern	3.22	1.39	4.82	1.60	6.59	1.46	3.54	1.75
Subdued	3.02	1.21	3.91	1.57	2.93	1.39	3.73	1.66
Subservient	3.38	1.24	4.77	1.60	2.79	1.60	3.27	1.69
Uneasy	3.24	1.19	5.21	1.49	4.46	1.90	3.69	1.44
Vibrant	8.48	0.97	6.86	2.05	6.03	1.73	7.95	1.05

The position of the 20 emotional concepts, based on the group means are displayed in a matrix scatter plot (Figure 2) The emotional concepts were categorised according to their position in the four dimensional space. As shown in Figure 2 and Table 3, valence and approach were highly correlated, that is emotions rated as positive in valence were also rated high in approach or vice-versa. This was true for all emotions with the exception of appealing which was rated low in valence but high in approach.

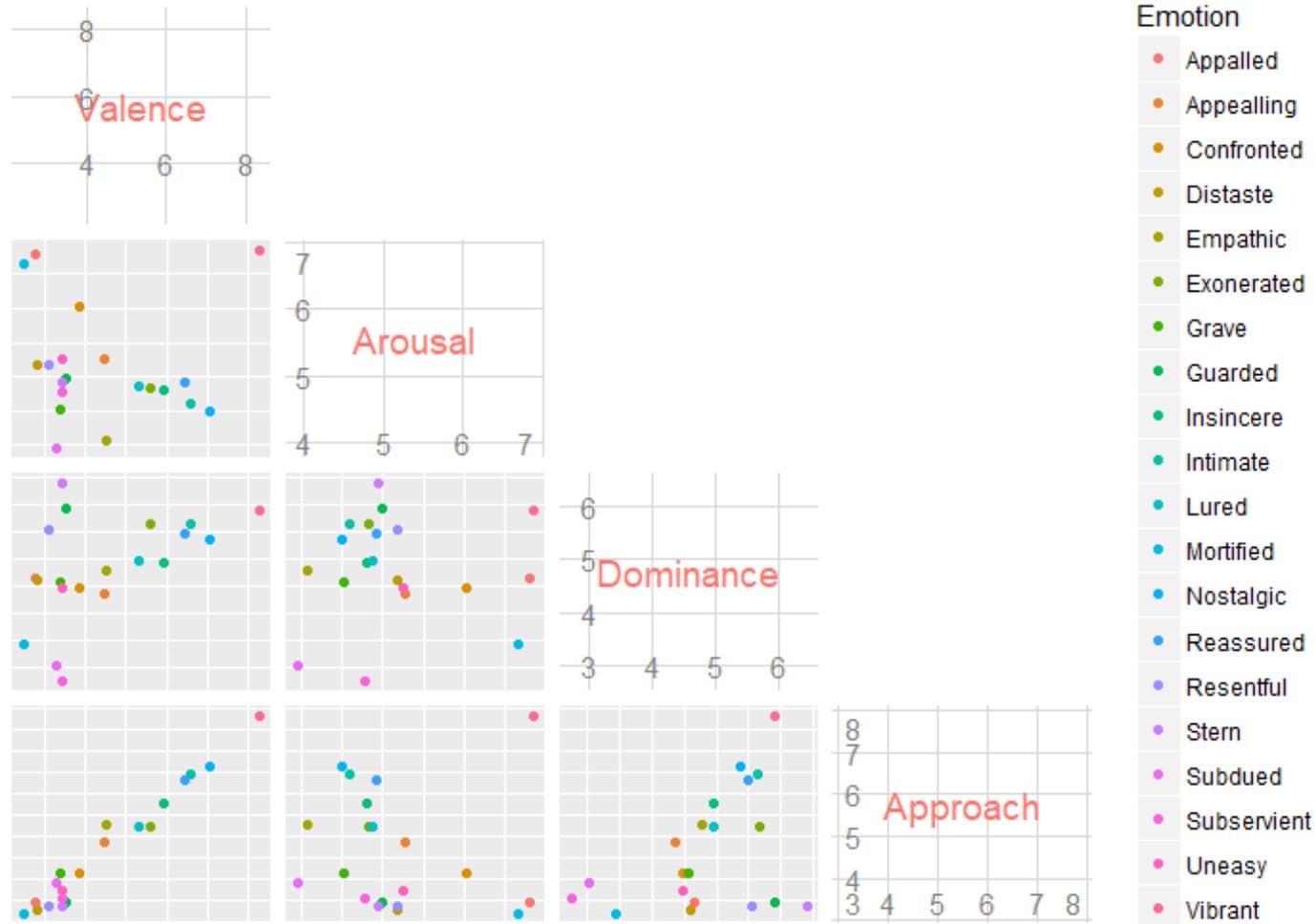


Figure 2. Matrix scatterplot of the 20 complex emotions from the Cambridge Mind Reading Face-Voice Battery on valence, arousal, dominance and approach dimensions.

*Table 3. Categorisation of emotions according to the four dimensions.*

	Low Valence	High Valence	Low Arousal	High Arousal	Low Dominance	High Dominance	Low Approach	High Approach
Appalled	X			X		X	X	
Appealing	X			X		X		X
Confronted	X			X		X	X	
Distaste	X			X		X	X	
Empathic		X	X			X		X
Exonerated		X		X		X		X
Grave	X		X			X	X	
Guarded	X			X		X	X	

*Table 3. Continued.*

	Low Valence	High Valence	Low Arousal	High Arousal	Low Dominance	High Dominance	Low Approach	High Approach
Insincere		X		X		X		X
Intimate		X		X		X		X
Lured		X		X		X		X
Mortified	X			X	X		X	
Nostalgic		X	X			X		X
Reassured		X		X		X		X
Resentful	X			X		X	X	
Stern	X			X		X	X	
subdued	X		X		X		X	

*Table 3. Continued.*

	Low Valence	High Valence	Low Arousal	High Arousal	Low Dominance	High Dominance	Low Approach	High Approach
Subservient	X			X	X		X	
Uneasy	X			X	X		X	
Vibrant		X		X		X		X

As it was observed that valence and approach were highly correlated a second 3-dimensional model was constructed using the dimensions of valence, arousal and dominance.

Using a three-dimensional model (Figure 3), the emotional concepts were observed to fall into six groups. Emotions which were low valence, but high in arousal and dominance included Appalled, Appealing, Confronted, Distaste, Guarded, Stern and Resentful. Emotions which were low in valence and dominance but high in arousal included Subservient, Mortified and Uneasy. One emotion, Subdued was considered low in valence, arousal and dominance, while Grave was considered low in valence and arousal but high in dominance. Exonerated, Intimate, Insincere, Lured, Vibrant and Reassured emotions were high in valence, arousal and dominance while Empathic and Nostalgic emotions were high valence and dominance but low in arousal.

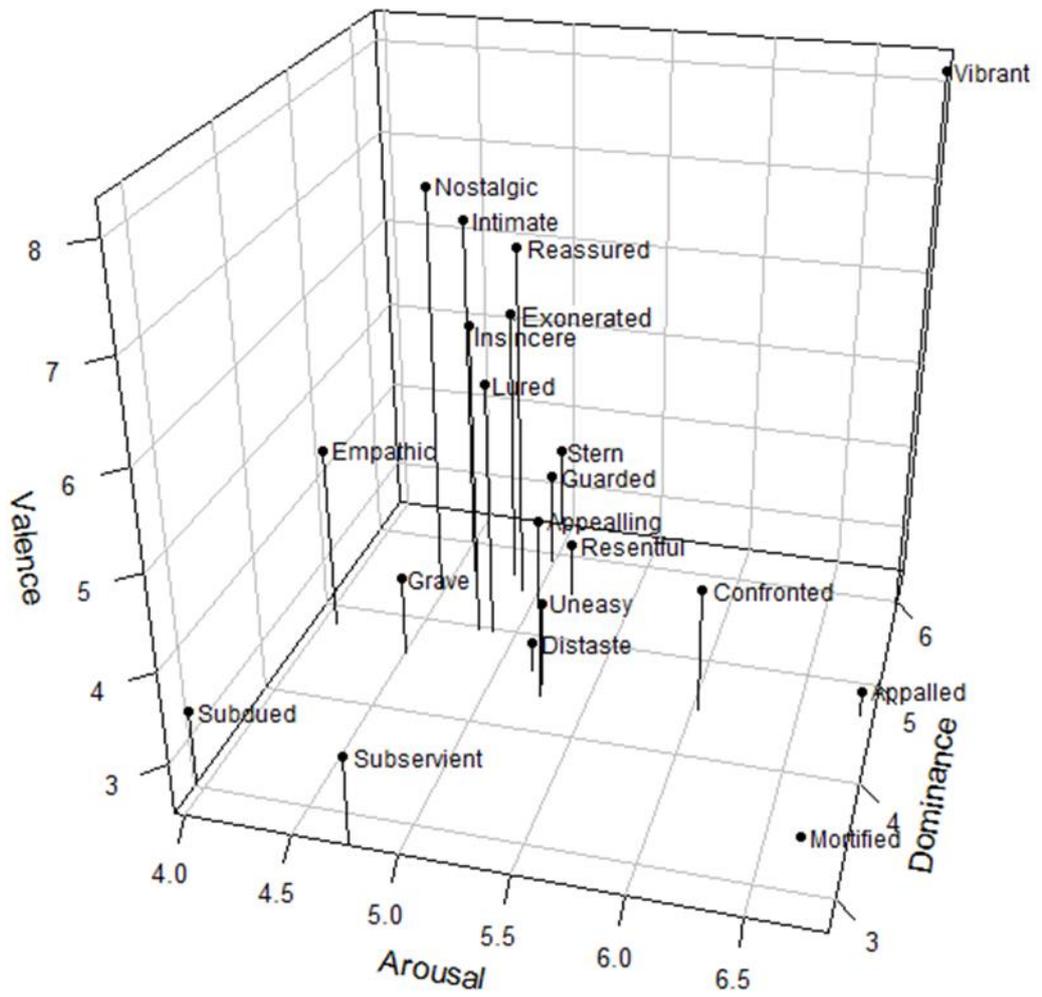


Figure 3. Representation of the 20 complex emotions presented in a 3-dimensional model of valence, arousal and dominance

## Mapping to Basic Emotion

Analysis undertaken to determine the combination of basic emotions contributing to the composition of the complex emotions is presented visually in Figure 4. Within this figure, thicker lines represent more significant associations.

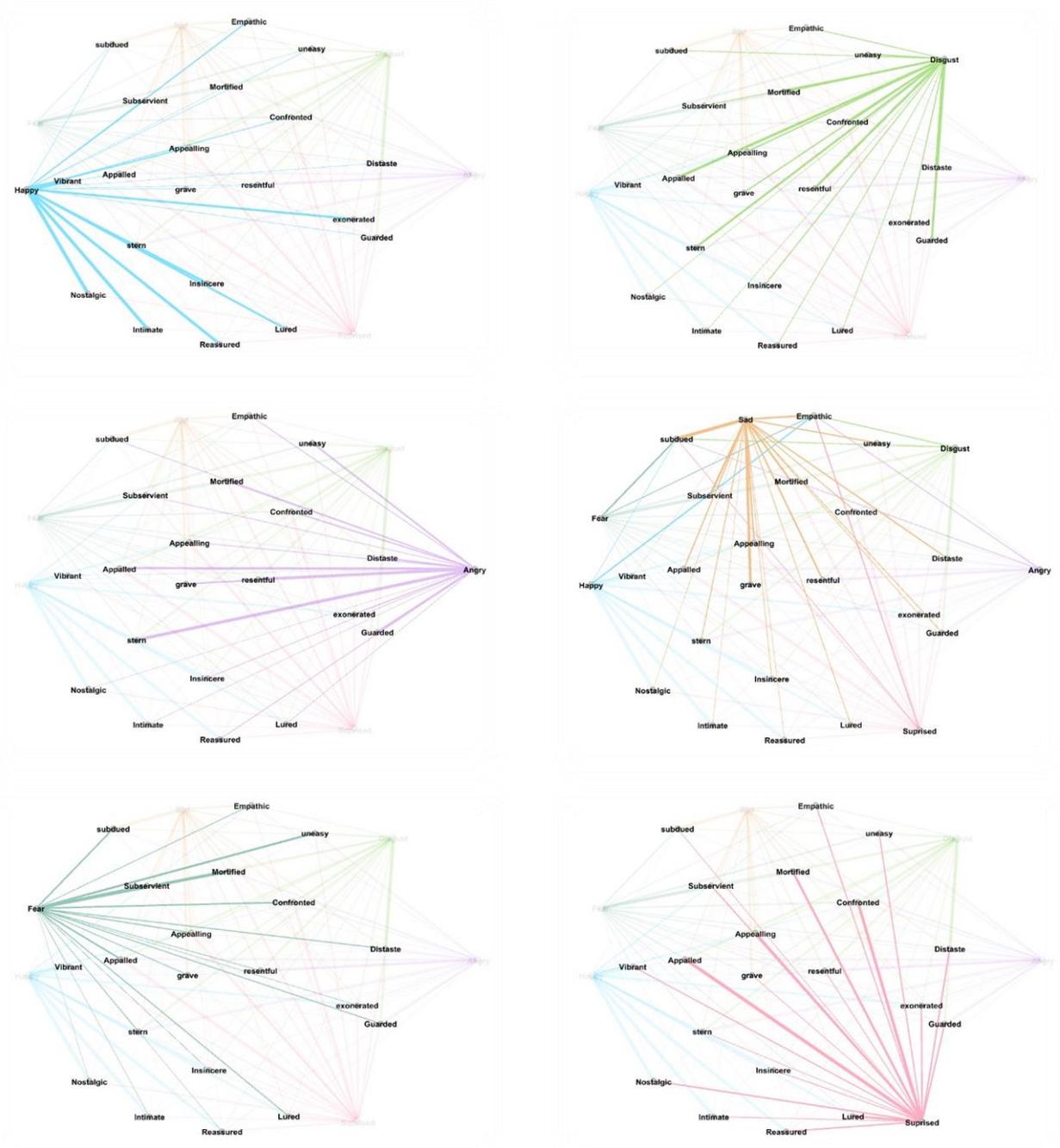


Figure 4. Mapping of complex emotions presented in the Cambridge Mind Reading Face-Voice Battery to the six basic emotions. Colours presented in figure correspond to each of the six basic emotions.

Table 4 provides data on the contribution of the basic emotions to each complex emotion. Higher ratings indicate a greater contribution. A mid-point cut-off of 4.5 or greater was used to categorise emotions based on their basic emotion compositions.

*Table 4. Mean ratings of the contribution of basic emotions to the 20 complex emotional concepts.*

	Anger	Happiness	Sadness	Fear	Disgust	Surprise
Appalled	4.55	1.56	2.73	3.45	5.17	6.12
Appealing	2.13	2.94	3.26	2.64	3.02	3.99
Confronted	3.09	2.14	2.45	3.27	4.03	5.45
Distaste	3.53	1.40	2.96	2.49	6.73	3.16
Empathic	2.24	2.84	3.95	2.05	2.37	2.53
exonerated	2.72	4.47	1.91	1.68	2.66	3.09
Grave	3.37	1.44	5.07	2.21	2.97	2.02
Guarded	4.54	1.56	2.25	2.37	4.57	3.04
Insincere	1.95	4.99	1.83	1.74	2.51	2.17
Intimate	1.62	6.02	1.41	1.50	1.59	2.00
Lured	1.74	4.30	2.01	2.48	1.88	4.20

*Table 4. Continued.*

	Anger	Happiness	Sadness	Fear	Disgust	Surprise
Mortified	2.84	1.28	3.93	5.66	4.57	4.45
Nostalgic	1.49	6.47	1.48	1.30	1.59	3.13
Reassured	2.12	5.52	1.57	1.43	2.00	2.93
Resentful	5.63	1.36	3.39	1.99	4.84	2.19
Stern	5.93	1.42	2.28	1.68	4.32	1.90
Subdued	1.96	1.44	6.18	3.27	2.15	1.86
Subservient	1.99	1.59	4.29	4.91	2.19	2.77
Uneasy	3.62	1.53	2.92	4.23	3.36	2.68
Vibrant	1.15	8.29	1.12	1.18	1.16	2.59

Vibrant, Nostalgic, Intimate, Insincere and Reassured mapped strongly to happy. Subdued and Grave mapped to sad. Subservient mapped to fear and Confronted to surprise.

Stern mapped to angry while Guarded and Resentful mapped to both Anger and Disgust. Lured, Exonerated, Empathic, Uneasy and Appealing complex emotional concepts did not appear to map strongly to any basic emotion.

## **DISCUSSION**

This study maps the complex facial emotions presented in the CAMs to a dimensional and discrete emotion model, providing normative ratings for a typically developing sample. In providing data reducing the complex emotions to their underlying dimensions, or foundational emotions, researchers are provided with the means to 1) exert greater control over their experimental paradigms and 2) gain a richer understanding of the mechanisms underlying emotion perception in typically developing and clinical populations.

Increasing interest has focused on using ecologically valid stimuli, able to adequately capture the complexity of day to day social interaction (Dziobek et al., 2008; Golan et al., 2006; O'Reilly et al., 2016). The complexity inherent in such aims however makes constructing experimental paradigms difficult. The CAMs battery itself was developed by Golan et al. (2006) from a larger stimulus battery of 412 stimuli (Baron-Cohen, Golan, Wheelwright, & Hill, 2004) in order to address major limitations with existing stimulus batteries for investigating emotion perception. In developing the CAMs, a variety of emotional concepts were selected from a larger battery in order to provide a measure of emotion perception which is feasible in regard to administration, but also is capable of providing a measure of the full extent of complex emotion perception (Golan et al., 2006).

Results from the current study may be considered to extend upon these aims, providing the means for a more rigorous investigation of complex emotion perception.

It is shown that the complex emotions differ significantly from each other on the three-dimensions of valence, arousal and dominance. It is perhaps not surprising that valence and approach dimensions were observed to be highly correlated. It is postulated that approach or avoidance behaviour may be facilitated by valence, in that an individual is more likely to approach positively valenced stimuli and avoid negatively valenced stimuli (Krieglmeyer, Deutsch, Houwer, & Raedt, 2010).

In demonstrating that the complex emotions presented in the CAMs can be mapped to a three-dimensional space, it is suggested that categorization of emotions based on their valence alone may not be sufficient to understand the perception of complex emotions. This has important implications not only for research seeking to understand the perception of emotion more generally, but also in elucidating the origins of impairment in clinical conditions. As the CAMs was originally developed to examine complex facial emotion recognition in autistic adults (Golan et al., 2006), these implications are exemplified using insights from this clinical condition, however may also extend to other conditions.

While autistic individuals have a recognised impairment in facial emotion recognition, which has been observed using both basic (Uljarevic & Hamilton, 2013) and complex emotions (Golan et al., 2006), the mechanisms which contribute to such impairment remain largely unknown (Harms, Martin, & Wallace, 2010). Previous research has suggested that autistic individuals may be particularly impaired in the recognition of negatively valenced emotions (Ashwin, Chapman, Colle, & Baron-Cohen, 2006; Wallace, Coleman, & Bailey, 2008) . Findings from the current study show that while a number of emotions were perceived as negative, the majority of these were also perceived as being

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high in dominance and arousal. Thus, it is possible that previously observed impairment in the perception of negative emotion in this population may in fact be driven by altered function of other neurophysiological systems, perhaps related to the perception of dominance or arousal. Indeed, support for such a hypothesis has been found in studies investigating physiological arousal in autistic individuals, finding that autistic individuals may perceive emotional stimuli to be more arousing than typically developing individuals (Bölte, Feineis-Matthews, & Poustka, 2008).

Using a discrete conceptualisation of emotion, it is further shown that the complex emotions presented in the CAMs may also be mapped to the six basic emotions. While many of the complex emotions appear to map strongly to one of the basic emotions, they were also networked to other basic emotions, although to a lesser extent. This may present key limitations in attempts to extrapolate findings based on the basic emotions to real-world social functioning, providing support for the use of complex emotional concepts to understand the nature of emotion perception.

### **Limitations and Future Directions**

The effect of poser gender or participant gender were not examined in this study. Previous evidence has shown that males and females differ in their emotion perception of emotion. Some studies have shown females may be more accurate than males at recognizing subtle facial emotions (Hoffman, Kessler, Eppel, Rukavina, & Traue, 2010) and are more sensitive to emotional expressions (Montagne, Kessels, Frigerio, de Haan, & Perrett, 2005). In regard to the influence of poser gender, during tasks involving judging the thoughts of others, females have an own-gender bias, and are more accurate at recognising the mental states of other females (Wacker, Bölte, & Dziobek, 2017), thus may have an advantage in recognising emotions in stimuli posed by female actors. In the current

sample, there were more female than male participants, perhaps biasing the results of the current study. Future research may benefit from investigating the effect of gender on the perception of complex emotion.

While the CAMs provides a reliable measure of complex FER, it must be noted that the facial emotion stimuli presented within the CAMs also differ in regard to actor ethnicity and age (Golan et al., 2006). It is likely that these factors influence emotion perception in clinical and typical populations (Lipp, Craig, & Dat, 2015). A consistent effect of poser race has been observed during emotion perception, indicating that individuals are more accurate at recognising emotions expressed by individuals from the same cultural and ethnic background (Elfenbein & Ambady, 2002), thus it is possible that differing actor ethnicities may influence the perception of the emotions presented in the CAMs. Descriptively speaking, the standard deviation in dimensional ratings for all 52 emotions appeared relatively high for some emotional concepts, indicative that there may be differences in how emotions presented by individual actors are perceived. It is possible that differences in regard to the gender, age or race of the stimuli may have driven these differences. Future stimulus sets may benefit from systematically including equal representation of poser sex, ethnicity and age across each emotional concept.

In regard to the valence of the stimuli presented, the valence categories for the CAMs found in the current study revealed that 12 emotions were negative and eight were positive. This is similar to the original valence categories provided by the CAMs which included 12 negative emotions, five positive and three neutral emotional concepts (Golan et al., 2006). This is perhaps not uncommon in stimulus sets used to examine emotion perception, which typically contain more negative than positive emotional stimuli (Golan, Baron-Cohen, Hill, & Golan; O'Reilly et al., 2016). The basic emotions for example

consist of primarily negative emotions (Ekman & Friesen, 1976) . It may be beneficial for future stimulus sets to consider including a greater number of positive emotions to ensure that positive complex emotions are adequately represented.

It must also be noted that the CAMs battery consists of not only facial stimuli but also audio stimuli. While these audio stimuli were not examined within the current study, it may be of interest to examine how these audio stimuli may be mapped to a dimensional approach.

In conclusion, investigation using complex emotional concepts is critical to deepen the understanding of emotion perception in typical and clinical populations. The normative dimensional and discrete data presented the CAMs may provide a means for researchers to exert a greater degree of control over their experimental paradigms.

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## CHAPTER FOUR

# COMPLEX FACIAL EMOTION RECOGNITION AND ATYPICAL GAZE IN AUTISTIC ADULTS

This chapter presents a manuscript currently under review

**Black, M. H.**, Chen, N. T., Lipp, O. V., Bölte, S., & Girdler, S. (under review). Brief report: Complex facial emotion recognition and atypical gaze patterns in autistic adults.

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## PREFACE

As found in Chapter Two, though reduced gaze to the eyes during FER tasks is commonly found in autistic individuals, there remains inconsistency in these findings. Further, there appears to be no clear consensus regarding whether aberrant gaze patterns are also observed when considering other facial features, such as the mouth.

It is possible that the lack of consistency in these results may be attributed to the stimuli used in past investigations. The vast majority of research has examined responses to static representations of the six basic emotions (Harms, Martin, & Wallace, 2010). Given that the recognition of basic emotions is postulated to reach maturity in late childhood (Tonks, Williams, Frampton, Yates, & Slater, 2006), autistic adults may not experience difficulty recognizing basic emotions and may instead have difficulty in recognizing more socially demanding complex or nuanced emotions (Smith, Montagne, Perrett, Gill, & Gallagher, 2010). Everyday social interactions are further rarely limited to the six basic emotions but involve subtle and nuanced expressions and movements. It is likely that static representations of basic emotions are limited in terms of their ecological validity and fail to approximate everyday social situations, limiting their ability to elicit true ASD-linked difficulties in FER (Chevallier et al., 2015).

Few studies have examined the eye gaze behaviour of autistic individuals in response to stimuli that exhibit complex (Kirchner, Hatri, Heekeren, & Dziobek, 2011; Rutherford & Towns, 2008; Sawyer, Williamson, & Young, 2012) or dynamic emotions (Han, Tijus, Le Barillier, & Nadel, 2015; Wieckowski & White, 2017) and no study has examined the eye gaze patterns of autistic adults to stimuli that are both complex and dynamic (Black et al., 2017). It is possible that the use of complex, dynamic stimuli may assist in elucidating the

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mechanisms underlying FER in ASD. There is also a need to determine whether previous gaze-based findings observed during previous FER investigation using the basic emotions is replicable in stimuli that have greater social relevance.

The aim of this Chapter was to investigate the eye gaze behaviour of autistic adults during the recognition of complex, dynamic emotions to provide insights in to the mechanisms underlying altered FER performance of autistic individuals. Based on findings from Chapter Two, it was hypothesised that autistic adults would be less accurate at FER than typically developing adults and present with reduced fixation time to the eyes and greater fixation time to the mouth during FER.

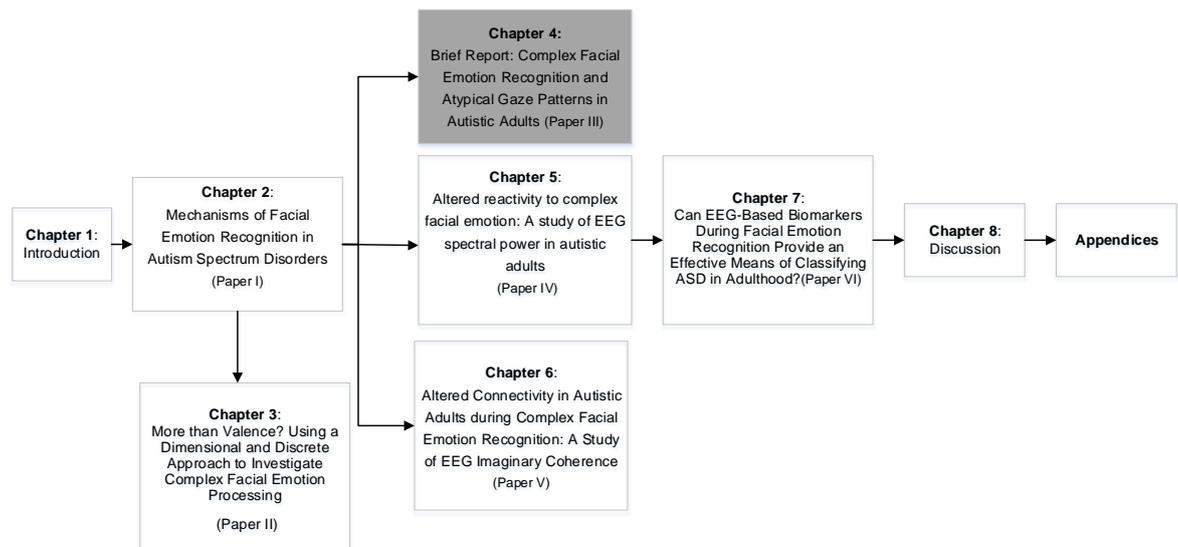


Figure 1. Thesis outline chapter four

**ABSTRACT**

While altered gaze behaviour during facial emotion recognition (FER) has been observed in autistic individuals, the majority of previous research has examined FER using stimuli that may not be commensurate to everyday social difficulties of autistic individuals. There is a need to examine whether atypical gaze during FER extends to more complex emotional concepts. Eye gaze of 20 autistic adults and 20 IQ matched typically developing (TD) participants was examined during an FER task of complex emotion concepts. Autistic adults had a greater fixation time to the mouths of complex emotions, suggesting altered gaze in ASD during FER may extend to ecologically valid contexts.

## INTRODUCTION

Individuals with a diagnosis of Autism Spectrum Disorder (ASD) commonly demonstrate difficulty during facial emotion recognition (FER). During behavioural assessment of FER, autistic adults present with measurable impairment in accurately recognizing the basic emotions (i.e. happiness, anger, fear, disgust, surprise, sadness) compared to typically developing adults (Uljarevic & Hamilton, 2013). This ASD-linked impairment in FER of basic emotions has been shown to be driven, in part, by aberrant gaze behaviour, typically characterized by reduced fixations to the eye regions of basic emotion stimuli (Harms et al., 2010).

While the majority of research to date has been conducted examining ASD-linked FER impairment to the basic emotions, there has been increasing recognition that investigation based on these is emotions alone may not commensurate to the everyday social functioning of autistic adults, as everyday FER often involves more nuanced, subtle and complex emotions (Golan, Baron-Cohen, & Hill, 2006). In addressing these limitations, accumulating research has sought to implement FER task using more complex emotional concepts (such as intimacy or resentment), with findings suggesting that autistic individuals may exhibit difficulties with such stimuli (Golan, Baron-Cohen, & Hill, 2006). While it has been shown that FER impairment indeed extends into more socially relevant and complex emotional concepts (Golan, Baron-Cohen, & Hill, 2006; Golan, Baron-Cohen, Hill, & Golan, 2006), it remains unknown what gaze patterns characterize this impairment. The present study therefore examined the gaze patterns associated with ASD during the recognition of complex emotions. It was predicted that autistic adults, compared to control, would exhibit poorer recognition performance, as well as reduced fixation time to eye regions.

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## **METHODS**

### **Participant Demographics**

Autistic (n=20) and typically developing (n=20) adults participated (Table 1). All autistic adults had a diagnosis of ASD according to the Diagnostic and Statistical Manual – 5<sup>th</sup> Edition (DSM-5) (American Psychiatric Association, 2013). Participants were matched on gender, verbal comprehension index (VCI), Perceptual Reasoning Index (PRI), full-scale IQ and Test of Everyday Attention (TEA) timed visual elevator scores. Groups differed significantly on age, TEA map search one minute, TEA map search two-minute, TEA visual elevator and on autistic trait severity (SRS-2). To account for possible differences in participant age, analysis was also conducted on a stratified sample of matched participants (age  $\pm$ 40 years) which revealed a similar pattern of results.

Table 1. Participant demographics

	TD	ASD	Test of Association
	Mean (SD)	Mean (SD)	
Age years	28.2 (9.5)	24.3 (7.9)	$p=.03$
Gender (Male: Female)	16:4	17:3	$p=.68$
VCI	103.8 (11.9)	101.3 (12.6)	$p=.52$
PRI	113.5 (14.6)	109.5 (18.4)	$p=.45$
FSIQ	109.4 (11.4)	105.7 (12.9)	$p=.45$
Map Search 1 minute	11.1 (2.6)	7.6 (3.7)	$p=.001$
Map Search 2 minute	9.9 (2.7)	6.2 (4.2)	$p=.001$
Visual Elevator	12.4 (2.3)	10.6 (3.0)	$p=.04$
Timed Visual Elevator	10.8 (3.6)	9.2 (4.8)	$p=.23$
SRS-2	35.1 (16.25)	81.5 (24.5)	$p<.01$

Note. TD; Typically Developing, ASD; Autism Spectrum Disorder, SD; Standard Deviation, VCI; Verbal Comprehension Index (composite score), PRI; Perceptual Reasoning Index (composite score), FSIQ; Full Scale Intelligence Quotient (composite score), SRS-2; Social Responsiveness Scale-2.

## **Measures**

### ***Social Responsiveness Scale – Second Edition (SRS-2)***

The SRS-2 Adult Self Report Form (Constantino, 2011) was used to measure autism trait severity. The SRS-2 is a standardized 65- item questionnaire pertaining to social communication, social motivation, social awareness, social cognition, and rigid behaviours. Items are Likert-scaled ranging from 0=not true to 3= almost always true (max score = 195).

### ***Wechsler Abbreviated Scale of Intelligence – Second Edition (WASI-2)***

The WASI-2 (Wechsler, 1999) provided an estimate of performance, verbal, and full-scale IQ. This assessment is an internationally and widely used short version of the full Wechsler Intelligence Scale battery, and includes the subtest for vocabulary, similarities, block design, and matrix reasoning. The WASI-2 is standardised for individuals aged 6 to 89 and has demonstrated good psychometric properties (Wechsler, 1999).

### ***Test of Everyday Attention (TEA)***

Four sub-tests of the Test of Everyday Attention (TEA) (Robertson, Ward, Ridgeway, & Nimmo-Smith, 1994) were administered, providing a measure of visual selective attention and attention switching: map search (1 minute, 2 minutes), visual elevator, and timed visual elevator tasks. The TEA is conceptualised for individuals 18 to 80 years of age. The four subtests applied in this study have adequate reliability (Robertson et al., 1994).

### ***Facial Emotion Recognition Task***

Stimuli were adapted from the Cambridge Mind Reading Face-Voice Battery (CAMs) (Golan, Baron-Cohen, & Hill, 2006), which has previously been used to demonstrate FER difficulties in autistic adults in the normative IQ range (Golan, Baron-Cohen, & Hill, 2006). For this study, a set of 15 complex emotional stimuli were presented in a pseudo-randomized order. Emotions included exonerated, intimate, empathic, vibrant, insincere, resentful, stern, grave, subservient, appalled, confronted, mortified, distaste, lured and appealing. Each trial consisted of an initial 1s fixation cross, followed by a silent video clip (3-5 seconds) of a single actor expressing a complex emotion. Following each video clip, participants were required to identify the emotion by selecting one of four options presented, through selecting their answer on a keyboard. The specific multiple choice options presented were taken from previous work using the CAMs (Golan et al., 2006).

### **Apparatus**

Eye movements were recorded using a SensoMotoric Instruments Remote Eye Tracker Device (R.E.D) (SensoMotoric Instruments (SMI), 2014). Stimulus presentation and behavioural data acquisition was controlled using E-Prime software (Psychology Software Tools, 2016) while eye movement data acquisition was controlled by SensoMotoric Instruments Eye View X software (SensoMotoric Instruments (SMI), 2014). The R.E.D was positioned in front of a 42inch screen on which the stimuli were presented. Participants were seated 70cm from the R.E.D on a height adjustable chair.

### **Procedure**

Ethical approval (Curtin University HREC) and written informed consent was obtained. This study was conducted as part of a larger experimental battery. Participants completed

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the WASI-2 and the TEA, before being familiarized with the eye tracker and FER task. A 9-point calibration procedure was then conducted. Upon adequate calibration, two practice items were shown, followed by the experimental trials of the FER task.

### **Data Preparation and Reduction**

Fixation accuracy checks were conducted on all data with eye movement data excluded if the calibration accuracy was in excess of 1.5° of visual angle (VA). Fixations were defined as consecutive gaze samples held within 1° of VA for a minimum duration of 100ms. Areas of Interest (AOIs) were dynamically defined over the actor's eyes, nose and mouth region for each video frame of each stimulus, using functionalities provided by SMI (SensoMotoric Instruments (SMI), 2014). Polygonal AOIs were used to increase the accuracy of the AOIs in fitting to the features of interest. Each frame was reviewed to ensure the accuracy of AOI coverage. The proportion of total fixation time to each of the eye, nose and mouth AOIs for each stimulus video was then calculated. As the purpose of this study was to examine eye gaze patterns during FER, analysis of fixation data was only conducted for correct response trials.

## **RESULTS**

### **Emotion Recognition Accuracy**

Proportion of correct responses were submitted to Mann-Whitney U tests. Analysis for FER accuracy revealed a near-significant trend indicating that autistic adults were less accurate in recognising complex emotions compared to TD adults ( $U=129$ ,  $Z=-1.95$ ,  $p=.056$ ).

## Fixation Time

Fixation time was subjected to a 2 group (TD, ASD) by 3 AOI (eyes, nose, and mouth) factorial mixed ANOVA with repeated measures on the last factor. The results of the multivariate solution are reported (Pillai's trace) with partial eta square as the measure of effect size.

A main effect of AOI,  $F(1, 37) = 58.41, p < .001, \eta^2 p = .76$ , was observed with overall longer fixations on the eyes ( $p < .001$ ) and nose ( $p < .001$ ) compared to the mouth. This was qualified by a group by AOI interaction  $F(2, 76) = 4.42, p = .02, \eta^2 p = .19$ , with Bonferroni corrected pairwise comparisons indicating that autistic adults fixated longer on the mouth compared to TD adults ( $p = .04$ ). There was no significant difference between groups for the eye AOI ( $p = .14$ ) or the nose AOI ( $p = .8$ ) (Figure 2).

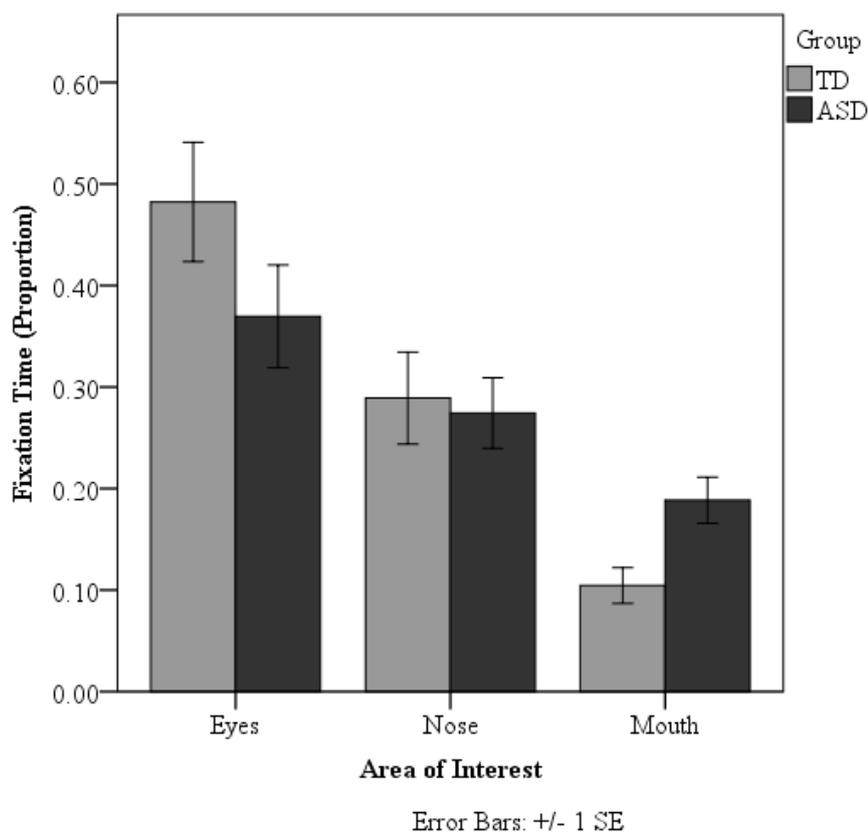


Figure 2. Proportion of fixation time areas of interest.

## DISCUSSION

It was hypothesised that autistic adults would demonstrate poorer FER accuracy and altered gaze behaviour. A marginal effect of was observed indicating that autistic adults had reduced accuracy during the FER task. Findings replicate previously demonstrated ASD impairment in the basic (Uljarevic & Hamilton, 2013) and complex emotions (Golan, Baron-Cohen, & Hill, 2006; Golan, Baron-Cohen, Hill, et al., 2006)

Increased gaze to the mouth was observed in autistic adults. Of critical importance, findings of altered gaze show that atypical gaze behaviour observed during the processing of emotional stimuli may hold direct practical relevance to autistic adults. While findings appear to confirm the presence of aberrant gaze behaviour in ASD, findings regarding

increased time spent fixating on the mouth contribute to heterogeneity within the current literature examining gaze to this region (Black et al., 2017).

Increased gaze to the mouth may indicate altered prioritisation of visual information. The mouth region is arguably more physically salient than other facial features and exhibits a larger degree of movement. Rather than prioritising information based on social salience, autistic adults may prioritise features based on other criteria, such as physical salience (Klin, Jones, Schultz, Volkmar, & Cohen, 2002). Though no pairwise difference was found in the fixation time to the eyes, descriptively speaking it is also possible that increased gaze to the mouth region may be resultant of difficulty retrieving information from the eyes (Neumann, Spezio, Piven, & Adolphs, 2006).

In largely replicating previous findings, it is shown that findings based on static and basic emotion paradigms may indeed commensurate to the everyday functioning of autistic adults. However, the use of complex, dynamic stimuli in the current study elicited gaze behaviour not consistently observed in the current body of literature, namely increased gaze to the mouth, indicating the importance of using ecologically valid stimuli. Future research should continue to use stimuli which is socially and ecologically valid to ensure that findings have a direct practical relevance to the difficulties faced by autistic individuals.

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## EXTENDED DISCUSSION

Further to the discussion provided in Chapter Four, a number of additional factors must be discussed.

Findings of increased time spent fixating on the mouth in absence of a difference in fixations to the eyes contribute to the heterogeneity within the current literature examining the gaze patterns in autistic individuals (Black et al., 2017; Harms, Martin, & Wallace, 2010). While results from some previous studies (Boraston, Corden, Miles, Skuse, & Blakemore, 2008; Neumann, Spezio, Piven, & Adolphs, 2006; Spezio, Adolphs, Hurley, & Piven, 2007; Wieckowski & White, 2017) are in line with the current pattern of results, other studies have found no difference in fixation time to the mouth between autistic individuals and their typically developing counterparts (Falkmer, Bjallmark, Larsson, & Falkmer, 2011; Hernandez et al., 2009; Kirchner, Hatri, Heekeren, & Dziobek, 2011; Pelphey et al., 2002; Rutherford & Towns, 2008; Sawyer, Williamson, & Young, 2012). Past studies reporting differences in gaze behaviour to the mouth have used Gaussian bubbles (Neumann et al., 2006; Spezio et al., 2007), more nuanced emotions such as genuine or posed smiles (Boraston et al., 2008) and dynamic stimuli (Wieckowski & White, 2017), raising the possibility that the observed divergence in gaze towards the mouth may have only been elicited in response to the increased difficulty presented by these stimuli. However, studies employing similar stimuli such as complex emotion (Kirchner et al., 2011; Rutherford & Towns, 2008; Sawyer et al., 2012) or puzzled stimuli (Falkmer et al., 2011), report no differences between autistic and typically developing adults in regard to fixation time to the mouth, suggesting differences in stimuli used across studies may only partially explain the heterogeneity in the current literature.

The social motivation hypothesis proposes that a lack of motivation to engage with social information may contribute to the social impairments observed in ASD (Chevellier, Kohls, Troiani, Brodtkin, & Schultz, 2012; Scott-Van Zeeland, Dapretto, Ghahremani, Poldrack, & Bookheimer, 2010). The increased propensity for viewing the mouth region observed in autistic adults may provide evidence for the social motivation hypothesis of ASD (Chevellier et al., 2012). In typically developing individuals, processing social information activates reward systems which contribute to social motivation (Chevellier et al., 2012) preferentially biasing the processing of socially salient information over non-social information (Birmingham & Kingstone, 2009; Chevellier et al., 2012). As the eyes provide essential information for gaze-cuing, joint attention, face recognition and emotion recognition, the eye region is arguably the most socially salient area for typically developing individuals (Birmingham, Bischof, & Kingstone, 2008). Increased gaze to the mouth region in autistic adults may suggest that the eye region lacks social salience for these individuals or point to a divergence in social motivation processes. Altered functioning of reward processing systems has been observed in both autistic children (Stavropoulos & Carver, 2014) and adults (Delmonte et al., 2012). It is possible that hypo-activation of these reward processes in response to social information may influence the top-down allocation of attention during FER in autistic individuals (Neumann et al., 2006; Spezio et al., 2007), resulting in the altered prioritization of facial regions during FER.

This proposed lack of orientation to socially salient information is consistent with the neural circuitry hypothesis of ASD (Ashwin, Chapman, Colle, & Baron-Cohen, 2006; Aswin, Baron-Cohen, Wheelwright, O'Riordan, & Bullmore, 2007; Schultz, 2005; Volkmar, 2011). Neuroimaging studies suggest that the function of areas of the social brain such as the amygdala and fusiform gyrus may be altered in ASD (Dziobek, Bahnemann, & Convit, 2010; Schultz, 2005). The amygdala in conjunction with the

orbitofrontal cortex and ventral striatum play essential roles in the evaluation of stimuli for social relevance with these structures involved in reward and decision making processes contributing to social motivation and social orientation (Chevellier et al., 2012). During reward processing, autistic individuals have demonstrated altered function of the dorsal striatum (Delmonte et al., 2012), ventral striatum (Scott-Van Zeeland et al., 2010), and the amygdala (Ditcher, Richey, Rittenberg, Sabatino, & Bodfish, 2011), indicating divergent function of social reward systems. The amygdala and fusiform gyrus also engage in feedback processes with the visual cortices (Baron-Cohen et al., 2000; Dziobek et al., 2010), orienting the direction of visual attention. It is possible that the altered function of these structures described by neuroimaging studies may underlie the divergent gaze behaviour observed in the present study, perhaps through influencing the prioritisation and orientation to facial regions. In this case, reduced social motivation or impaired social reward systems may result in reduced tendency to fixate to more socially relevant facial features, such as the eyes.

Interpretation of the current results based on the social motivation hypothesis is limited however by the fact that reduced gaze to the eye region was not observed in autistic individuals in the current study. Nevertheless, despite presenting with similar fixations to the eyes compared to typically developing adults, it is also possible that a may find retrieving information from the eye region challenging (Neumann et al., 2006; Riby, Doherty-Sneddon, & Bruce, 2009; Spezio et al., 2007; Weigelt, Koledewyn, & Kanwishner, 2012). As this study was conducted with adults of average intellectual capabilities, a lack of observable difference in gaze to the eyes between autistic and typically developing adults may be resultant of compensatory strategies evolved along the developmental trajectory (Harms et al., 2010).

If autistic individuals do not readily orient to features based on social salience, they may prioritise features based on other criteria, such as physical salience. The mouth region exhibits a larger degree of movement compared to other facial features. The greater physical salience of the mouth region may attract the attention of autistic individuals to a greater extent than their typically developing counterparts. A preference for physically salient over socially salient information may have been pronounced given the dynamic nature of the stimuli presented in the current study. This may in part explain the significant heterogeneity in the current body of literature surrounding gaze to the mouth region in autistic individuals. Unlike the present study the vast majority of previous literature examining eye gaze behaviour in ASD has used static representations of emotion (Harms et al., 2010), negating their ability to observe the effect of physically salient dynamic information on FER.

As FER abilities underpin other domains of social functioning (Baron-Cohen, 1995; Shamay-Tsoory, 2011; Strand, Downs, & Barbosa-Leiker, 2016), it is likely that difficulties in this domain contribute significantly to the broader social and communication impairments in ASD including empathy (Shamay-Tsoory, 2011) and theory of mind (Baron-Cohen, 1995). The development of FER and other social skills builds on experience and exposure (Leppänen, Nelson, & Charles, 2006), therefore ASD-linked difficulty in FER of positive expressions in youth may lead to inadequate evaluation and response to positive social interaction in autistic adults.

There are a number of areas where future consideration is required. In this study FER performance was examined using a labelling task, with the resultant possibility that performance on these tasks did not solely tap into the perception of emotion but was also be influenced by the participants' verbal abilities. While autistic and typically developing

samples were matched on cognitive measures, including verbal abilities, further research may benefit from the use of non-labelling tasks such as those involving matching (Palermo, O'Connor, David, Irons, & McKone, 2013). On a related note, the use of a multiple-choice variant on complex emotions may have reduced the intended complexity of the stimuli. Further limitations relate to the sample of individuals included in this study who all had average or above average IQ scores, limiting the extrapolation of the results to samples of autistic individuals with co-occurring intellectual impairment. It is also possible that results were limited by the small sample size of individuals included in this study (n=40). While the present study examined gaze during emotion processing, future research may seek to compare and contrast the gaze patterns which occur during non-emotional face processing (e.g. when recognising identity), to further elucidate the emotional specificity of the present effects.

Future studies investigating ASD-linked impairments in the processing of complex emotion may also benefit from corroborating gaze data with other measures. For example recent evidence suggests that mirror neuron activity is associated with the perception of action and biological motion (Rizzolatti & Craighero, 2004; Ulloa & Pineda, 2016) and may be altered in autistic individuals (Perkins, Stokes, McGillivray, & Bittar, 2010). Further research may benefit from elucidating the potential role and function of this system in directing attention to social information in autistic adults.

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## CHAPTER FIVE

### ALTERED REACTIVITY TO COMPLEX FACIAL EMOTION: A STUDY OF EEG SPECTRAL POWER IN AUTISTIC ADULTS

This chapter presents a manuscript currently pending publication

**Black, M. H., Iyer, K. K., Albrecht, M., Lipp, O. V., Chen, N. T., Bölte, S., . . .**  
Girdler, S. (Pending publication). Altered reactivity to complex facial emotion: A study  
of EEG spectral power in autistic adults.

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## PREFACE

It was observed in Chapter Four that autistic adults showed aberrant gaze behaviour during the FER of complex, dynamic stimuli. Similar to previously conducted studies in the basic emotions, it was hypothesised that altered function of neural circuits involved in social motivation or the processing of socially salient information may contribute to an atypical pattern of gaze observed during FER tasks. It was further hypothesised that the complex, dynamic nature of the stimuli used assisted in eliciting this atypical gaze behaviour.

In Chapter Five, EEG is used to investigate the neural correlates associated with complex, dynamic FER in autistic adults. The Alpha, Theta, Beta and Mu rhythm frequency band power of autistic and typically developing adults is investigated during a complex, dynamic FER task.

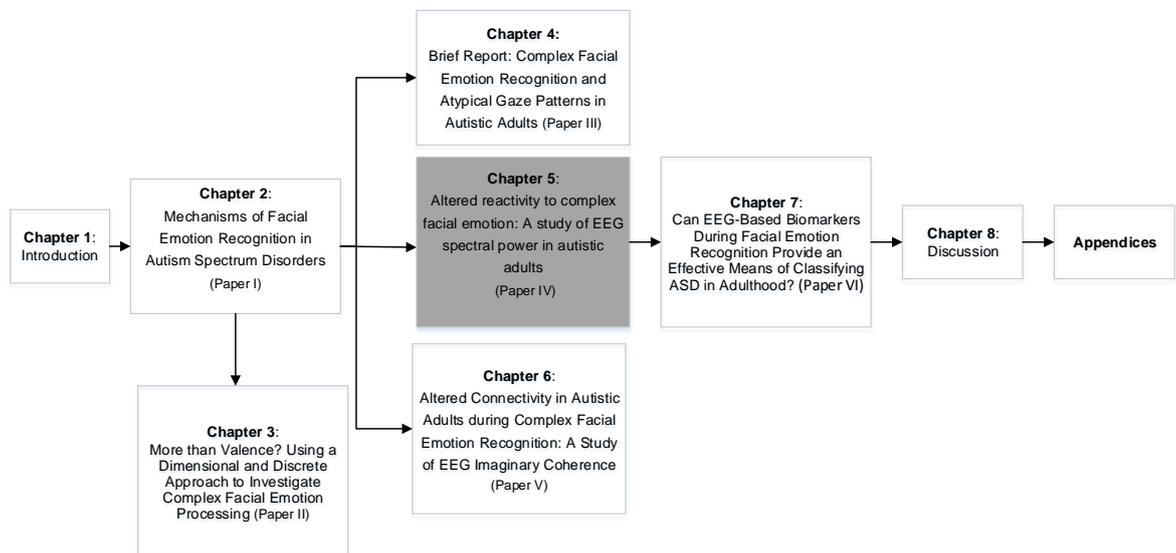


Figure 1. Thesis outline chapter five

**ABSTRACT**

The mechanisms underlying facial emotion recognition (FER) in adults diagnosed with Autism Spectrum Disorder (ASD) are poorly understood. Electrophysiological responses to complex, dynamic facial expressions may provide insights into this facet of social functioning in ASD. Neural oscillations of 22 autistic adults and 23 matched typically developing (TD) adults were examined during a complex, dynamic FER task. Autistic adults were less accurate during positive FER which elicited increased theta power in the left occipital lobe and an altered pattern of hemispheric activation in the alpha frequency. They displayed a global increase in theta power during negative expression recognition and trends for altered differentiation of mu rhythm activity. Results suggest hyper-reactivity and an enhanced withdrawal motivation response to emotional stimuli in autistic adults.

## INTRODUCTION

A growing body of evidence suggests that individuals diagnosed with Autism Spectrum Disorder (ASD) experience difficulties during facial emotion recognition (FER) (Harms, Martin, & Wallace, 2010; Uljarevic & Hamilton, 2013). Across the developmental trajectory, and extending into adulthood, autistic individuals show measurable alterations in FER, even after accounting for age, gender or intellectual capacity (Lozier, Vanmeter, & Abigail, 2014; Uljarevic & Hamilton, 2013).

Given the complex, hierarchical nature of brain networks involved in emotion processing (Adolphs, 2009), the ability for electrophysiology (EEG) to capture the dynamic communication between neural networks of the brain (Başar, 2006) makes it a valuable measure to assist in elucidating the neural correlates contributing to ASD-linked FER impairment. Oscillatory patterns generated within and between brain regions are purported to reflect a range of cognitive functions. Alpha activity (8-13 Hz) has been associated with inhibitory control (Klimesch, Sauseng, & Hanslmayr, 2007) and desynchronizes, for example, during tasks that require attention (Klimesch, 1997, 1999) or semantic memory (Klimesch, 1997, 1999). Investigation of alpha activity during emotion paradigms has suggested that right frontal activity may be associated with withdrawal motivation while left frontal activity may be associated with approach motivation (Güntekin & Basar, 2014). Beta (16-30 Hertz) activity has been linked with visual attention processes, particularly in the occipital cortex (Gola, Magnuski, Szumska, & Wrobel, 2013), while theta activity, generated in frontal (Raghavachari et al., 2006) and limbic networks (Buzsaki, 2002; Talk, Kang, & Gabriel, 2004; Woodnorth, Kyd, Logan, Long, & McNaughton, 2003) has been associated with working memory (Klimesch, 1999; Klimesch, Doppelmayr, Pachinger, & Ripper, 1997), attention (Klimesch, 1999), cognitive

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control (Cavanagh & Frank, 2014; Nigbur, Cohen, Ridderinkhof, & Sturmer, 2012) and the processing of emotional valence (Aftanas, Varlamov, Pavlov, Makhnev, & Reva, 2002; Diao, Qi, Xu, Fan, & Yang, 2017).

Despite the potential for electrophysiological investigation to provide insight into the mechanisms of ASD-linked FER impairment, few studies to date have examined the spectral frequency oscillations of autistic individuals during FER. During paradigms using static representations of the basic emotions (happiness, anger, sadness, fear, disgust, surprise), autistic individuals show reduced theta synchronization and coherence (Tseng, Yang, Savostyanov, Chien, & Liou, 2015; Yeung, Han, Sze, & Chan, 2014), pointing to possible atypical modulation of attention to emotion stimuli (Yeung et al., 2014), or in the subcortical unconscious processing pathways involved in the recognition of emotion (Tseng et al., 2015). While less conclusive, alterations in alpha and beta oscillations have also been found during FER, with greater beta 2 (16 – 20 Hz) synchronization in posterior regions and alpha desynchronization in autistic adults (Yang, Savostyanov, Tsai, & Liou, 2011). Alterations in mu rhythm suppression, which has been linked to the mirror neuron system (Fox et al., 2006), and is evident during motor activation and observation of movement in others (Pineda, 2005; Rizzolatti & Craighero, 2004; Rizzolatti, Fabbri-Destro, & Cattaneo, 2008) has also been found in a single study in a non-clinical sample of participants with autistic-like tendencies (Cooper, Simpson, Till, Simmons, & Puzzo, 2013). When examining mu suppression, typically measured over sensorimotor regions within the 8-12 Hz (McFarland, Miner, Vaughan, & Wolpaw, 2000; Perry, Bentin, Bartal, Lamm, & Decety, 2010) or 8-13 Hz frequency range (Perry, Stein, & Bentin, 2011), individuals with high autistic traits were characterised by reduced lower beta band activity in response to depictions of happiness when compared to a low trait group. Of particular

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interest, individuals with high autistic traits showed an opposite pattern of mu suppression to low autistic trait individuals. While high autistic trait individuals showed greater low beta mu suppression to angry faces compared to happy, individuals with low autistic symptomology showed greater mu suppression to happy faces (Cooper et al., 2013).

While these previous studies provide promising findings that may help to understand the mechanisms underlying FER alteration in autistic adults, these previous studies investigating the neural underpinnings of FER in autistic individuals has been largely confined to using static representations of the six basic emotions (happiness, anger, sadness, fear, disgust, surprise) as stimulus material (Black et al., 2017; Harms et al., 2010). Recognition of these basic emotions reaches maturity in childhood and adolescence, with the ability to accurately recognise more complex emotions (such as resent, intimacy, sincerity) perhaps developing later in adolescence (Tonks, Williams, Frampton, Yates, & Slater, 2006). Complex FER development is driven by a need to function in an increasingly complex social world, with proper development reliant on improvements in understanding contextual and belief based information (Harris, 1989; Tonks et al., 2006), and on the maturation of socially sensitive neural structures and networks (Lidquist, Wager, Kober, Bliss-Moreau, & Barrett, 2012). Further issues may arise when using prototypical static expressions which may also be limited in respect to ecological relevance. Day to day social interaction relies on the timely recognition of an emotion that is often nuanced, dynamic and complex (Arsalidou, Morris, & Taylor, 2011). Neuroimaging investigation has shown that dynamic emotion, compared to static representations, produces divergent neural activity (Kilts, Egan, Gideon, & Hoffman, 2003; Trautmann, Fehr, & Herrman, 2009). Dynamic emotion elicits stronger and more

wide-spread recruitment of neural networks, arguably reflecting the increased ecological validity provided by dynamic stimuli (Trautmann et al., 2009).

In light of this previous research, investigation of the ASD-linked alterations of FER in adults using stimuli that is not only complex, but also dynamic, is essential. This study aimed to examine the neural oscillations of autistic adults during the recognition of a socially-relevant set of complex, dynamic facial emotion stimuli. Unlike previous studies which have largely examined coherency and synchrony, this study examines the spectral frequency power of alpha, theta, beta and mu rhythm bands to provide insights into the processes underlying FER in ASD.

## **MATERIALS AND METHODS**

### **Participants**

Thirty-three TD adults and 33 autistic adults, were recruited via research institutions, service providers and social media in Perth, Western Australia. Autistic adults were eligible for inclusion if they presented with a clinical services diagnoses of ASD according to the Diagnostic and Statistical Manual for Mental Disorders 5th Edition (American Psychiatric Association, 2013) or equivalent diagnosis of Autism Spectrum Disorder, Asperger Syndrome or Pervasive Developmental Disorder according to the DSM-IV-TR (American Psychiatric Association, 2010). Autistic adults were excluded if they presented with a co-occurring diagnosis of epilepsy, intellectual disability or major depressive disorder. The TD group was matched to the autistic group on chronological age, gender, and intelligence quotient. TD participants with a disability or mental health diagnosis were excluded, as well as those who reported a score greater than 67 (T score 60) on the Social Responsiveness Scale-2 (SRS-2 (Bölte, 2012; Constantino, 2011) in order to increase

sensitivity to effects. Data from 10 TD participants was excluded due to comorbidities (n=2), high autism traits (n=4), incomplete datasets (n=1) and incomplete EEG data (n=3). Data from 11 autistic participants were also excluded due to incomplete EEG data (n=3), no formal ASD diagnosis (n=4), significant inattention during the trial (n=1) and incomplete data (n=4). The final sample comprised 22 autistic adults (3 female) and 23 TD adults (7 female). The autistic group consisted of individuals with a confirmed diagnosis of Asperger Syndrome (11/22) or Autism Spectrum Disorder (11/22). Autistic and TD participants were matched on age, gender, Full scale IQ, verbal IQ, and performance IQ as shown in Table 1. Groups differed significantly on both subtests of the map search of the TEA (Robertson, Ward, Ridgeway, & Nimmo-Smith, 1996), with autistic participants having a lower response score.

*Table 1. Sample characteristics*

	ASD mean (SD)	TD Mean (SD)	Test of Association
n	22	23	
Age years	25.18 (9)	25.07 (5.63)	p=0.68
Gender (male : female)	19:3	16:7	p=0.18
SRS-2 (T Score)	66.15 (9.3)	47.8 (8.6)	p<0.01
VCI	102 (11.64)	103.32 (11.88)	p=0.60
PRI	109.9 (15.06)	112.32 (14.11)	p=0.60
FSIQ	106.35 (10.5)	108.55 (11.21)	p=0.45
TEA map Search 1 minute (SSE)	7.45 (3.62)	10.5 (3.13)	p=0.01
TEA map Search 2 minute (SSE)	6.3 (4.1)	9.23 (3.02)	p=0.01
TEA visual elevator (SSE)	11.05 (2.87)	12.55 (2.3)	p=0.06
TEA visual elevator time (SSE)	9.4 (5.01)	10.9 (3.5)	p=0.22

Note. TD; Typically Developing, ASD; Autism Spectrum Disorder, SD; Standard Deviation, VCI; Verbal Comprehension Index (composite score), PRI; Perceptual Reasoning Index (composite score), FSIQ; Full Scale Intelligence Quotient (composite score), SRS-2; Social Responsiveness Scale-2.

## **Ethical Considerations**

Ethical approval was obtained from the Human Research Ethical Committee at Curtin University, Perth Western Australia (HR52/2012) and complied with the guidelines set by the National Health and Medical Research Council, Australia. Participants were provided with information outlining the aims and procedures of the study prior to providing written informed consent. Participants were informed of their ability to withdraw from the study at any point without the provision of justification or prejudice. Participants were provided with their choice of two cinema tickets or a \$40 gift card as a token of appreciation for their involvement.

## **Measures**

### ***Facial Emotion Stimuli***

The stimuli were selected from the Cambridge Mind Reading Face Voice Battery (Golan, Baron-Cohen, & Hill, 2006) (CAMs) which was derived from an original battery of 412 complex emotions from the Mind Reading stimuli set developed by Baron-Cohen, Golan, Wheelwright, and Hill (2004). This study employed a subset of complex emotion stimuli, inclusive of two practice and 15 test items of 3-7 second silent video clips of actors expressing a facial emotion. Individual stimuli included a single actor (9 female and 6 male) expressing a complex emotion. Videos were selected on the basis of providing a spectrum of positive and negative complex emotions with four positive (exonerate, empathic, intimate, vibrant), two neutral (lured, appealing) and nine negative (resentful, stern, grave, subservient, appalled, confronted, insincere, mortified, distaste) emotions included in the stimulus battery. For consistency across stimuli, all videos were presented for 5 seconds, for videos 3-4 seconds in length ( $k=6$ ), stimuli remained static on the screen

for the remaining 1-2 seconds. Following the presentation of each clip, participants were asked to select from four options, which emotion they believed was portrayed in the clip. The four word responses presented by Golan et al. (2006) were used.

### ***The Social Responsiveness Scale – Second Edition***

Autistic traits were measured using the Social Responsiveness Scale – Second Edition Adult Self Report Form (SRS - 2). It provides a self-report estimate of dimensional autistic-like traits across five domains (social communication, social cognition, social awareness, social motivation, autistic mannerisms) using 65 items presented on a four-point Likert scale format generating a total score of 0-195 with higher values indicating increasing autistic traits. The SRS-2 has been shown to have good to excellent inter-rater reliability (.61 – .92) and strong internal consistency ranging from .94 to .96 (Constantino, 2011) and cross cultural validity (Bölte, 2012).

### ***Wechsler Abbreviated Scale of Intelligence – Second Edition (WASI-2)***

General intellectual level (IQ) was measured via the Wechsler Abbreviated Scale of Intelligence – Second Edition (WASI-2), standardized for individuals aged 6-89 years, consisting of four subtests of the full length Wechsler, namely vocabulary, similarities, block design and matrix reasoning, and providing a measure of performance IQ, verbal IQ and full-scale IQ (Wechsler, 1999).

### ***The Test of Everyday Attention (TEA)***

The Test of Everyday Attention provides a means of assessing attentional capacities across several clinical domains of attention including selective attention, attention switching and sustained attention (Robertson et al., 1996). The complete TEA consists of eight subtests

(map search, telephone search, visual elevator task, lottery task, elevator counting, elevator counting with distraction and dual task telephone search) designed to provide an ecologically valid assessment of everyday attention functioning (McAnespie, 2001; Robertson et al., 1996). Two subtests of the TEA, the Map Search and Visual Elevator Counting subtests, were administered to participants to measure visual selective attention and attention switching, respectively. The Map Search subtest requires participants to locate symbols on a coloured map within a two minute period (broken into two one minute segment). One point is assigned to participants per symbol located during the two minute period with a total possible score of 80 being achievable. The Visual Elevator Counting subtest presents participants with a series of drawings of elevator doors which they must count to establish the building level which they are currently on. Arrows are presented within the series of elevators, signalling that the direction of counting must change (decreasing or increasing). An accuracy score and a timing score are calculated from this subtest. An accuracy score (maximum score of 10) is calculated based on the participants accuracy in correctly counting the elevators, while the timing score is calculated based on the total time taken for correct responses divided by the number of switches (arrows) for items in which the participant was correct (lower values represent greater performance) (Robertson et al., 1996). The complete TEA is standardized for adults aged 18-30 years of age and is reliable with test-retest reliability ranging from .61 to .90 (Robertson et al., 1996).

### **Apparatus**

Electrophysiological data were recorded using a 40-channel Compumedics Neuroscan EEG Quik Cap with Ag/AgCl electrodes. The 40-channel electrodes labels included 14 frontal electrodes (Fp1, Fp2, F7, F3, Fz, F4, F8, FT7, FC3, FCz, FC4, FT8, FT9, FT10),

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six central electrodes (C3, Cz, C4, CP3, CPz, CP4), six temporal electrodes (T3, T4, TP7, TP8, T5, T6), five parietal electrodes (P3, Pz, P4, PO1, PO2), three occipital electrodes (O1, Oz, O2) and six supplementary electrodes (HEOL, HEOR, VEOU, VEOL, A1, A2). Electrodes were injected with conductive gel and the impedance reduced to below 5 kOhms. Supplementary electrodes were placed on the outer Canthi of each eye and above and below the left eye to record horizontal and vertical electroculogram (EOG). EEG data was sampled continuously at 1000 Hz. Default internal hardware filters for DC component removal and antialiasing were used. EEG data were collected with the reference at Cz and virtual ground at AFz. Acquisition was controlled through Scan 4.5 (Neuroscan, 2014) and EEG then further processed offline (see below). E-Prime was used to control stimulus presentation and behavioural data collection (Psychology Software Tools, 2016). EEG data collected using Scan 4.5 were timestamped to the beginning and end of stimuli presentation. Specific event tags (including subject keyboard response), encoded using E-Prime hardware instruction and timing triggers, were used for data synchronization. Drifts in video synchronization and subject response were minimal (<5% of subject epochs) and drift was auto-corrected in EEG post-processing to ensure EEG trial accuracy. Participants were seated in front of a 42" television screen.

## **Procedure**

During EEG preparation, participants completed the vocabulary and similarity sub tests of the WASI-2 (Wechsler, 1999). Participants then viewed two practice and 15 test items of the CAMs stimuli. The TEA was completed as a distractor task during other emotion recognition tasks not presented here. Stimulus videos were presented in a pseudo-randomised order, preceded by a fixation cross presented for 1 second. Following the presentation of each video, four word options appeared on the screen, with participants

requested to select the emotion portrayed from one of the four options by pressing the corresponding key on the keyboard (Figure 2).

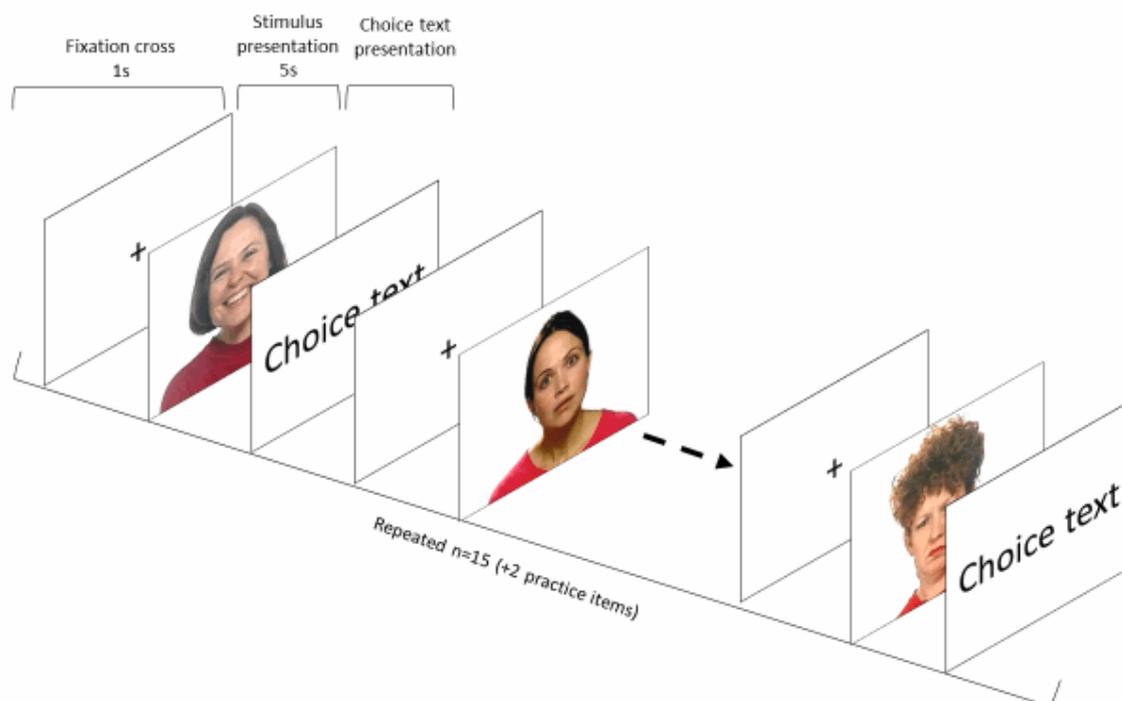


Figure 2. Presentation of stimuli

## EEG Offline Processing and Analysis

Data were re-referenced using the Reference Electrode Standardization Technique (REST) (Yao, 2001); a reference independent procedure whereby EEG data are referenced to a point at infinity (Yao, 2001). An initial bandpass filter (0.5 and 40 Hz) was then applied to the data, before undergoing Independent Components Analysis (ICA) (Jung et al., 2000). ICA is an automated process using blind source separation to identify artefact laden epochs of data (e.g., due to muscle movement) with corrections performed via

decomposition. (Jung et al., 2000). An automated constrained ICA (cICA) approach was used to identify and remove eye –blink artefacts recorded via EOG electrodes. The cICA approach employs a mean squared error estimate to identify and subtract eye-blink and other artefact sources via deflation (Lu & Rajapakse, 2005).

Following pre-processing, 5500 ms epochs of EEG data were extracted, covering a 500 ms baseline period and 5000 ms emotion recognition stimulus period. Power spectral densities for four predefined frequencies were obtained via Fast Fourier Transform (FFT) for the following frequencies: theta  $\theta$  (4-8 Hertz), alpha  $\alpha$  (8-15 Hertz), beta  $\beta$  (16-30 Hertz) and mu  $\mu$  (8-12 Hertz) using the Welch's Power Spectrum Density estimate (PSD) equation (Welch, 1967) below.

$$\text{PSD (EEG (t))} = \frac{1}{N} \|X(e^{jw})\|^2$$

Baseline power for each frequency band was calculated using the entire 500 ms pre-stimulus fixation cross viewing period. Stimulus-induced power during the 5000 ms stimulus interval were baseline corrected on a trial-by-trial basis for each frequency utilising the baseline power across each electrode to correct for any baseline drift prior to stimuli exposure.

For each subject, the median values for each frequency and electrode were first extracted for corrected and incorrect trials for positive and negative emotions. Here median values were extracted in order to provide a more accurate representation of the total spectra. Mean values in each median power spectra were then calculated. EEG data were processed using Matlab with the EEGLAB signal processing library (The MathWorks Inc, 2017).

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## Data Preparation and Statistical Analysis

Data analysis was undertaken using SPSS version 20. Statistical analyses of the sample demographics were first undertaken using Mann-Whitney U or independent samples t-tests to determine if the autistic and TD groups were comparable.

Accuracy during the FER task was examined using repeated measures ANOVA (rmANOVA) with emotional valence (positive, negative) as a within-subjects factor and diagnostic group as a between-subjects factor. Neutral expressions (k=2 stimuli) were not considered as many of the participants responded incorrectly to both stimuli resulting in a limited number of epochs for subsequent EEG analysis.

Statistical analysis of EEG data was undertaken only for correctly identified expressions to ensure that the EEG data corresponded with accurate emotion recognition. On average, TD participants correctly identified 7.3 negative epochs and 3 positive epochs while autistic participants identified 7.04 negative epochs and 2.33 positive epochs. Given that differing regions of the brain engage in the diverse processes involved in the perception of emotion (Adolphs, 2002; Adolphs, Damasio, Tranel, & Damasio, 1996) electrodes were grouped into regions of interest (ROI) according to region and hemisphere. Spectral analysis was performed by converting each response per EEG trial stimuli, per channel via FFT analysis and averaged to derive an individual spectra response for a particular region montage (e.g., left frontal region), these montages were then averaged over specific stimuli valences (positive, negative). Region montages used in analysis included: (right frontal =  $\acute{x}$ (FP2, F4, F8, FC4, FT8, FT10), left frontal =  $\acute{x}$ (FP1, F3, F7, FC3, FT7, FT9), right central =  $\acute{x}$ (C4, CP4), left central =  $\acute{x}$ (C3, CP3), right temporal =  $\acute{x}$ (T4, TP8, T6),

left temporal =  $\acute{x}$ (T3, TP7, T5), right parietal =  $\acute{x}$ (P4, PO2), left parietal =  $\acute{x}$ (P3, PO1), right occipital =  $\acute{x}$ (O2), left occipital =  $\acute{x}$ (O1)

Frequency data deviated significantly from normality for all frequency bands, therefore box cox transformations were undertaken on the data to improve normality prior to analysis (Box & Cox, 1964).

Preliminary analysis of alpha, theta, beta and mu frequency data were undertaken on baseline EEG data to investigate group differences at baseline. This preliminary analysis was conducted using an rmANOVA within each frequency band with the factors group (ASD, TD), hemisphere (left, right), and region (frontal, central, temporal, parietal, occipital) with repeated measures on the latter two factors.

Analyses of alpha, beta and theta frequencies during the emotion recognition phase were conducted for each frequency band and stimulus valence separately with the factors of group (ASD, TD), region (frontal, central, temporal, parietal, and occipital) and hemisphere (left, right) with repeated measures on the last two factors.

As mu rhythm shows maximal topography over lateralised central electrodes (i.e., C3 and C4), analysis investigating group differences in mu rhythm activity during the emotion recognition phase consisted of a group (ASD, TD) by hemisphere (C3, C4) by valence (positive, negative) rmANOVA, where hemisphere and valence were treated as within-subjects factors.

For all rmANOVA analyses, where assumptions of sphericity were violated, multivariate solutions were used. Partial  $\eta$  squared is reported to provide a measure of effect size.

## RESULTS

### Accuracy in Emotion Recognition

Autistic adults were less accurate at the FER task compared to TD adults  $F(1, 43) = 6.87$ ,  $p = 0.01$ . There was a near-significant trend for a group by emotion interaction  $F(1, 43) = 4.01$ ,  $p = 0.05$ ,  $\eta^2 p = 0.09$  with Bonferroni corrected pairwise comparisons revealing that this was driven by autistic adults being less accurate than TD adults during positive FER  $p = 0.01$ .

### Baseline

During baseline viewing of the fixation cross, no main effects were found between autistic adults and TD adults in alpha  $F(1, 43) = 0.47$ ,  $p = 0.5$ ,  $\eta^2 p = 0.01$ , mu  $F(1, 43) < 0.01$ ,  $p = 0.94$ ,  $\eta^2 p < 0.01$  or beta frequencies  $F(1, 43) = 0.72$ ,  $p = 0.79$ ,  $\eta^2 p < 0.01$ . The main effect of group for the theta frequency trended towards significance  $F(1, 43) = 3.19$ ,  $p = 0.08$ ,  $\eta^2 p = 0.07$  with the autistic adults showing greater theta power than TD participants.

### Theta

There was a significant group by region by hemisphere three-way interaction during FER of positive emotion,  $F(4, 172) = 5.51$ ,  $p < 0.01$ ,  $\eta^2 p = 0.11$ . Bonferroni corrected pairwise comparisons of the three-way interaction revealed that this was driven by autistic participants having greater theta power in the left occipital region  $p = 0.02$  compared to TD adults (Figure 3). There was also a near-significant interaction between hemisphere and group, two-way interaction,  $F(1, 43) = 3.68$ ,  $p = 0.06$ ,  $\eta^2 p = 0.08$ ; however, Bonferroni corrected pairwise comparisons revealed no effects. No main effect of group was found,

$F(1, 43) = 1.32, p = 0.26, \eta^2p = 0.03$ , as were main effects for region:  $F(4, 172) < 0.05, p = 0.1, \eta^2p < 0.01$  and hemisphere:  $F(1, 43) = 0.08, p = 0.78, \eta^2p < 0.01$ .

In response to negative emotion, autistic participants had greater theta power during FER than their TD counterparts, main effect  $F(1, 43) = 5.27, p = 0.03, \eta^2p = 0.11$ . No other effects were found  $F < 1.067, p > 0.37, \eta^2p < 0.02$  during negative FER (Figure 3).

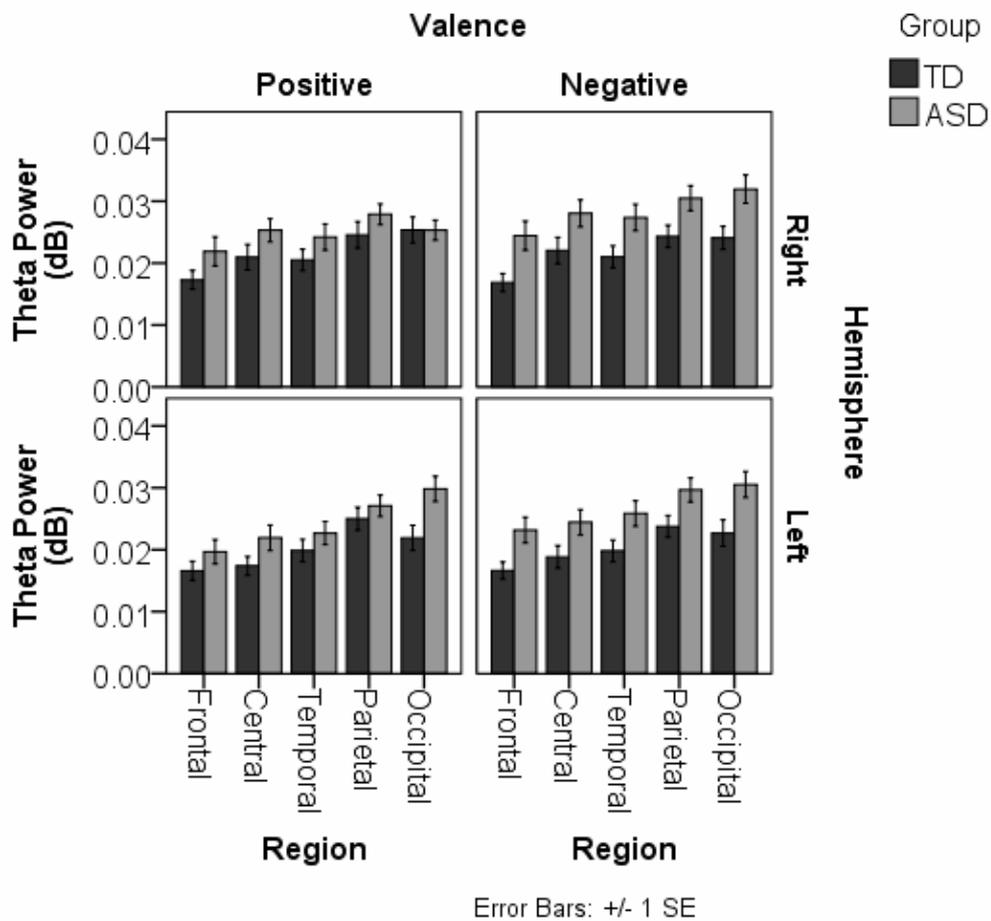


Figure 3. Theta power in autistic and TD groups in response to positive and negative emotion across hemisphere and region.

## Alpha

In response to positive emotion, a three-way interaction between region, hemisphere and group was found,  $F(4, 172) = 4.05, p = 0.01, \eta^2 p = 0.09$ . While pairwise comparisons of this interaction revealed no significant differences between autistic and TD adult responses to positive emotion, it was observed that autistic adults showed greater alpha power over the right hemisphere compared to the left hemisphere in frontal, parietal, central and temporal regions. By comparison, TD adults showed greater alpha power in the left hemisphere compared to the right hemisphere in frontal, parietal, central and temporal regions. There was no main effect of group  $F(1, 43) = 0.76, p = 0.38, \eta^2 p = 0.018$ . No other effects were found to be significant during positive FER  $F < 1.056, p > 0.31, \eta^2 p < 0.024$ . There was no main effect of group on alpha power during negative FER  $F(1, 43) = 0.43, p = 0.52, \eta^2 p = 0.01$ , nor were any other effects significant  $F < 1.12, p > 0.35, \eta^2 p < 0.025$ .

## Beta

There were no group differences when responding to positive emotion, main effect  $F(1, 43) = 0.25, p = 0.88, \eta^2 p = 0.01$ , or negative emotion, main effect,  $F(1, 43) < 0.01, p = 0.95, \eta^2 p < 0.01$ . No other main effects or interactions were found during positive  $F < 1.28, p > 0.28, \eta^2 p < 0.03$  and negative  $F < 1.71, p > 0.2, \eta^2 p < 0.04$  FER.

## Mu

Analysis of the mu rhythm at C3 and C4 electrodes revealed no main effect of group  $F(1, 43) = 0.15, p = 0.7, \eta^2 < 0.01$ , however a significant valence by group interaction was observed  $F(1, 43) = 7.32, p = 0.01, \eta^2 = 0.15$ . Between group pairwise comparisons for this interaction showed no significant effects for positive ( $p = 0.1$ ) or negative ( $p = 0.37$ ) emotions, however, when exploring within group pairwise comparisons, it was found that

this significant interaction was driven by a trend for TD participants to have greater mu power to negative emotions compared to positive ( $p=0.06$ ) and a trend for autistic participants to have greater mu power to positive emotion compared to negative ( $p=0.06$ ) (Figure 4).

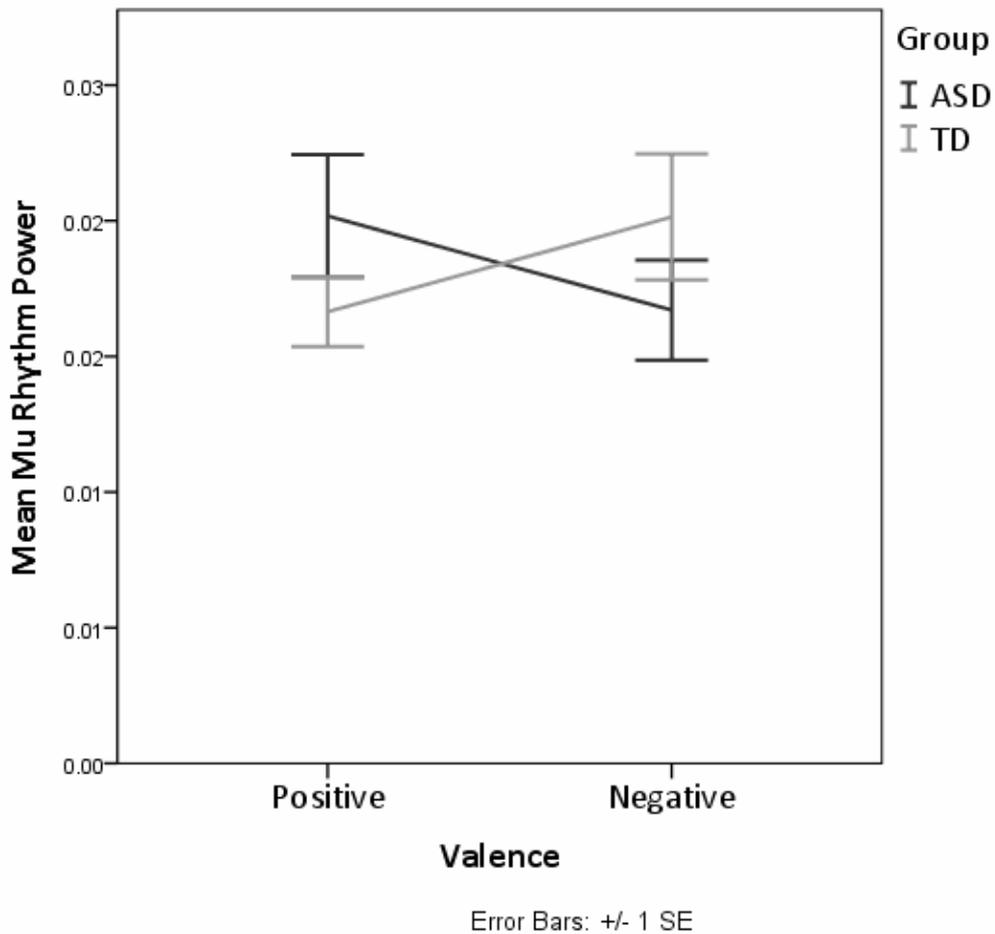


Figure 4. Mean mu rhythm power for autistic and TD participants according to valence.

## DISCUSSION

Autistic adults were less accurate at recognising complex dynamic emotional expressions, a finding consistent with a number of previous studies (Golan et al., 2006; Harms et al., 2010; Lozier et al., 2014; Uljarevic & Hamilton, 2013). Autistic adults also displayed

altered power in the theta, alpha and mu frequency bands in response to emotional stimuli compared to TD adults. In particular, autistic adults showed increased theta power over frontal and occipital regions, and an atypical pattern of hemispheric activation in the alpha frequency during the recognition of positive emotions and a general enhancement of theta power during the recognition of negative emotions. Altered mu rhythm in autistic adults was characterised by greater mu power to positive emotion compared to negative emotion, the converse of TD adults.

Theta power has been associated with the processing of valence during either emotion recognition or the viewing of affect-laden images (Aftanas et al., 2002; Diao et al., 2017). Threatening stimuli, such as pain-related images or anger expressions, have been shown to elicit elevated theta power in central and occipital regions (González-Roldan et al., 2011). Further, greater theta power in occipital (Aftanas et al., 2002) and frontal (Balconi, Brambilla, & Falbo, 2009a, 2009b) regions have been observed during the viewing of highly arousing stimuli. These theta responses in anterior and posterior regions during the processing of high intensity and arousing stimuli suggest that theta activity in these areas may represent increased arousal in response to the motivationally significant stimuli (Aftanas et al., 2002) and the elicitation of vigilance mechanisms (Balconi et al., 2009a). Given that autistic adults demonstrated increased theta power in occipital regions during recognition of both positive and negative expressions, it is possible that autistic adults perceived emotions of both valence to be more arousing or possibly threatening compared to TD adults. Such a notion converges with previous studies that have examined autonomic responses to facial stimuli in ASD, whereby enhanced autonomic arousal has been observed in autistic individuals across a range of measures such as skin conductance and heart rate variability (Cheshire, 2012). These differences in physiological reactivity

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have been suggested to index social-emotional alterations in ASD (Bölte, Feineis-Matthews, & Poustka, 2008).

It is possible that an elevated theta in autistic adults may also be due to reduced attenuation of the initial reactive response during the processing of emotional stimuli. While amygdala response habituates to emotional stimuli over time (Breiter et al., 1996), this may not be true for autistic individuals (Kleinhans, Clark, Todd, Roderick, & Greenson, 2009). Reduced habituation to emotional stimuli may result in anxiety or an increased threat response to stimuli (South & Rodgers, 2017). A reduced ability to adequately attenuate responses to emotional stimuli may be in part due to a lack of expertise with or previous exposure to socially significant stimuli. Social motivation theories propose that autistic individuals may not readily orient to social information (Chevallier, Kohls, Troiani, Brodtkin, & Schultz, 2012). In support, we have eye tracking data on the sample employed in the present study showing preferential orientation to physical aspects of the emotional stimuli in autistic adults (Black et al., in prep). If autistic adults do not typically orient to social aspects of emotional stimuli, then being directed to do so for the purposes of experimental tasks may elicit this elevated response.

Conversely, increased frontal cortical activation (especially in the midcingulate cortex) is associated with both the elicitation of negative affect and cognitive control (Shackman et al., 2011), with a prominent role for mid-frontal theta in co-ordinating the adaptive brain responses required for action monitoring and selection (Cavanagh & Shackman, 2015). Adaptively, greater theta to negative stimuli supports the monitoring of alternative behavioural responses (Shackman et al., 2011), which may result in conflict between selecting avoidant adaptive behaviours that reduce the discomfort associated with negative

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affect and behaviours that enhance success with the task at hand at the expense of affective discomfort.

The notion that autistic adults may have greater reactivity to emotional stimuli may be further supported by findings in the alpha frequency. Alpha asymmetry, particularly in the frontal region, has been associated with approach-withdrawal hypotheses of emotion (Adolphs, von Glischinski, Wannemuller, & Margraf, 2017; Briesemeister, Tamm, Heine, & Jacobs, 2013; Coan & Allen, 2004) and is postulated to mediate emotional responding (Coan & Allen, 2004). Withdrawal related stimuli elicits greater right frontal lateralization, with postulations that left frontal lateralization is associated with approach-related stimuli (Briesemeister et al., 2013; Coan & Allen, 2004). During positive FER, atypical alpha asymmetry in autistic adults was characterised by greater right hemispheric activity, whereas greater left hemispheric lateralization was observed in TD adults. In line with these previous findings, it is possible that the atypical pattern of alpha lateralization observed in autistic adults is reflective of a greater tendency to evaluate positive stimuli negatively and an enhanced withdrawal motivation response (Adolphs et al., 2017).

In addition to the increase in cortical theta, group differences in the modulation of the mu rhythm were observed. Mu rhythm activity has been suggested to provide a measure of activation of the mirror neuron system (Fox et al., 2006) with larger suppression becoming more apparent with greater recruitment of the system (Pineda, 2005). The Mirror Neuron System activates in response to observing action in others (Rizzolatti & Craighero, 2004), contributing to the understanding of action (Iacoboni & Dapretto, 2006; Rizzolatti & Craighero, 2004; Rizzolatti et al., 2008), and is associated with several cognitive functions, including theory of mind (Schulte-Rüther, Markowitsch, Fink, & Piefke, 2007), and emotion recognition (Enticott et al., 2014). Differentiation of mu suppression in this

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sample of autistic adults may corroborate previous reports of dysfunction of the mirror neuron system in autistic individuals (Bernier, Dawson, Webb, & Murias, 2007; Cooper et al., 2013; Perkins, Stokes, McGillivray, & Bittar, 2010; Rizzolatti et al., 2008) and contribute to the FER difficulty this population experiences.

Although the current study provides some insights into the underlying mechanisms of FER in autistic individuals, a number of limitations must be noted. First, while we sought to recruit a matched TD sample, it is noted that autistic and TD groups were found to differ on TEA performance. While such differences in attention are well documented in ASD, the extraneous influence of attentional differences cannot be fully ruled out. As the analysis presented in this study was primarily interested in examining the neural correlates of FER, only responses where the participant was correct were included in the EEG spectral power analysis, possibly impacting the power of the analysis, particularly given the unbalanced distribution of positive and negative emotions. Future research should seek to employ a balanced stimuli set, enabling more rigorous investigation of the impact of emotional valence on neural correlates. As some stimulus videos were also minimally altered to ensure consistency in stimuli presentation timing (5 seconds), it is possible that this static component may have potentially influenced the results. Given that this study sought to understand the nature of ASD-linked FER alteration using more socially relevant stimuli, the ecological nature of this stimuli may have potentially involved a trade-off in experimental control. For instance, the dynamic nature of the stimuli may have had significant influences on the EEG responses of participants and may have had a particular impact on the mu rhythm activity. Mu rhythm activity has been associated with action observation along with more complex socially relevant skills such as theory of mind (Oberman, Pineda, & Ramachandran, 2007). Thus, it is possible, that the ecological nature

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of the stimuli may have elicited extraneous oscillation responses reflective of more basic action perception atypicalities. Furthermore, while mu rhythm has been suggested to be a valid index of the mirror neuron system (Fox et al., 2006), future research is warranted as there has been some disagreement regarding its utility (Hobson & Bishop, 2016). Thus, caution must be exerted during the interpretation of the current mu rhythm results in relation to the mirror neuron system.

## **CONCLUSION**

Differences in theta, alpha and mu frequencies in response to dynamic emotional faces were observed in autistic adults. Autistic adults showed greater right alpha activity and increased left occipital power during the processing of positive emotion and a global increase in theta power in response to negative emotion. These findings may indicate a hyper-reactivity to emotional stimuli and a greater withdrawal motivation response to emotions. Altered differentiation of the mu rhythm to emotional stimuli in autistic adults may also suggest that atypical function of the mirror neuron system may also contribute to ASD-linked FER alterations.

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**CHAPTER SIX****ALTERED CONNECTIVITY IN AUTISTIC ADULTS DURING  
COMPLEX FACIAL EMOTION RECOGNITION: A STUDY OF  
EEG IMAGINARY COHERENCE**

This chapter contains a manuscript published with IEEE Engineering in Medicine and  
Biology

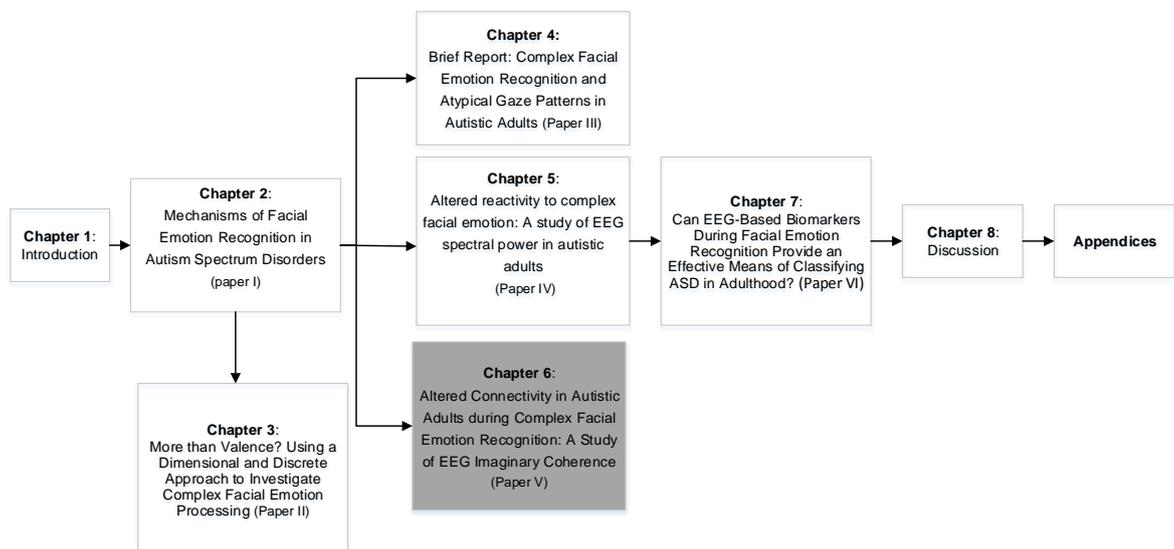
**Black, M. H.**, Almabruk, T., Albrecht, M., Chen, N. T., Lipp, O. V., Tan, T., . . .  
Girdler, S. (2018). Altered connectivity in autistic during complex facial emotion  
recognition: A study of EEG imaginary coherence. *40th Annual International  
Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*.



## PREFACE

In Chapter Five, EEG spectral frequency power revealed atypical neural responses during FER in autistic adults, perhaps indicative of hyper-reactivity or enhanced withdrawal responses to emotional stimuli.

In Chapter Six, findings of atypical response during FER tasks in autistic adults are further examined through applying imaginary coherence analysis techniques.



*Figure 1 Thesis outline chapter six*

Coherency provides a measure of the functional connectivity between brain regions. Coherence is calculated by evaluating how correlated signals arising from two different regions are (Nolte et al., 2004). When the relative amplitude and phase between two spatially distinct electrode pairings is similar, it is reflective of connectivity or communication between these two brain regions (Figure 2).

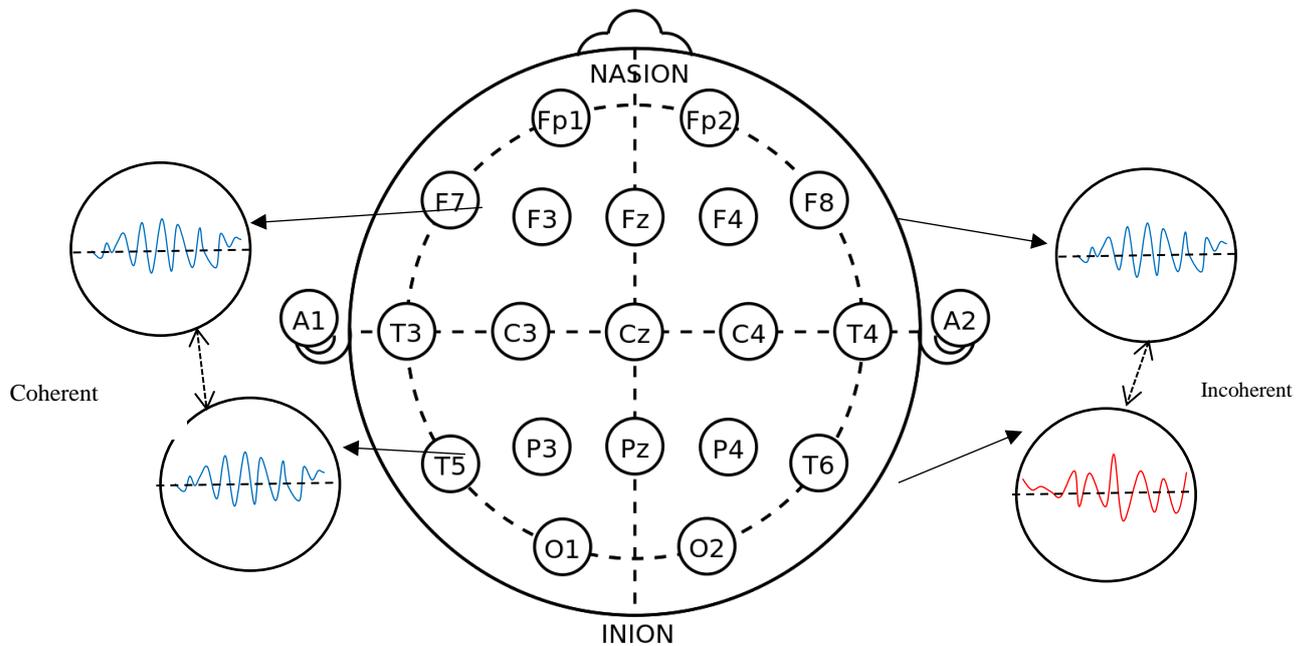


Figure 2. Example of coherence using 10-20 EEG system. Diagram adapted from source available at: [https://commons.wikimedia.org/wiki/File:21\\_electrodes\\_of\\_International\\_10\\_20\\_system\\_for\\_EEG.svg](https://commons.wikimedia.org/wiki/File:21_electrodes_of_International_10_20_system_for_EEG.svg)

In conducting this study, the imaginary part of coherency was used. Estimates based on typical coherence measures are limited by issues related to volume conduction (Nolte et al., 2004). Volume conduction issues arise due to the fact that sources of electrical activity generated by neural sources must travel through brain tissue and the skull, becoming diffused. This can contribute to volume conduction artefacts which may provide 'false' estimates of coherency. Estimates based on the imaginary part of coherency as described by Nolte et al. (2004) essentially eliminate these issues, providing a measure of coherency which is more reflective of true activity within the brain.



**ABSTRACT**

Difficulties in Facial Emotion Recognition (FER) are commonly associated with individuals diagnosed with Autism Spectrum Disorder (ASD). However, the mechanisms underlying these impairments remain inconclusive. While atypical cortical connectivity has been observed in autistic individuals, there is a paucity of investigation during cognitive tasks such as FER. It is possible that atypical cortical connectivity may underlie FER impairments in this population. Electroencephalography (EEG) Imaginary Coherence was examined in 22 autistic adults and 23 typically developing (TD) matched controls during a complex, dynamic FER task. Autistic adults demonstrated reduced coherence between both short and long range inter-hemispheric electrodes. By contrast, short range intra-hemispheric connectivity was increased in frontal and occipital regions during FER. These findings suggest altered network functioning in ASD.

## INTRODUCTION

Difficulties in facial emotion recognition (FER) are commonly observed in individuals diagnosed with Autism Spectrum Disorder (ASD), a neurodevelopmental condition associated with alterations in social communication and interaction (American Psychiatric Association, 2013). However, the mechanisms underlying these impairments in FER remain inconclusive (Black et al., 2017). As FER relies on the function of distributed networks within the brain (Adolphs, 2002), it is possible that deficits in FER may arise from more complex interactions within and between networks and may not be fully explained by dysfunction of individual structures.

Atypical cortical connectivity has been commonly observed in ASD (Schwartz, Kessler, Gaughan, & Buckley, 2017). Given that the integration and transfer of information between and within neural networks is essential for cognition, altered connectivity may be a mechanism contributing to the expression of the core diagnostic characteristics of ASD, including impairments in FER.

To date the majority of coherency investigations in autistic individuals have used resting state conditions, with a dearth of connectivity studies during cognitive tasks (Schwartz et al., 2017). Further, drawing conclusions regarding atypical connectivity in ASD has been hindered by the use of differing tasks, participant groups and measures (Nair et al., 2014). Some investigations of connectivity in ASD during FER using coherence and synchrony have found atypical connectivity in autistic individuals, particularly in the theta band (typically 4-8 Hertz) (Tseng, Yang, Savostyanov, Chien, & Liou, 2015; Yang, Savostyanov, Tsai, & Liou, 2011; Yeung, Han, Sze, & Chan, 2014). Weaker delta/theta synchronization during the viewing of static basic emotions (such as happiness, anger,

fear, disgust, surprise, sadness) has been observed in autistic adolescents and adults (Tseng et al., 2015) with similarly weaker theta synchronization found in autistic adults during the viewing of happy, angry and neutral faces (Yang et al., 2011). Reduced right frontal theta modulation has also been observed in autistic children during the recognition of static basic emotions (Yeung et al., 2014).

Differences in alpha and beta frequencies have also been observed; however, they are less consistent (Tseng et al., 2015; Yang et al., 2011). These previous investigations have been limited to the use of stimuli which may not provide an ecologically valid assessment of FER in autistic adults. Given the developmental trajectory of FER (Lawrence, Campbell, & Skuse, 2015), it is possible that the use of more complex emotions such as intimacy, jealousy, or guilt presented dynamically may provide a more socially-relevant assessment of FER for autistic adults.

The coherency of autistic and typically developing adults was examined during the FER of complex, dynamic stimuli to determine if altered connectivity contributes to ASD-linked FER impairments during the processing of more socially relevant stimuli.

## **METHODS**

### **Participants**

Data from 22 autistic adults and 23 typically developing (TD) adults were included in this study. Autistic adults were diagnosed with Autism Spectrum Disorder/High Functioning Autism (n=11) and Asperger Syndrome (n=11). Autistic adults and TD participant groups had a mean age of 25.2 (SD 9) years and 25.1 (SD 5.6) years respectively. Groups were matched on age ( $p=0.68$ ), gender ( $p=0.18$ ), verbal IQ ( $p=0.60$ ), performance IQ ( $p=0.60$ )

and full-scale IQ ( $p=0.45$ ). Groups differed significantly on the map search subtests of the Test of Everyday Attention ( $p=0.01$ ) and on autistic traits measured by the Social Responsive Scale – second edition ( $p<0.01$ ).

## **Measures**

### ***Facial Emotion Stimuli***

The stimuli set consisted of 15 silent videos of adult actors expressing complex emotions derived from the Cambridge Mind Reading Face-Voice Battery (Golan, Baron-Cohen, & Hill, 2006). Stimuli were between 3 to 5 seconds in length. All stimuli were presented for 5 seconds with images remaining static on the screen for the remaining 1-2 seconds if the videos were 3-4 seconds in length. Stimuli consisted of 4 positive (exonerated, empathic, vibrant, intimate), 9 negative (resentful, stern, grave, subservient, insincere, mortified) and 2 neutral (lured, appealing) emotions.

### ***Wechsler Abbreviated Scale of Intelligence – Second Edition***

The WASI-2 (Wechsler, 1999) provided a measure of intelligence. The WASI-2 provides measures of verbal, performance and full-scale IQ based on four subtests (vocabulary, similarities, block design and matrix reasoning). The WASI-2 has been validated for use with individuals aged 6-89 years of age (Wechsler, 1999).

### ***Social Responsiveness Scale – Second Edition***

The SRS-2 provided a self-reported measure of autistic traits. The SRS-2 asks participants to rate statements relating to social communication and reciprocity on a 4-point Likert scale, providing a self-report measure of autism symptomatology (Constantino, 2011).

### ***Test of Everyday Attention***

To provide a measure of attention in the groups, the Map Search and Elevator Counting subtests of the TEA were used to provide measures of selective and sustained attention (Robertson, Ward, Ridgeway, & Nimmo-Smith, 1996).

### **Data Acquisition**

Stimulus presentation and behavioural data acquisition were controlled via E-Prime software (Psychology Software Tools Inc, 2016) with stimuli presented on a 106.7cm TV screen. A 40-channel Compumedics Neuroscan EEG Quik Cap with Ag/AgCl electrodes and NeuroScan 4.5 Software (Compumedics Neuroscan, 2014) was used to record EEG data with a reference at Cz and virtual ground at AFz. EEG signals were recorded with an impedance of 5k Ohms or lower and sampled at 1000 Hertz. A NuAmps 40-channel amplifier was used to amplify the EEG signal with default internal hardware filters used for DC component removal and antialiasing. Vertical and horizontal electroculograms (EOGs) were recorded via electrodes placed on out outer canthi of each eye and above and below the left eye.

### **Procedure**

The experimental procedures involving human subjects described in this paper were reviewed and approved by the Curtin University Human Ethics Research Committee. Written informed consent was obtained from participants. Vocabulary and similarities WASI-2 subtests were administered during preparation of the EEG. Participants were orientated to the FER task and were asked to complete two practice items followed by 15 FER test items. The FER stimuli were presented in a pseudo-randomized order. A fixation cross was presented for 1 second prior to the presentation of each stimulus. Following

each stimulus, four complex emotion labels were presented on the screen with participants required to select one of the four labels they believed described the stimulus by indicating their answer on a keyboard.

## **Data Analysis**

EEG data were initially processed to obtain the frequency bands. This process included an initial band pass filter (0.5 and 40 Hertz) and independent component analysis to subtract ocular artefacts. Analysis included 33 electrodes which were referenced to CZ. Data were baseline corrected to the last 500ms of fixation cross viewing prior to stimulus presentation. As stimuli were presented for 5 seconds, EEG data during the stimulus presentation were then segmented into 1000ms epochs relative to stimulus onset, with each stimulus providing 5 epochs.

As analysis were undertaken only when participants correctly identified the emotion, the number of segments of EEG data provided by each participant varied as a function of their accuracy. The EEG data for each participant was averaged for each condition (positive, negative) prior to calculating coherence. Calculations described in Almabruk, Iyer, Tan, Roberts, and Anderson (2015) were then used to estimate the imaginary part of coherency at alpha (8-15 Hz), beta (16-30 Hz) and theta (4-8 Hz) bands. As we aim to compare between the connectivity of autistic and TD groups per condition (e.g. ASD (positive) vs. TD (positive)), epoch counts were randomly matched. Therefore, 22 epochs were used in the analysis from each dataset.

Imaginary part of coherency between signals  $x$  and  $y$  as introduced in Nolte et al. (2004) is calculated by assessing their auto ( $s_{xx}$ ,  $s_{yy}$ ) and cross spectrum ( $s_{xy}$ ) as shown in Eq. (1).

$$icoh_{xy}(f) = \text{imag}\left(\frac{\langle s_{xy}(f) \rangle_n}{\sqrt{\langle s_{xx}(f) \rangle_n \langle s_{yy}(f) \rangle_n}}\right), \quad (1)$$

We extracted coherence matrices for each group (ASD, TD), frequency (alpha, beta, and theta) and valence (positive, negative) resulting in 12 coherence matrices in total. These matrices presented EEG connectivity values for all possible electrode pairings, resulting in matrices with dimension of 33x33. Following the removal of diagonal features due to the symmetry of the matrices, each matrix resulted in 528 unique coherence values, with values in the range [-0.94, 0.93].

Analyses on these matrices were conducted with the aim of identifying coherency differences between autistic and TD adults during FER of positive and negative emotion in the three frequency bands. For each frequency band and valence, the TD matrix was subtracted from the ASD matrix to obtain a difference matrix (dif). Prior to subtracting the coherency matrices, imaginary coherence values were normalized.

Trivial connectivity differences were then omitted by applying thresholds known as coherence deviation. Calculating these thresholds as shown in Eq. (2) depends on the epoch counts and frequency counts in each band.

$$\sigma = \frac{1}{\sqrt{(\text{number of epochs}) * (\text{number of frequencies})}} \quad (2)$$

Coherency values above threshold of the difference matrices were visualized in figures labelled with their electrode pairs (Fig.3 (a)). Green pixels refer to an increase in the coherency of the ASD compared to the TD group which means that  $d_{(x,y)} > \sigma$  (i.e. ASD  $(icoh_{xy}) - \text{TD} (icoh_{xy}) > \sigma$ ). While red pixels refer to decrease in the coherency of ASD

group compared to TD group, which means that  $d_{(x,y)} < -\sigma$  (i.e. ASD ( $icoh_{xy}$ ) - TD ( $icoh_{xy}$ )  $< -\sigma$ ). These green and red pixels were then depicted in topography figures (Fig 3(b)).

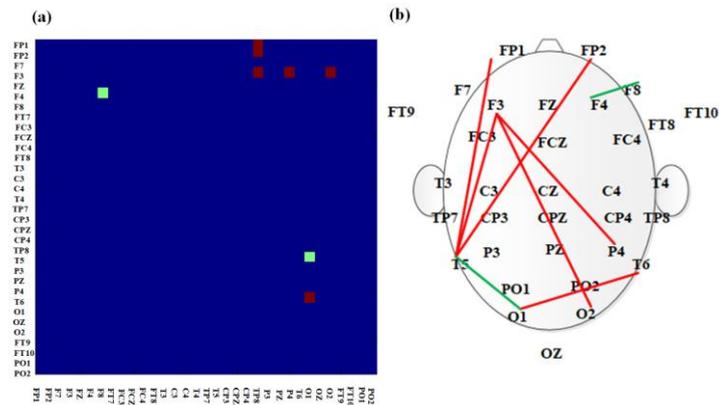


Figure 3. (a) Green pixels represent increment in EEG electrode connectivity of autistic compared to TD groups. Red pixels represent decrements in connectivity of the autistic compared to the TD group. (b) Topography figure for the electrode pairs identified in (a).

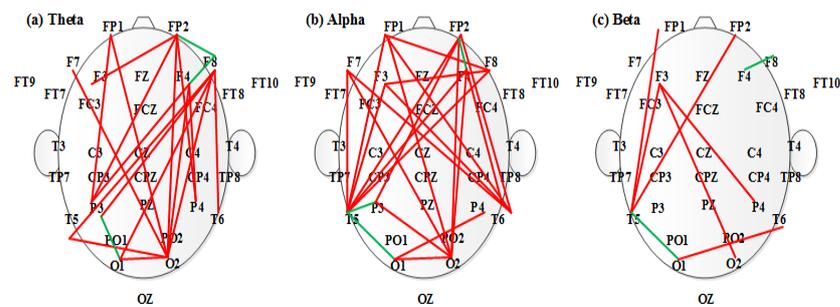
## RESULTS

### Positive Emotion

Figure 4 displays the topographical representation of the imaginary coherency differences between autistic and TD adults during FER. Autistic adults had reduced short range inter-hemispheric coherency in frontal regions in theta (FP1/F8, F7/F8 and F3/F8) and alpha (FP1/F8, F7/F8, F3/F4, F3/F8) frequencies. In the beta frequency, reduced short range and mid-range inter-hemispheric coherency was found in in parietal (P3/P4) and parietal-temporal regions (P3/T6). Across frequency spectra, autistic adults demonstrated reduced anterior-posterior connectivity between inter-hemispheric electrode pairs (theta: F4/P3, beta; F8/T5, F4/T5, F4/O1, FP1/P4, F3/P4, FP1/T6, F3/T6, F7/P4, F7/T6) and intra-hemispheric pairs (theta: F4/O2, F4/P4; alpha: F7/O1, beta: F8/T6, FP2/P4, FP2/T6,



coherency was observed between frontal-temporal (F7/T5, FP1/T5, F3/T5, FP2/T6, F4/T6) and frontal-occipital (FP2/O2, F4/O2) electrode pairs. In beta, reduced intra-hemispheric coherency was restricted to frontal-temporal (FP1/T5, F3/T5) electrode pairs. Greater coherency in autistic adults was observed in parietal-occipital electrode pairs in the theta frequency (P3/O1), temporal-parietal electrode pairs (T5/P3) in the alpha frequency and temporal-occipital (T5/O1) pairs in the alpha and beta frequencies. Increased short range intra-hemispheric coherency was also found in the frontal regions (theta: FP2/F8, F8/F4, alpha; FP2/F4, beta; F8/F4).



*Figure 5. Topographical representation of electrode connectivity between autistic and TD groups during negative FER.*

## DISCUSSION

Autistic adults demonstrated reduced long range global coherency with concurrent coherency increases in short range frontal and occipital regions during FER, supporting the hypothesis that altered network function contributes to ASD-linked FER impairment. An effect of stimulus valence on coherency differences between groups was evident. Autistic adults showed reduced coherency primarily in alpha and theta bands during negative FER, with reduced coherency during positive FER being more evident in the beta

frequency. This may indicate that while connectivity in autistic adults is altered during FER generally, the mechanisms contributing to FER impairment may vary in accordance with emotional valence.

Decreased coherency in all frequency bands in autistic adults was characterized by reduced coherency between anterior and posterior electrode pairs. It is possible that this pattern of reduced coherency indicates atypicalities in the transfer of information between posterior visual processing areas with higher order affective and decision-making networks in frontal regions, required for FER processes (Adolphs, 2002). Similar patterns of reduced anterior-posterior coherency have been found in theory of mind tasks in autistic individuals (Kana, Keller, Cherkassky, Minshew, & Just, 2009), postulated to reflect increased autonomy of posterior networks in an attempt to remediate the lack of input from frontal regions (Kana et al., 2009). The notion that autistic adults had reduced input from anterior regions, resulting in greater autonomy of posterior networks may be further supported by the observations of increased parietal-occipital and occipital-temporal connections in autistic adults during FER. In this case, autistic adults may place a greater reliance on visual spatial processes to visually mediate deficits in networks involved in higher order FER processes (Minshew & Keller, 2010).

Reduced anterior-posterior beta coherency has also been associated with greater emotional involvement during emotion stimulation paradigms, perhaps indicating decreased involvement of the prefrontal cortex when evaluating emotional information (Reiser et al., 2012). It is possible that reduced beta coherency represents hyper-reactivity to the emotional stimuli in autistic adults with less prefrontal involvement to control this response (Reiser et al., 2012). Decreased alpha coherency with increased right theta coherency during negative FER was also observed, possibly suggesting that autistic adults

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had atypicalities in the modulation of attention and greater voluntary control of emotion processing during negative FER (Tseng et al., 2015; Yang et al., 2011).

While this study provides insights into the mechanisms of FER processing in ASD, a number of limitations must be noted. While the accuracy of coherence measures may be questioned, in extracting the imaginary part of coherency, issues related to volume conduction associated with traditional coherency calculations are effectively resolved (Nolte et al., 2004). Further, while findings of altered connectivity in autistic adults differed as a function of emotional valence, providing intriguing insights into the mechanisms of FER in autistic adults, these findings were based on a limited number of stimuli. Future research may benefit from more thorough investigation of these potential valence-linked differences in connectivity.

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## **EXTENDED DISCUSSION**

In addition to the discussion provided in Chapter Six, a number of other factors related to this study must be discussed.

The pattern of reduced connectivity observed in the current study are similar to those observed in previous studies. Reduced input of higher order frontal regions in affective processes in ASD has been hypothesized to result in emotion processing impairments in previous studies of autistic adolescents and adults, with connectivity of the beta band being particularly implicated (Leung, Ye, Wong, Taylor, & Doseburg, 2014; Mennella, Leung, Taylor, & Dunkley, 2017). These studies found reduced beta synchronization in response to angry emotions but not happy emotions, hypothesised to be due to impaired abilities to recruit task-relevant networks during FER. Given that reduced coherency was similarly observed in the current sample, it is possible that findings in beta coherency support this notion of impaired information transfer from visual processing to higher order task relevant networks in ASD (Leung et al., 2014). The lack of observable difference in the beta connectivity to positive emotions (e.g. happy) seen in these previous studies (Leung et al., 2014; Mennella et al., 2017) was not however replicated in the current study. While reduced beta connectivity in response to negative emotion was observed, reduced coherency was far more evident in response to positive emotion. It is possible that the more complex and dynamic nature of the stimuli used in the current study placed a great load on social cognitive functions in autistic individuals compared to the basic representations of happiness used in previous studies (Leung et al., 2014; Mennella et al., 2017).

Reduced anterior-posterior beta coherency has also been associated with higher emotional involvement during emotion stimulation paradigms, perhaps indicating decreased involvement of the prefrontal cortex in evaluating emotional information (Reiser et al., 2012). It is therefore possible decreased beta coherency represents hyper-reactivity to the emotional stimuli in autistic adults with less prefrontal involvement to control this response (Reiser et al., 2012). It is perhaps of interest to note that in this context, the pattern of beta connectivity in autistic adults would indicate that while autistic adults had reduced control of emotion responses, this was most evident in response to positive FER rather than negative.

This hypothesis is contradictory to previous emotion processing studies of autistic individuals, which describe deficits more consistently during negative FER (Uljarevic & Hamilton, 2013). Further, the oscillatory power responses of these individuals during the same task indicated the opposite, with hyper-reactivity being more prevalent to negative FER (Chapter Five). This discrepancy may however be remedied by examining the pattern of coherency in both theta and alpha bands. In response to negative emotion, significantly reduced alpha coherency is observed. Alpha desynchronization has been shown to occur with increased attention (Klimesch, 1999) and active information processing (Klimesch, Sauseng, & Hanslmayr, 2007) with a previous FER study of autistic adults hypothesising greater alpha desynchronization to be the result of greater voluntary control of FER (Tseng, Yang, Savostyanov, Chien, & Liou, 2015). In addition, right frontal activity is increased in autistic adults, particularly in the theta band. Altered right frontal theta activity has also been observed in autistic children during basic FER (Yeung, Han, Sze, & Chan, 2014), postulated to be resultant in atypicalities in the modulation of attention to the stimuli. It is therefore possible that both positive and negative FER elicited increased

responses in ASD, this effect may have been partially resolved through the deployment of control processes during negative FER.

Largely consistent with investigation of the power of neural oscillations during FER (Chapter Five), it is possible that while the emotional stimuli elicited hyper-reactivity in autistic adults, greater cognitive appraisal and control processes may have been undertaken during negative FER to mediate this response. Increased responses to FER in autistic individuals may be largely driven by inadequate communication between anterior and posterior networks, resulting in reduced influence of higher-order affective processes in evaluating the stimuli.

While this study provides intriguing insights into the underlying mechanisms of ASD-linked FER impairment, a number of limitations and future directions need to be addressed. Firstly, due to the clinical sample and nature of the experimental paradigm, analysis and conclusions are based on a moderate amount of data. Caution must therefore be used when generalising these findings. Furthermore, coherency was used as a measure of connectivity in the current study, although concerns regarding volume conduction are effectively resolved through the use of the imaginary part of coherence. Future research may benefit from investigating the more precise timing of processes during FER and the directionality of communication between networks involved in FER.

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## CHAPTER SEVEN

### CAN EEG-BASED BIOMARKERS DURING FACIAL EMOTION RECOGNITION PROVIDE AN EFFECTIVE MEANS OF CLASSIFYING ASD IN ADULTHOOD?

This chapter contains content from a manuscript currently pending publication

**Black, M. H.,** Tan, T., Bölte, S., Chen, N.T., Lipp, O.V. & Girdler, S (pending publication). Can EEG based biomarkers during facial emotion recognition provide an effective means of classifying ASD in adulthood?



## PREFACE

In Chapters Five and Six, atypical neural functioning was observed in autistic individuals during FER. In these previous chapters, analysis was driven by a priori hypothesis testing, machine learning instead provides an alternative data – driven approach to examining these observed differences. In this chapter, machine learning algorithms are applied to the EEG frequency power data examined in Chapter Five to investigate whether observed differences in neural oscillations can be utilised to classify ASD adulthood.

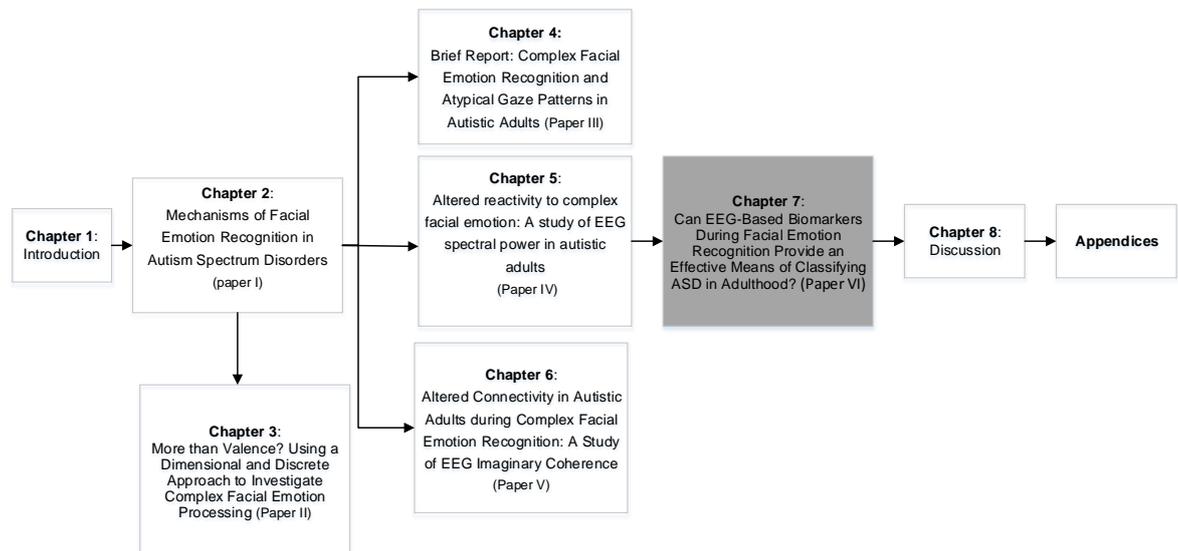


Figure 1 Thesis outline chapter seven

**ABSTRACT**

**Background:** Current evaluation for Autism Spectrum Disorders (ASD) is largely based on clinical judgement and behavioural assessment. Electrophysiological biomarkers may provide an objective means to assist in the effective and accurate classification of ASD, providing improved avenues for diagnosis, prognosis and treatment.

**Method:** Electroencephalogram (EEG) frequency power was collected for 22 autistic adults and 27 typically developing (TD) adults during a complex facial emotion recognition (FER) task. Machine learning algorithms were applied to the data to investigate the accuracy of EEG based biomarkers in classifying ASD in adulthood. Further classifications were conducted based on participants Social Responsiveness Scale scores -2 (SRS-2) and combining EEG and SRS-2 scores to determine the utility of EEG-based classification compared to a popular screening measure.

**Results:** Area under the receiving curve (AUC) revealed that classifier accuracy based on EEG alone ranged from 0.62 – 0.88, while accuracy on the SRS-2 ranged from 0.73 – 0.87. Classifications based on EEG and SRS-2 combined ranged from 0.72 – 0.97.

**Conclusion:** EEG biomarkers collected during FER may provide a prospective means of classifying ASD, offering an accuracy similar to that of the SRS-2 screening measure and similar to current diagnostic assessments. The use of EEG biomarkers and SRS-2 combined resulted in the highest accuracy. The use of EEG-based biomarkers may provide a means of assisting in diagnosis and prognosis through triangulation with traditional behavioural assessment.

## INTRODUCTION

Evaluation of Autism Spectrum Disorder (ASD) largely relies on clinical judgment and behavioural assessment (Falkmer, Anderson, Falkmer, & Horlin, 2013). Currently, assessments based on diagnostic criteria outlined in the Diagnostic and Statistical Manual for Mental Disorders (DSM) (American Psychiatric Association, 2013) and the International Statistical Classification of Diseases and Related Health Problems -10 (ICD-10) (World Health Organization, 1993) form the basis for evaluating the presence of ASD symptomatology.

ASD is a complex neurodevelopmental condition, with the manifestation of symptoms influenced by developmental abilities (Mayes & Calhoun, 2011), gender (Holtmann, Bolte, & Poustka, 2007; Mayes & Calhoun, 2011) and chronological age (Mayes & Calhoun, 2011; Seltzer et al., 2003). ASD often shares symptomatology similar to that of other clinical conditions (Levy et al., 2010) such as psychiatric conditions including anxiety and attention deficit hyperactivity disorder (Mazzone, Ruta, & Reale, 2012), attention difficulties (Goldstein & Schebach, 2004) and language delays (Paul, Charwarska, & Volkmar, 2008), and a high proportion autistic individuals also present with comorbid diagnoses (Abdallah et al., 2011). These factors contribute to difficulty in accurately classifying ASD, posing significant challenges for diagnosis, prognosis and treatment (Goldani, Downs, Widjaja, Lawton, & Hendren, 2014).

Biomarkers to assist in classifying ASD have received increasing attention, with a wide range of metabolic, genetic, electrophysiological and brain-based markers investigated as potential candidates (Goldani et al., 2014). While the identification of biomarkers for ASD is appealing from an early screening and diagnostic standpoint, biomarkers may also lead to advances in understanding the mechanisms underlying the core diagnostic criteria for

ASD, contributing to improved prognostic and treatment capabilities (Goldani et al., 2014; Jeste, Frohlich, & Loo, 2015).

In the realm of diagnosis, biomarkers may reduce the potential for administrator bias, and lessen the time and costs associated with the diagnostic process (Jeste et al., 2015). The Autism Diagnostic Observation Schedule – Second Edition (ADOS-2) (Lord et al., 2012) and the Autism Diagnostic Interview-Revised (ADI-R) (Rutter, Couteur, & Lord, 2003) are currently considered the gold standard for ASD diagnosis (Ozonoff, 2005), with the use of these assessments simultaneously providing a diagnostic accuracy of 0.8 (Falkmer et al., 2013). While these procedures are considered gold standard, their reliance on behavioural assessment for diagnosis is not without limitation. Assessment administration requires significant clinical training and is often financially costly and time consuming for both the clinician and the family (Charman & Gotham, 2013). Diagnostic accuracy of these assessments further relies on the clinicians experience and expertise (Charman & Gotham, 2013). The high proportion of individuals presenting with co-occurring diagnoses and the similarities of symptoms with other diagnoses can also make differentiating between ASD symptomology and symptoms arising from other clinical conditions difficult (Levy et al., 2010; Mazzone et al., 2012).

From a prognostic and treatment perspective, biomarkers may provide a prospective means of predicting and evaluating treatment outcomes. There is increasing interest in providing individualized and precision medicine approaches for ASD (Loth, Murphy, & Spooren, 2016). It is likely that biomarkers will be important in assisting the stratification of individuals to intervention based on individual profiles, ultimately improving the effectiveness of treatment (Loth et al., 2016). Recently research has sought to understand

how interventions can influence change at a neural level (Bölte et al., 2015), working towards the development of markers for treatment response (Jeste et al., 2015).

The observation of atypical brain function in autistic individuals, and the relative ease of collecting electrophysiological (EEG) data has led to EEG methods being considered as a potential avenue for elucidating ASD biomarkers (Jeste et al., 2015). In the investigation of EEG-based biomarkers, data driven approaches such as machine learning may provide particularly unique insights into the identification EEG-based biomarkers which characterize ASD (Orrù, Pettersson-Yeoe, Marquand, Sartori, & Mechelli, 2012). Limited data driven approaches to EEG based biomarker detection has however been conducted. One study which used multiscale entropy derived from EEG measures to classify young children at risk of developing ASD with an accuracy of over 90% and 80% for males and females respectively (Jeste et al., 2015). Given that ASD is an enduring condition across the lifespan (American Psychiatric Association, 2013), it is critical to also determine the EEG biomarkers which may be detectable in adulthood.

Specifically, it may be particularly useful to investigate the patterns of EEG activity which are elicited in response to experimental conditions reflective of the social difficulties characteristic of ASD. Atypical brain activity during facial emotion recognition tasks (FER) is commonly reported in autistic individuals (Black et al., 2017), with difficulties in this domain purportedly at the core of the social communication and interaction difficulties experienced by this population. Given that altered processing of FER in autistic individuals has been reported previously, it is possible that EEG power measured during a FER task may provide a valuable means to assist in the classification of autistic from Typically Developing (TD) individuals (Black et al., 2017).

This study aimed to investigate the utility of using EEG frequency power measured during a FER task in autistic and TD adults to serve as a potential biomarker using data driven approaches. Here machine learning algorithms were applied to EEG data collected during an FER task in order to determine the potential utility of EEG data to classify autistic adults. This was compared to the classification accuracy yielded by the Social Responsive Scale -2 (SRS-2) a screening measure commonly used to identify individuals presenting with high autistic-like traits (Constantino, 2011).

It was hypothesized that both the SRS-2 and EEG data independently would yield useful classification results, however, it is possible that classifications combining both the SRS-2 and EEG may provide optimum classification results.

## **METHODS**

### **Participants**

In total, data from 22 autistic adults with a clinical diagnosis of ASD (mean age: 25.18 years, SD: 9) based on the DSM-5<sup>th</sup> edition (American Psychiatric Association, 2013) or equivalent DSM-IV-TR (American Psychiatric Association, 2010) diagnosis and 27 TD adults (mean age: 25.62 years, SD: 6.2) were included in the study. Autistic adults had previously received a multidisciplinary team community based clinical diagnoses of Asperger Syndrome (n=11) or Autism/High Functioning Autism (n=11). TD adults presented with no other disability or mental health diagnosis. The Social Responsiveness Scale-2 (SRS) (Constantino, 2011) was used to provide a measure of autistic-like traits in the autistic and TD samples. To provide a measure of attention switching and visual selective attention capabilities, the map search and visual elevator counting subtests of the Test of Everyday Attention (TEA) (Robertson,

Ward, Ridgeway, & Nimmo-Smith, 1996) were employed. Participant full scale IQ, performance IQ and verbal IQ were measured using the Wechsler Abbreviated Scale of Intelligence (WASI-2) (Wechsler, 1999). Groups did not differ on age ( $p=0.61$ ), gender ( $p=0.11$ ), performance IQ ( $p=0.60$ ), verbal IQ ( $p=0.60$ ), and Visual Elevator sub-tests ( $p=0.06$ ,  $p=0.22$ ) of the TEA. Groups differed significantly on map search measures of the TEA ( $p<0.01$ ) and on SRS-2 score ( $p=0.01$ ). EEG data presented in this study were part of a larger study and have been reported previously (Black et al., 2017).

### **Facial Emotion Recognition Task**

The Facial Emotion Stimulus battery consisted of stimuli selected from the Cambridge Mind Reading Face Voice Battery (CAMS) (Golan, Baron-Cohen, & Hill, 2006). The battery used in the current study included 2 practice items and 15 test items with stimuli selected to provide a range of emotions, this included: Four positive (exonerate, empathic, intimate, vibrant), and nine negative (resentful, stern, grave, subservient, appalled, confronted, insincere, mortified, distaste) emotions. Two neutral (lured, appealing) stimuli were also included however were not analysed for the purposes of this study. Stimulus videos ran for between 3-5 seconds, however, to increase consistency across stimuli, stimulus videos which were 3-4 seconds in length remained static on the screen for 1-2 seconds. Following the viewing of each stimulus video, participants were presented with four-word options and were required to select the answer which they believed corresponded with the emotion shown in the stimulus.

## **Social Responsiveness Scale -2**

The SRS-2 adult self-report form (Constantino, 2011) provided a measure of autistic-like traits and was employed as a comparative measure to determine the utility of EEG-based biomarkers compared to a commonly used screening measure. The SRS-2 is a self-report assessment consisting of 65 items across five domains, including social communication, social awareness, social motivation, and social cognitive and autistic-like mannerisms. Responses are rated on a four-point Likert scale with a maximum possible score of 195 (indicative of higher autistic-like traits). The SRS is widely used within clinical and research settings to provide an estimate of autistic-like traits (Bölte, 2012; Chan, Smith, Hing, Greenberg, & Mailick, 2017; Constantino, 2011). The assessment has been used cross-culturally, with high validity (Bölte, 2012; Takei et al., 2014).

## **Procedure**

SRS-2 adult self-report forms were completed at the beginning of the trial. EEG data preparation were completed during completion of two WASI-2 subtests. Participants were then orientated to the FER task by completing 2 practice items followed by the 15 test items. A one second fixation cross was presented prior to stimulus presentation and stimuli were presented in a pseudo-randomized order. The remaining two WASI-2 subtests were completed as distractor tasks during other emotion recognition tasks not presented in the current paper.

## **Data Acquisition and Pre-Processing**

Stimulus presentation and behavioural data acquisition were controlled via E-Prime software (Psychology Software Tools, 2016). A 40 channel Ag/AgCl Compumedics

Neuroscan EEG Quik Cap with Scan 4.5 software (Neuroscan, 2014) was used to record EEG data. For the purposes of eye movement artefact removal, electrodes were placed on the outer Canthi of each eye and above and below the left eye to record vertical and horizontal electrooculograms (EOG). Impedance was reduced to 5 kOhms or below prior to data collection and data were sample at 1000 Hz using default internal hardware filters for DC component removal and antialiasing. A Cz reference and virtual ground at AFz were used during EEG data acquisition which was later re-referenced during offline processing to a point at infinity using the Electrode Standardization Technique (Yao, 2001).

Following re-referencing, offline processing was undertaken whereby a bandpass filter (0.5 and 40 Hz) and Independent Component Analysis (ICA) was applied to the data. An automated constrained ICA (cICA) approach was used whereby artefacts recorded by EOG were identified and removed. Epochs 5500ms in length were extracted consisting of 500ms pre-stimulus fixation cross and 5000ms of stimuli presentation. Fast Fourier Transform and Welch's Power Spectrum Density (PSD) were used to extract theta  $\theta$  (4-8 Hertz), alpha  $\alpha$  (8-15 Hertz) and beta  $\beta$  (16-30 Hertz) power.

Data collected during the stimulus presentation were baseline corrected using the 500ms of pre-stimulus fixation cross viewing on a trial by trial basis for each frequency and electrode. Median values for each frequency and electrode were subsequently extracted. For the purposes of classification, EEG data was of interest only if the participant correctly identified the emotion, thus EEG data corresponding with incorrect answer was discarded.

## **Classification**

WEKA software (Witten, Frank, & Hall, 2011) was used to classify autistic and TD participants based on their SRS-2 scores and EEG responses during the FER task. The classification process trialled six machine learning algorithms, including Naïve Bayes, Sequential Minimal Optimization (SMO), Multilayer Perception (MLP), Decision Stump, Random Forest and Random Tree (Witten et al., 2011).

All analyses were undertaken on 49 participants in total (22 autistic, 27 TD). Classifications were first undertaken to determine the classification accuracy of the SRS-2. Classifications using the SR-2 consisted of two attributes (SRS-2 raw score and group variable).

Classifications seeking to classify autistic and TD adults based on their EEG responses were conducted based on the EEG data collected during positive and negative FER of the Facial Emotion Stimuli to determine if valence influenced classifier performance. Initially, 100 features were available for classification (33 electrodes x 3 frequencies) with the class specified as ASD and TD.

Prior to classification, attribute/feature selection was undertaken to identify irrelevant features for each classifier (Witten et al., 2011). The selection of attributes prior to classification is suggested to reduce overfitting of the algorithms and to remove features which may have negatively influenced the classifiers accuracy (Witten et al., 2011). A Wrapper Method which is part of the WEKA function was used whereby a predictive model evaluates feature subsets and assesses its accuracy using a cross-validation procedure (Witten et al., 2011).

Following the selection of attributes, classifiers were run on the data using the selected attributes to classify autistic and TD individuals based on their EEG power frequency (refer to appendix A for selected attributes). For all classifications, default WEKA parameters were used with 10-fold cross validation procedures applied to evaluate the classifier (Witten et al., 2011).

A third set of classifications were then undertaken combining SRS-2 score and EEG responses to determine if SRS-2 score and EEG combined resulted in improved accuracy. The classification approach described for EEG responses was replicated in this third set of classifications, with the inclusion of SRS-2 scores (refer to Appendix for selected attributes).

For all classifications, the Area Under Curve (AUC) of the Receiving Operator Characteristic (ROC) was extracted to evaluate their performance. Compared to other means of evaluating classifier performance (such as accuracy), AUC is preferred for single number evaluations as it has greater sensitivity, is not reliant on a threshold and is not influenced by prior class probabilities (Bradley, 1997). The AUC is calculated by examining instances of ‘true positive’ classifications compared to the instances of ‘false positive’ classifications using different thresholds (Bradley, 1997).

## **RESULTS**

### **SRS-2 Classification Accuracy**

As shown in Table 1. Classification accuracy based on participant SRS-2 raw scores ranged from 0.72 – 0.85. The highest AUC was provided by Naïve Bayes and Random

Forest Classifiers (0.85), followed by Random Tree and MLP (0.78). The lowest AUC (0.72) was yielded from both SMO and Decision Stump Classifiers.

*Table 1. SRS- 2 classifier accuracy (%) and AUC in identifying autistic adults.*

<b>Classifier (Witten et al., 2011)</b>	<b>AUC</b>
Naïve Bayes	0.85
SMO	0.72
MLP	0.78
Decision stump	0.72
Random Forest	0.85
Random Tree	0.78

Note: AUC; Area under Curve, SMO; Sequential Minimal Optimization, MLP: Multilayer

## **EEG-Based Classification Accuracy**

Classification based on EEG data collected during positive and negative FER revealed an AUC ranging from 0.62 – 0.87 (Table 2).

*Table 2. Classifier accuracy (%) and AUC in identifying autistic adults using positive and negative facial emotion recognition data after feature subset selection using the Wrapper Method.*

<b>Classifier(Witten et al., 2011)</b>	<b>AUC</b>	<b>Number of Attributes</b>
Naïve Bayes	0.73	2
SMO	0.73	5
MLP	0.88	4
Decision stump	0.62	1
Random Forest	0.82	4
Random Tree	0.81	3

Note: AUC; Area under Curve, SMO; Sequential Minimal Optimization, MLP: Multilayer

The MLP classifier had the highest accuracy, providing an AUC 0.88 (Figure 2).

Random Forest classifiers had the second highest accuracy with an AUC of 0.82.

Decision stump classifiers had the lowest AUC (0.62).

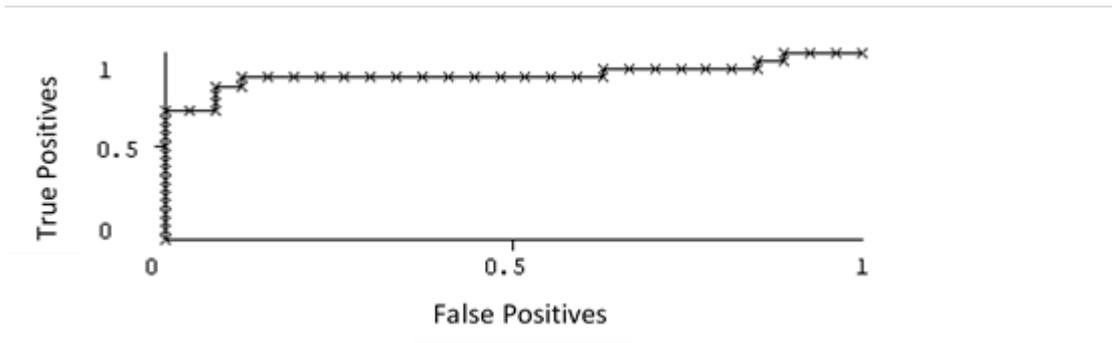


Figure 2. Receiving Operator Characteristics of MLP classification based on EEG data

### SRS-2 and EEG-Based Classification

Classification of autistic and TD individuals using both EEG data and SRS-2 raw scores resulted in an AUC ranging from 0.72 to 0.97 (Table 3).

Table 3. Classifier accuracy (%) and AUC in identifying autistic adults using positive and negative facial emotion recognition data after feature in combination with SRS-2.

Classifier (Witten et al., 2011)	AUC	Number of Attributes
Naïve Bayes	0.97	5
SMO	0.91	5
MLP	0.96	5
Decision stump	0.72	1
Random Forest	0.87	4
Random Tree	0.78	3

Note: AUC; Area under Curve, SMO; Sequential Minimal Optimization, MLP: Multilayer

As shown in Table 3, the highest classification accuracy was found using Naïve Bayes classifiers, which yielded an AUC of 0.97 (Figure 3), followed by MLP classifiers for negative emotion (0.96). Decision stump classifiers had the lowest AUC with 0.72.

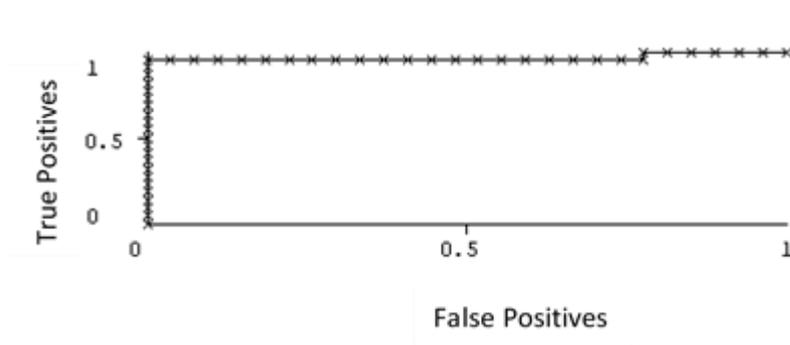


Figure 3. Receiving Operator Characteristics for Naive Bayes classification based on EEG and SRS-2 data

## DISCUSSION

EEG frequency power during FER has shown utility as a potential biomarker for the classification of ASD in adulthood. AUC of the classifiers based on EEG alone ranged from 0.62 to 0.88 with the majority of classifiers having a performance of 0.70 or greater. This classification accuracy was similar to that yielded by the SRS-2. When EEG and SRS-2 attributes were combined, AUC improved with the highest AUC provided being 0.97.

Although the utility of EEG markers for the diagnosis of ASD is promising, these biomarkers are not yet capable of being used during the diagnostic process. The current study represents a proof of concept in using EEG to classify ASD in adults. Current diagnostic assessments rely on the expertise of the clinician and require extensive clinical training and administration time (Charman & Gotham, 2013), in

comparison, application of EEG is relatively inexpensive, requires less time to administer and is less vulnerable to the potential of administrator bias. EEG-based biomarkers may present an appealing future avenue to assist in classifying or screening for ASD in adulthood. Given that behavioural based assessments are an essential component of determining an individual's unique strength and difficulty profile, EEG-based biomarkers are unlikely to replace behavioural assessment but may provide a means of objectively triangulating observation by a trained professional. The fact that the highest classification accuracy yielded was from the combination of both EEG and SRS-2 scores may indicate that the triangulation of biomarkers with behavioural assessment may assist in the identification of autistic individuals. The use of multiple data sources for the identification of ASD may have the potential to provide added clarity and verification to the diagnostic process.

Biomarkers presented in this study may also present avenues for future research. As biomarkers in the current study were measured while completing a FER task, they may prove particularly useful from a prognostic and treatment standpoint. While FER impairments are commonly observed in autistic individuals, questions have arisen as to whether these difficulties are evident among all autistic individuals (Tracy, Robins, Schriber, & Solomon, 2011), given the significant variability of ASD, it is possible that not all autistic individuals will experience the same difficulties. The biomarkers identified here may therefore provide a means to stratify individuals as part of individualised treatment guided by a precision medicine approach. As part of a precision medicine approach to treatment, these biomarkers present avenues for treatment evaluation and monitoring (Jeste et al., 2015). Though extensive research has attempted to provide intervention aimed at improving social functioning for

autistic individuals, the evaluation of these interventions is largely focused on examining behavioural outcomes. The ability for intervention to influence neural plasticity has received growing attention (Bölte et al., 2015) and there has been some demonstrated utility of using EEG-based biomarkers to monitor treatment response in autistic toddlers (Dawson et al., 2012). Biomarkers identified in the current study may similarly provide a means of monitoring responses to treatment and intervention in adulthood and warrants investigation.

It is critical to note that participants in this study were adults who had previously received a clinical diagnosis of ASD. While it is shown that EEG-based classification during FER may provide a potential biomarker for classifying ASD in adults, future research is required to determine the utility of identifying autistic individuals who have not yet received an ASD diagnosis. Autistic adults included in the study represented a relatively homogenous sample, with all participants having a diagnosis of high functioning autism/Asperger Syndrome and at least average IQ. Given the complexity and variability of ASD symptomology, it is necessary to determine if the EEG –based classification presented here can extend to a more heterogeneous sample. It may also prove beneficial to determine the utility of EEG –based classification of ASD in the presence of other differential diagnoses.

Future research should further investigate the utility of EEG-based biomarkers for ASD. Given the number of potential uses biomarkers present, there is a need to examine their utility in not only diagnosis and screening, but also during prognosis and treatment.

## **CONCLUSION**

While preliminary, these findings suggest that EEG-based biomarkers may provide an effective means of classifying ASD in adulthood. The use of EEG collected during a cognitive task such as FER may provide a means of triangulating results from traditional screening and diagnostic assessments.

## **Ethics, Consent and Permissions**

This research complied with guidelines outlined by the National Health and Medical Research Council, Australia and ethical approval was obtained from the Curtin University Human Research Ethical Committee (HR52/2012).

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**CHAPTER EIGHT: SYNTHESIS OF FINDINGS AND FUTURE  
DIRECTIONS**



## **THESIS AIMS**

Autistic individuals experience significant difficulties in FER, impacting upon their broader social communication and interaction (American Psychiatric Association, 2013). While it is known that autistic individuals have these difficulties, the underlying mechanisms contributing to such impairments remain unknown. Developing an understanding of the mechanisms contributing to FER impairment in this population is of critical importance to broaden the understanding of ASD, facilitating improvements in intervention, as well as potentially in prognosis and diagnosis.

Previous research seeking to understand the cognitive and neural basis of FER difficulties in ASD has focused on examining FER and its correlates using experimental paradigms which may not be commensurate with the everyday functioning of autistic individuals. This thesis attempted to address these gaps in the current body of literature investigating ASD-linked FER impairment. In meeting these aims, complex, dynamic emotions were used within this thesis to investigate the eye tracking and EEG-based correlates of FER in autistic adults. This thesis contributes new knowledge to the understanding of the mechanisms underlying FER in autistic individuals.

## **OVERVIEW OF FINDINGS**

### **Mechanisms of Facial Emotion Recognition in Individuals with Autism Spectrum Disorder: Insights from Eye tracking and Electroencephalography (Paper I)**

In undertaking this research, a systematic review was first conducted to examine the existing eye tracking and EEG based investigation of FER in autistic individuals. In this review, 54 articles were examined using a developmental approach. While a number of

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EEG and gaze-based characteristics appeared to be common in autistic individuals during FER, heterogeneity was observed between studies. In regard to eye tracking findings, it has been generally accepted in the literature that reduced gaze to the eyes is characteristic of autistic individuals (American Psychiatric Association, 2013; Baron-Cohen et al., 2000). In reviewing the evidence for this however the results were not as consistent as perhaps thought, at least in FER tasks. While the gaze-based findings here were restricted to FER tasks, if the entirety of face-processing tasks were examined, it is possible that the effect would be more conclusive. For example, while few child studies reported reduced gaze to the eyes of emotional faces during FER tasks, in other paradigms, atypical scanning patterns to faces and social stimuli is commonly observed in autistic children (Chawarkaska & Shic, 2009; de Wit, Falck-Ytter, & von Hofsten, 2008; Sasson & Touchstone, 2013) and infants who develop ASD (Shic & Macari, 2014). It was hypothesized that a lack of observable difference in eye gaze between typically developing and autistic children may have been resultant from differences in task demands, which may have had difficulty capturing the attention of younger children. Reduced gaze to the eyes of emotional faces during FER tasks was more commonly observed in adolescent and adult studies. It may also be possible that differences in gaze to the eyes across the developmental trajectory may be indicative of altered maturation of FER processes. Altered gaze to other facial features, such as the mouth, was also found, however there was marked inconsistency between studies. The at least partial confirmation of reduced gaze to the eyes during FER tasks supports two primary hypotheses of ASD. One being the social salience hypothesis (Baron-Cohen, Jolliffe, Mortimore, & Robertson, 1997; Langton, Watt, & Bruce, 2000) and the other being the eye avoidance hypothesis (Tanaka & Sung, 2016).

When examining investigation of EEG-based literature, the N170 ERP was consistently delayed and smaller in autistic individuals during FER tasks, other ERPs, such as the P100 were also altered but these differences were not consistently observed. Together, ERP findings provide evidence for altered function of systems involved in the early processing of visual information. Few studies sought to examine later occurring stages of FER processing in autistic individuals and few employed other EEG based measures such as examining the spectral power frequencies. EEG based investigation of FER in autistic individuals has primarily focused on early stages of visual processing, thus there is currently a limited understanding as to the extent of FER impairment in ASD. While studies applying quantitative EEG methods show some evidence for altered processing at later stages of perception, these findings remain limited in regard to real-world applicability (Gross et al., 2012; Tseng, Yang, Savostyanov, Chien, & Liou, 2015; Yang, Savostyanov, Tsai, & Liou, 2011; Yeung, Han, Sze, & Chan, 2014). Studies which examined coherency and synchrony during FER tasks found evidence to suggest that autistic individuals may have reduced ability to automatically process facial emotion information, requiring more voluntary control of visual processing (Tseng, Yang, et al., 2015; Yang et al., 2011).

### **More than Valence? Using a Dimensional and Discrete Approach to Investigate Complex Facial Emotion Processing (Paper II)**

In Chapter Three, the importance of using complex emotional stimuli is discussed. As confirmed in Chapter Two, the vast majority of research to date examining FER in autistic individuals have been restricted to static representations of the basic emotions. This study sought to advance the understanding of complex emotions and their underlying qualities. Both a dimensional and discrete approach to the conceptualization of emotion was used

to develop an understanding of the underlying characteristics of the complex facial emotions presented in the CAMs battery (Golan, Baron-Cohen, & Hill, 2006). It was shown that the CAMs can be mapped to three dimensions of valence, arousal and dominance, with valence and approach being highly correlated. It was also observed while the complex emotions could also be mapped to the six basic emotions, this was not true for all complex emotions, providing evidence to suggest that findings based on basic emotions may not extrapolate to complex emotional concepts. The findings of this paper contribute to an understanding of the complexity and multi-dimensionality of complex emotion. This information may influence the understanding of emotional processing and the mechanisms of FER which may contribute to improvements in the understanding of FER impairment in clinical conditions, including ASD.

### **Brief Report: Complex Facial Emotion Recognition and Atypical Gaze Patterns in Autistic Adults (Paper III)**

The gaze-based correlates of FER impairment in autistic adults were observed in Chapter Four using complex, dynamic emotional stimuli (Golan et al., 2006). Despite prior hypotheses regarding reduced gaze to the eyes, this was not found. However, it was observed that autistic adults had a preference to gaze towards the mouth compared to matched typically developing adults. It was hypothesized that this altered gaze behavior may be indicative of altered function of neural systems involved in detecting and prioritizing socially relevant information. In particular, it was proposed that increased gaze towards the mouth in autistic adults is perhaps indicative of a preference for physically rather than socially salient information (Klin, Jones, Schultz, Volkmar, & Cohen, 2002). Though not statistically significant, it was descriptively observed that autistic individuals may have preferred the mouth region compared to the eyes. On this

basis, it was hypothesized that the preference for the mouth region may lend support to the notion that autistic individuals may have difficulty extracting information from the eye region (Neumann, Spezio, Piven, & Adolphs, 2006). Through employing complex, dynamic stimuli, this chapter extends the current understanding of gaze-based mechanisms contributing to FER impairment in autistic adults.

### **Altered Reactivity to Complex Facial Emotion: A study of EEG Spectral Power in Autistic Adults (Paper IV)**

In Chapter Five, the EEG spectral power of autistic adults were observed during a complex, dynamic FER task and compared to typically developing, age, gender and IQ matched controls. Altered activity was observed in alpha, theta and mu rhythm bands.

An atypical pattern of hemispheric activation was observed in autistic adults during positive FER, with greater alpha power activity in right frontal, central, parietal and temporal regions. Alpha asymmetry is associated with approach-withdrawal responses (Adolphs, von Glischinski, Wannemuller, & Margraf, 2017; Briesemeister, Tamm, Heine, & Jacobs, 2013; Coan & Allen, 2004), thus this observed activity in autistic adults may be indicative of enhanced withdrawal response in this population.

Greater theta activity was also observed during both positive and negative FER in autistic adults. During positive FER this was characterized by greater occipital theta power and a global increase in theta activity, which was descriptively speaking, concentrated primarily to frontal and occipital regions during negative FER. Theta activity has been postulated to be involved in processing the motivational significance of stimuli is often enhanced in response to stimuli that is threatening (González-Roldan et al., 2011) or arousing (Aftanas, Varlamov, Pavlov, Makhnev, & Reva, 2002; Balconi, Brambilla, & Falbo, 2009). Theta

activity observed in the cingulate gyrus may also be indicative of adaptive control processes undertaken during the processing of negative stimuli (Shackman et al., 2011). Findings in the theta band may therefore represent enhanced reactivity to emotional stimuli in autistic adults.

Alterations in mu rhythm activity were also observed, with autistic adults showing trends towards having the opposite pattern of mu power during positive and negative FER compared to their typically developing counterparts. Though less robust, altered mu rhythm power in autistic adults may also be indicative of atypical activation of the mirror neuron system in autistic adults during FER, providing some limited evidence to mirror neuron dysfunction theories in ASD (Perkins, Stokes, McGillivray, & Bittar, 2010).

### **Altered Connectivity in Autistic Adults during Complex Facial Emotion Recognition: A Study of EEG Imaginary Coherence (Paper V)**

The imaginary coherency during FER was examined in autistic adults and their typically developing counterparts in Chapter Six. In choosing to apply imaginary coherence estimations as opposed to traditional coherence, issues related to volume conduction associated with typical coherency measures are resolved (Nolte et al., 2004), providing a more robust measure of connectivity (Nolte et al., 2004). During the complex, dynamic FER tasks, it was observed that autistic adults had reduced long range inter-hemispheric and intra-hemispheric connectivity, however appeared to have enhanced connectivity in intra-hemispheric short-range connections in frontal and occipital regions.

Similar patterns of altered connectivity, are commonly observed in autistic individuals during a variety of experimental paradigms (O'Reilly, Lewis, & Elsabbagh, 2017).

Findings of the current study, when examined in light of the broader connectivity differences observed in this population may suggest that connectivity differences may perhaps not be solely related to FER, but may present as a general feature of the autistic brain.

While findings are similar to that of other studies, it also appeared that there was an effect of emotional valence on the coherency differences between groups. During positive FER, reduced connectivity was most prevalent in the beta frequency band, however during negative FER, reduced connectivity was most prevalent in alpha and theta bands. The pattern of reduced coherency in autistic adults was hypothesized to be indicative of reduced information transfer from visual processing regions to frontal regions involved in higher order processes. In this case it may be possible that autistic adults had a greater reliance on visual processing to compensate for reduced involvement of frontal regions mediating emotion perception. Such a hypothesis was based on previous reports of reduced beta coherency being associated with hyper-reactivity to emotional stimuli due to reduced pre-frontal involvement (Reiser et al., 2012). Hypotheses of greater independence of visual processing and frontal regions may be supported by the observation of increased coherency between local short-range connections in frontal and occipital regions in autistic adults. Results of Chapter Six corroborate findings of hyper-reactivity to emotions in autistic adults found in Chapter Five. It must be noted however that the findings of Chapter Five suggest greater reactivity to negative as opposed to positive emotion, however, based on coherency findings in the beta frequency in the current study, the opposite is proposed. It is possible that the patterns of alpha and theta activity observed more prevalently during negative FER are however indicative of altered attention or control mechanisms (Tseng, Yang, et al., 2015; Yang et al., 2011) possibly mediating this response during negative FER.

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## **Can EEG-Based Biomarkers During Facial Emotion Recognition Provide an Effective Means of Classifying ASD in Adulthood? (Paper VI)**

A novel data driven approach to investigate the utility using EEG-based biomarkers in detecting ASD in adulthood was used in Chapter Seven. Using machine learning algorithms, it was found that EEG-based biomarkers collected during FER had an accuracy similar to that of the Social Responsiveness Scale -2 (SRS-2), a measure widely used to screen for autistic-like symptomology (Constantino, 2011). While EEG-based biomarkers alone had a high accuracy, comparable to the SRS-2, it was shown that the combination of SRS-2 and EEG data yielded the highest accuracy, with classifiers based on EEG and SRS-2 providing an AUC of 0.72 – 0.97. Through applying these data-driven machine learning approaches, this chapter provides a new understanding of biomarkers in ASD and provides an innovative perspective on utilizing EEG-based biomarkers to triangulate the diagnosis of ASD with more traditional behavioral assessments used for diagnosis.

### **IMPLICATIONS**

#### **Implications for Understanding FER in ASD**

First and foremost, the findings presented in this thesis have important implications for the understanding FER in ASD and the mechanisms contributing to FER impairment. As found in Chapter Two, the vast majority of understanding of the mechanisms underlying FER impairment in autistic individuals is built upon the basic emotions or use paradigms which may be limited in respect to their ability to generalize to the day to day social interaction difficulties experienced by autistic adults. Findings reported in the chapters of

this thesis may provide findings more reflective of the mechanisms underlying FER in socially relevant contexts.

In regard to eye gaze findings, Chapter Four shows that autistic adults had a greater fixation time to the mouth compared to typically developing adults. As discussed in Chapter Two, findings regarding gaze to the mouth have not been consistently observed in previous studies. The observation of increased fixation time to the mouth in autistic adults during the recognition of complex, dynamic stimuli may assist in providing clarity to the characteristics of eye gaze during FER in ASD and the potential task demands which may elicit this divergent gaze. Along a similar vein, previous EEG-based investigation has been largely restricted to ERP investigation and has focused on earlier stages of visual processing. In examining both the EEG spectral power and imaginary coherency of FER in ASD using complex, dynamic stimuli evidence was found suggesting that altered neural activity during FER may contribute to the impairments in FER observed in this population.

The eye tracking and EEG findings reported within this thesis have important implications for existing theories regarding FER impairment in ASD. For example, it has been proposed that autistic individuals may have reduced social motivation, perhaps due to dysfunction in reward processing systems (Chevellier, Kohls, Troiani, Brodtkin, & Schultz, 2012). Evidence for this purported reduced social motivation was not found. In fact, accumulatively, eye tracking and EEG findings presented in this thesis provides evidence to suggest that autistic adults respond hyper-reactively during complex FER tasks. This hyper-reactive response may contribute to withdrawal responses in autistic individuals as indicated by Chapter Five. The findings of this thesis may provide more evidence for the eye avoidance hypothesis (Tanaka & Sung, 2016). This hypothesis proposes that autistic individuals may avoid gazing towards the eye region due to an

increased perception of threat (Tanaka & Sung, 2016). Indeed, there is converging evidence from the findings of thesis to support such a claim. As indicated by EEG findings, it is possible that emotional stimuli presented in the FER task is perceived as more threatening or arousing in autistic adults, this may in turn result in potential gaze based compensatory strategies (such as increasing time spent fixating on the mouth) (Dalton et al., 2005; Tanaka & Sung, 2016) as observed in Chapter Four.

It is possible that this hyper-reactive responding to emotional stimuli evident within this thesis was due to the developmental age of the participants and may differ along the developmental trajectory. While future research is required to determine how these factors mature across the developmental trajectory, it is apparent, at least in adulthood that aberrant gaze, and impaired FER are perhaps resultant of hyper-reactivity and enhanced emotional responding to emotional stimuli. If autistic individuals do have this enhanced reactivity to emotional stimuli, questions remain as to whether autistic individuals are inherently hyper-responsive to emotional stimuli, influencing their development, or whether a lack of social motivation in infancy and childhood (Chevellier et al., 2012) results in reduced experience with social information such as FER, contributing to inexperience and thus difficulty mediating responses during FER tasks.

It should be noted that other theories have also been proposed to account for the broader social difficulties experienced by autistic individuals. These theories for example propose that characteristics associated with ASD may be due to deficits in theory of mind, language processing or central coherence (Levy, 2007). While it is acknowledged that it is possible that these theories may also provide an explanation for impairments in FER in autistic individuals, the tasks employed within this thesis are not well-suited to draw conclusions based on these theories. Thus, additional research may be required to investigate the

potential validity of these theories in explaining the origins of FER impairment in autistic adults.

### **Implications for Research Design and Methodology**

Chapters, Four, Five and Six largely confirm that findings based on the use of basic emotions may indeed have a direct practical relevance to the real-world functioning of autistic adults. At least in a general sense, it was observed that altered eye gaze and atypical patterns of neural activity that have been observed during the use of static basic emotions were replicated when using more complex, dynamic emotional concepts. However, it did appear that the use of complex, dynamic stimuli elicited a number of eye gaze and EEG characteristics perhaps not observable through the previous use of basic and static stimuli. Thus, findings from this thesis thus support the need to use complex or ecologically valid stimuli to determine mechanisms contributing to FER impairment in real-life social interaction.

The utility of employing complex and dynamic stimuli was perhaps most evident in the eye gaze findings presented in Chapter Four in light of the significant body of existing eye tracking research examining FER in autistic individuals. In Chapter Two it was found that despite heterogeneity, reduced gaze towards the eyes was commonly observed in autistic individuals, however findings regarding gaze to other regions of the face were largely inconsistent. While aberrant gaze to the mouth has been observed previously, this is not observed in all studies (Falkmer, Bjallmark, Larsson, & Falkmer, 2011; Hernandez et al., 2009; Kirchner, Hatri, Heekeren, & Dziobek, 2011; Pelphrey et al., 2002; Rutherford & Towns, 2008; Sawyer, Williamson, & Young, 2012), and those studies that do report atypical gaze to the mouth region were not consistent (Bal et al., 2010; Bekele et al., 2014; Bekele et al., 2013; Corden, Chilvers, & Skuse, 2008; Leung, Ordqvist, Falkmer, Parsons,

& Falkmer, 2013; Nuske, Vivanti, & Dissanayake, 2014; Nuske, Vivanti, Hudry, & Dissanayake, 2014). Examinations of gaze behavior during the recognition of complex, dynamic facial emotion in Chapter Four however found evidence for increased gaze towards the mouth. It is possible that the dynamic nature of stimuli employed in this study may have elicited a preference for physically salient information, difficult to detect when using static images.

The use of complex, dynamic stimuli is also important from an EEG standpoint. Previous research has shown that dynamic stimuli may activate different neural networks compared to static images (Kilts, Egan, Gideon, & Hoffman, 2003; Trautmann, Fehr, & Herrman, 2009). Using static versus dynamic stimuli of facial expressions, dynamic stimuli elicited more wide-spread and enhanced activation in areas such as the amygdala, fusiform gyrus, occipital cortex, orbitofrontal cortex, fusiform gyrus and para-hippocampal gyrus (Trautmann et al., 2009). This evidence has been used to justify the importance of investigation using dynamic stimuli (Trautmann et al., 2009).

Chapter Three also discussed the importance of employing complex emotional concepts in research seeking to understand emotion perception in typical and clinical populations. In Chapter Three, normative data for a typically developing sample is provided for the complex emotions presented in the CAMs (Golan et al., 2006). Findings of Chapter Three demonstrate that it may not be adequate to categorize emotions based on valence alone as is typically done in emotion perception research. This research presents a new understanding of the qualities and characteristics of complex emotional concepts and provides normative data which may provide a pathway to facilitate the use of complex emotions in clinical research.

## **Implications for Prognosis and Intervention**

It has been demonstrated that FER difficulties in autistic individuals may be due to altered function of underlying attentional and cognitive mechanisms involved in the processing of emotional information. It is possible that these eye gaze and EEG-based characteristics may constitute potential 'biomarkers' perhaps assisting in characterizing FER impairment in autistic adults.

Using a novel data driven approach in Chapter Seven, it is demonstrated that EEG obtained during FER in autistic adults may provide an effective means of discriminating autistic adults from typically developing populations. Compared to a commonly used screening measure, the SRS-2 (Constantino, 2011), EEG based biomarkers provided a similar classification accuracy. Further though tentative, it is also shown that the accuracy yielded by the use of the SRS-2 and EEG combined was similar to that afforded by current gold standard assessments for the diagnosis of ASD (Falkmer, Anderson, Falkmer, & Horlin, 2013).

These findings may present numerous promising avenues for research, diagnosis, prognosis and intervention. In showing that autistic adults can be identified through their EEG responses during a complex, dynamic FER task. These findings may have some intriguing future applications for the diagnosis and prognosis for autistic individuals. The highest accuracy yielded was from the combination of the SRS-2 and EEG combined, these results in particular may provide evidence to support the use of biomarkers to supplement traditional behavioral assessment. As these biomarkers were identified through the use of emotional stimuli, implications for intervention were also discussed. For example, there is increasing interest in using biomarkers to monitor the effect of treatment or intervention (Dawson et al., 2012; Jeste, Frohlich, & Loo, 2015; Ozonoff,

2005). There is further interest in using biomarkers for intervention themselves through biofeedback (Holtmann et al., 2011).

## **LIMITATIONS**

### **Research Design**

Chapters Four, Five, Six and Seven employ stimuli obtained from the Cambridge Mind Reading Face-Voice Battery (Golan et al., 2006). The stimuli used consisted of four positive, nine negative and two neutral stimuli. When this stimulus battery was first developed by the original authors (Golan et al., 2006), there was little understanding of complex emotional concepts and their underlying qualities. This resulted in a stimulus battery which was unbalanced in regard to valence. Future research seeking to employ complex emotional concepts in their investigation may benefit from ensuring a balanced stimulus battery. Nevertheless, despite the uneven distribution of valences within the battery used and the sample number of stimuli, significant differences between autistic and typically developing adults were found across measures (accuracy, fixation time, spectral power and coherency). Future research seeking to examine EEG and eye tracking behaviour during complex FER should seek to employ a larger stimuli battery, perhaps including multiple versions of the same stimuli to improve the validity of observed results.

### **Sample**

Limitations associated with sample sizes may be evident throughout this thesis. In Chapter Three, a total of 141 typically developing adults participated in this study. While attempts were made to recruit participants from a diverse range of backgrounds, the majority of participants were based in Australia, limited the cultural generalisability of findings. Further the mean age of included participants was also young, thus it is unknown if the

perception of these complex emotional concepts may differ in older adults. There were also significantly more female participants than males, though the potential effect of participant gender on emotion perception was not conducted within Chapter Three, it is possible that females and males may differ in their perception of emotional concepts (Montagne, Kessels, Frigerio, de Haan, & Perrett, 2005; Wacker, Bölte, & Dziobek, 2017). Results may be skewed due to the higher prevalence of females in this study.

In Chapters, Four, Five, Six and Seven, autistic adults were compared to typically developing adults. In Chapter Four analyses of eye gaze data were conducted on  $n=20$  for each group and for Chapters Five and Six analyses included 22 autistic adults and 23 typically developing control adults. Though this sample size is comparable to other eye tracking and EEG-based investigation, the ability to interpret findings of the data would be improved with a larger sample size.

Similarly, for Chapter Seven, analysis was conducted based on 22 autistic adults and 27 typically developing controls. It was possible to increase the sample size of the control group in this trial as it was not necessary to exclude typically developing participants on the basis of having autistic-like symptomology. Ideally, a larger sample size in Chapter Seven would have allowed the machine learning algorithms to be more rigorously tested.

Throughout all chapters included in this thesis there was a focus on individuals with average intellectual abilities. Further, participants included in the research conducted in Chapters Four, Five, Six and Seven may be thought to be a relatively high functioning sample. The participants thus included in this thesis represent a largely homogenous sample. ASD itself is however considered a heterogeneous condition and can often present with co-morbidities (Levy et al., 2010). There is a significant dearth of research which

examines the potential influence of co-morbidity on the mechanisms of FER. There is a need for future research to replicate findings in more diverse samples.

### **Outcome Measures**

Limitations associated with outcome measures must also be discussed. In Chapter Four, gaze behaviour was measured through examining fixation time or the time spent fixating on the areas of interest of the stimuli. It should be noted that while this measure is commonly used in eye tracking investigation, a number of factors warrant consideration. Firstly, the reliability of the eye tracking data collected is reliant upon the accuracy of the calibration achieved at the beginning of the trial (Holmqvist et al., 2011). While attempts were made to ensure adequate calibration was maintained throughout the trial, it is possible that drifts occurred through the trial, resulting in reduced accuracy of the gaze-based data. To increase the comfort of participants and to accommodate for potential sensory difficulties in autistic participants, the head of participants was not stabilised during data collection. Though the equipment utilised does allow free-head movements within a certain range, it is possible that head movement during the trial increased the possibility of calibration drifts. Other factors such as blinking may have also contributed to missing or invalid data. Analysis was further conducted based on Areas of Interest. These Areas of Interest were defined with a margin of error to accommodate non-perfect calibrations which are inevitable when dealing with a clinical population, however may have introduced noise to the data (Holmqvist et al., 2011). Finally, fixation data were analysed in regard to fixation time to the Areas of Interest, with this analysis commonly used to examine the overall distribution of attention to a stimulus. It is however possible that more nuanced or specific saccade effects may influence FER in autistic individuals

that were not captured by the methods applied in this thesis (Shic, Chawarkaska, Bradshaw, & Scassellati, 2008).

In Chapter Five and Six, EEG spectral power and imaginary coherence estimates were used to provide measures of the neural activity occurring during FER tasks in autistic and typically developing adults. Similar to eye-tracking based methods, a number of potential limitations must also be considered.

Firstly, the connection between the scalp and electrode largely determines the accuracy of the EEG signal (Cacioppo, Tassinari, & Bernston, 2007). While attempts were made to ensure electrode impedance was maintained below 5kohms, changes in impedance throughout the trail may have also impacted the accuracy of the EEG data collected. Artefacts during recording of EEG including participant related artefacts such as blinks, head movements or jaw clenching and technology-related artefacts (e.g., power line noise) may have also contributed to distortions in the data or invalid data (Cacioppo et al., 2007). While all attempts were made to reduce the potential impact of artefacts during data collection and in pre-processing their potential impact must be noted.

The population of interest likely also contributed to a number of limitations associated with the EEG data collected. Webb et al. (2015) discuss a number of guidelines and considerations when collecting EEG data in autistic individuals. These factors include, but are not limited to, participant related factors such as developmental and mental age, co-morbid psychological or physical conditions and medications potentially influencing EEG data. The head circumference of autistic individuals may also be larger than typically developing individuals, possibly impacting electrode positioning and thus the spatial accuracy of the data (Webb et al., 2015). Other experiment related factors must also be considered including ensuring a space free of distractions, ensuring an adequate

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understanding of expectations and accommodating potential sensory needs of the participants (Webb et al., 2015).

While EEG based-measures are capable of providing insights into the mechanisms underlying FER, EEG is limited in regard to spatial resolution (Cohen, 2014). Due to the nature of recording electrical data from the scalp there are significant limitations in the ability to draw conclusions regarding the function of underlying neural structures and systems. More sophisticated analysis techniques exist which may provide afford greater insights into the neural correlates of FER in ASD (Cohen, 2014). Analysis techniques such as Granger Causality are capable of providing insights into the flow of information and interaction between different regions (Hesse, Möller, Arnold, & Schack, 2003) and advances in source localization techniques provide a means to better understand the underlying sources of activity measured at the scalp level (Jatoi, Kamel, Malik, Faye, & Begum, 2014).

## **FUTURE DIRECTIONS**

Through examining FER in autistic adults using complex, dynamic stimuli, and a combination of EEG and eye tracking measures, the body of research presented in this thesis presents a unique and novel contribution to the understanding of the mechanisms underlying FER in autistic adults. Based on the findings presented in this thesis, a number of new and insights for FER investigation in ASD are discussed.

While the complex emotional concepts from the CAMs arguably have greater direct practical relevance to the day to day social functioning of autistic adults, it must be noted that the stimuli are still experimental in nature, consisting of actors posing facial expressions. In comparison, real-life day to day facial emotion recognition is likely subtler

and more inclusive of other contextual factors. While the complex and dynamic nature of stimuli presented in this thesis are more ecologically valid than previously used static and basic expressions, there are still limitations in regard to its ecological validity. Previous studies have found differences in the detection of subtle basic expressions and differences have been observed in the viewing of acted compared to naturalistic scenes (Hanley, McPhillips, Mulhern, & Riby, 2012). Future research may benefit from the investigation of eye gaze and EEG outcomes using increasing naturalistic and ecological stimuli. In doing this however, an important balance must be maintained between using stimuli that is ecologically valid, that also allows sufficient experimental control over confounding factors.

While Chapter Three presents' normative data for the facial stimuli presented in the CAMs in a typically developing sample, it may prove useful to examine the potential influence of autistic-like traits on the perception of complex emotion through applying dimensional and discrete emotions. Using a circumplex model of emotion, autistic children have been shown to have a restricted representation of emotion in regard to valence and arousal (Tseng, Bansal, et al., 2015), however the effects of other dimensions or are groups are yet to be examined. Building upon the normative data provided by Chapter Three, it may be of interest to conduct research seeking to understand the underlying origins of these dimensions and to investigate how impairment in these various dimensions may influence both behavioural responding in autistic individuals and the underlying attentional and neural mechanisms.

More recently, the effect of gender on the phenotypic presentation of ASD has received increasing interest. While the samples included in this thesis did not permit investigation of gender-linked differences, it is possible that participant gender may influence FER.

Differences in the processing of emotion are observed in typically developing males and females (Montagne et al., 2005; Wacker et al., 2017), so it is possible that similar effects may be observed in autistic individuals.

While also not included in the scope of this thesis, the influence of comorbidities on FER in autistic individuals may also be necessary to investigate. In Chapter Two it is noted that comorbidities are likely to play a role in influencing FER impairment in ASD. In Chapter Two some studies provide evidence for an effect of social anxiety or fear of negative evaluation on gaze behaviour and FER abilities in autistic populations (Tottenham et al., 2014; White, Maddox, & Panneton, 2015). A high proportion of autistic individuals present with co-morbid social anxiety disorder (Maddox & White, 2015) so it is perhaps not unreasonable to suggest that Social Anxiety Disorder or similar traits may play a role in FER impairment in autistic individuals.

While speculative, evidence may point to the possibility of social anxiety or anxiety traits influencing the FER abilities of ASD. Findings from Chapter Four examining the eye gaze behaviour of autistic adults showed that autistic adults had a greater fixation time to the mouth of emotions, while there was no statistically significant effect on the eye region, it was at least descriptively observed that autistic adults may have had a preference to gaze towards the mouth over the eyes. Similar altered gaze patterns are observed in individuals with Social Anxiety Disorder (Daly, 1978; Wang, Hu, Short, & Fu, 2012).

Other potential comorbidities such as Attention Deficit Hyperactivity Disorder may also influence FER in ASD. Similar to Social Anxiety Disorder, Attention Deficit Hyperactivity Disorder is also recognized as having a potential influence on FER in Chapter Two. Though few studies in Chapter Two discussed or accounted for this condition in their investigation, some indication is provided to suggest that Attention

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Deficit Hyperactivity Disorder occurring in ASD can influence FER. Autistic children with co-morbid Attention Deficit Hyperactivity Disorder show distinctly different modulation of the N170 ERP compared to autistic children without co-occurring Attention Deficit Hyperactivity Disorder (Tye et al., 2014) and may influence behavioural responding (Sinzig, Morsch, & Lehmkuhl, 2008).

Future research may benefit from investigating the potential influence of these co-occurring conditions on FER abilities in ASD and how these conditions may influence the underlying eye gaze and EEG based mechanisms underlying FER. Such investigation may provide insights to assist in the identification of ASD, such as through methods described in Chapter Seven and in determining the potential effects or outcomes of intervention.

While Chapter Seven demonstrates that EEG-based biomarkers may provide an effective means of classifying ASD in adulthood, some emerging research has provided evidence to suggest that neurological and psychological disorders may be classified through eye movements (Morita et al., 2017; Shic, 2016; Tseng et al., 2013). Future research investigating the utility of eye-tracking based biomarkers may also be warranted.

## **CONCLUDING COMMENTS**

The research presented in this thesis used complex, dynamic stimuli to investigate the eye tracking and EEG based mechanisms underlying FER impairment in autistic adults. Using complex, dynamic stimuli, insights have been provided which extend beyond previous findings based on static and basic representations of emotion. The importance of complex emotion is discussed, with normative data provided to assist in not only the investigation of FER impairment in ASD but also other clinical populations. Eye tracking investigation has shown that autistic adults spend a greater fixation time on the mouth of complex,

dynamic stimuli compared to typically developing adults. Using EEG based investigation it is then shown that autistic adults demonstrate altered patterns of neural activity during FER tasks. Findings suggest that autistic adults may have hyper-reactive responses to FER stimuli, perhaps as a result of increased physiological arousal or due to perceiving stimuli as more threatening or arousing than typically developing adults. It is further shown through the use of imaginary coherency analysis that reduced global connections in autistic adults may be indicative of greater independence of visual processing systems, with a lack of input and mediation from pre-frontal regions perhaps resulting in reduced ability to modulate responding to FER stimuli. The findings in this thesis highlight the need for the continued use of complex, dynamic stimuli in investigation seeking to understand the underlying mechanisms of FER and provides a number of potential implications and future directions for the investigation of FER impairment in ASD.

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## **APPENDIX A**

Published Manuscript: Mechanisms of facial emotion recognition in autism spectrum disorders: Insights from eye tracking and electroencephalography (Paper I)



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## Neuroscience and Biobehavioral Reviews

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## Review article

## Mechanisms of facial emotion recognition in autism spectrum disorders: Insights from eye tracking and electroencephalography

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## ABSTRACT

While behavioural difficulties in facial emotion recognition (FER) have been observed in individuals with Autism Spectrum Disorder (ASD), behavioural studies alone are not suited to elucidate the specific nature of FER challenges in ASD. Eye tracking (ET) and electroencephalography (EEG) provide insights in to the attentional and neurological correlates of performance, and may therefore provide insight in to the mechanisms underpinning FER in ASD. Given that these processes develop over the course of the developmental trajectory, there is a need to synthesise findings in regard to the developmental stages to determine how the maturation of these systems may impact FER in ASD. We conducted a systematic review of fifty-four studies investigating ET or EEG meeting inclusion criteria. Findings indicate divergence of visual processing pathways in individuals with ASD. Altered function of the social brain in ASD impacts the processing of facial emotion across the developmental trajectory, resulting in observable differences in ET and EEG outcomes.

## 1. Introduction

A considerable degree of human communication occurs through nonverbal means, with actions, gestures and postures conveying signals to others about an individuals' thoughts, feelings and intentions (Darwin, 1872; Meeran et al., 2005). Facially expressed emotions contribute significantly to this communication with movements presented on the face relaying information about internal emotional and mental states (Ekman and Friesen, 1978; Ekman and Oster, 1979). In typical development, the ability to recognise emotions begins in early infancy, developing and improving throughout adolescence and adulthood (Herba and Phillips, 2004; Somerville et al., 2011). Emotion recognition abilities typically begin with the six basic emotions (happy, sad, fear, anger, disgust, surprise) with discrimination of these emotions reported to be present in children aged five to seven months (Barrera and Maurer, 1981). By 10 years of age, children are postulated to perform at a level similar to adults when asked to match neutral, surprised, happy and disgusted expressions (Mondloch et al., 2003).

Complex emotions (such as jealousy or guilt) are distinct from basic emotions in that they are typically more nuanced, rely more heavily on context, and usually involve greater theory of mind and belief-based decision making (Johnson and Oatley, 1989). Given the increased complexity of these emotions, their processing reaches maturity considerably later (Tonks et al., 2006), improving throughout adolescence and adulthood (Rodger et al., 2015; Thomas et al., 2007).

Impairments in FER are consistently associated with Autism Spectrum Disorder (ASD); an early onset neurodevelopmental condition characterised by deficits in social communication and social interaction alongside stereotypic, repetitive, restricted behaviours and interests causing adaptive impairments (American Psychiatric Association, 2013). In previous research these behavioural difficulties have, in part, been attributed to challenges in recognising the emotions of others (Baron-Cohen et al., 1985; Bölte and Poustka, 2003; Harms et al., 2010; Kuskikko et al., 2009; Lozier et al., 2014; Uljarevic and Hamilton, 2013). A meta-analysis concluded that these impairments are apparent across the developmental trajectory and the six basic

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emotions, and cannot be accounted for by the intellectual capabilities of the individual with ASD (Uljarevic and Hamilton, 2013). Recent research conducted with children suggests that ASD linked difficulties in FER appear cross-culturally, indicating a universal nature of FER challenges in the ASD population (Fridenson-Hayo et al., 2016).

While it appears that emotion recognition is an area of significant challenge for those with ASD, questions have arisen surrounding the extent of these alterations (Lozier et al., 2014; Rutherford et al., 2012). Studies have reported that individuals with ASD perform no differently to their typically developing (TD) peers on emotion recognition tasks (Castelli, 2005; Evers et al., 2014; Tracy et al., 2011), while others have postulated that perhaps not all, but a subset of the ASD population experience difficulty with emotion recognition (Nuske et al., 2013). These disparate findings have been attributed to a variety of participant and experiment related factors (Harms et al., 2010; Nuske et al., 2013; Uljarevic and Hamilton, 2013). Primarily, the demographic characteristics of the participants included in studies, for example age, intellectual capacity (Harms et al., 2010; Uljarevic and Hamilton, 2013) or comorbid conditions (Berggren et al., 2016) have been identified as playing a potential role in the variability of findings. Other possible explanations relate to the compensatory strategies employed by individuals with ASD, which possibly remediate any observable behavioural deficits (Harms et al., 2010).

While individuals with ASD may exhibit impairments in FER, further empirical efforts have sought to elucidate the mechanisms which may characterize ASD-linked impairment in FER, of note, research incorporating eye tracking (ET) and electroencephalography (EEG) methods has been used to provide crucial insights into these processes which may underpin FER impairments.

ET is a valuable tool in elucidating underlying visual processing strategies (Rayner, 1998). As emotions are expressed on the face through the differential activation of facial muscles (Ekman and Friesen, 1978), eye gaze patterns that most effectively assist in identifying different emotions will vary across expressions. In typical development ET research has shown that gaze patterns differ in relation to the valence of emotions, whereby individuals fixate more on the eyes of negatively valenced emotions and the mouths of emotions that are positively valenced (Eisenbarth and Georg, 2011; Messinger et al., 2012).

In addition to ET, EEG may provide insights into the neurological correlates of information processing during FER. EEG measures the electrical activity of the brain and provides superior temporal resolution to measures such as Functional Magnetic Resonance Imaging (fMRI) and Positron Emission Tomography (PET) (Scheuer, 2002). Electrical activity time locked to events, or event related potentials (ERPs) are one of the most common measures extracted from EEG. In the processing of facial expressions, a number of early and late occurring ERPs appear to change and mature throughout development (de Haan et al., 2003), notably including P100, N170 and N250. The P100 is largest over occipital areas between 80 milliseconds–120 milliseconds after stimulus presentation, and associated with the early processing of visual information (Magnun, 1995). The N170 component, a negative ERP, occurs between 130 and 200 milliseconds over the temporal–occipital areas and is selectively enhanced in response to faces (Eimer et al., 2011). This component is posited to reflect the structural processing of faces (Schyns et al., 2003) and is potentially indicative of the processing of higher order configural information (Eimer et al., 2011). The N250 ERP has been associated with valence specific processing, occurring over frontal regions and peaking at 250 milliseconds (Liu et al., 2012; Streit et al., 2001). In children, other ERPs such as the N290 and P400 components have been identified (Leppänen et al., 2007) as presenting as possible precursors to the adult N170 (Halt et al., 2004). Although less frequently investigated in research on FER, EEG analysed in the frequency domain may provide measures of cortical activity, and the topographical coordination of such activity over time, which may be reflective of a number of relevant cognitive

processes (Sauseng and Klimesch, 2008). Desynchronization of alpha frequencies (815 Hz) have been associated with increasing task demands and attention (Klimesch, 1999; Ward, 2003) and an increase in theta power (4–7 Hz) has been associated with memory and encoding (Klimesch, 1999). Gamma frequencies have been associated with processes such as working memory (Barr et al., 2014) and attention (Ward, 2003), while beta (15–30 Hz) has been associated with local information processing (Schutter and Knyszev, 2012).

To date, no review has been conducted in order to specifically examine the differences in ET and EEG characteristics of individuals with ASD during FER. Both ET and EEG provide insights in to the temporal dynamics of attention and cognition during the processing of facially expressed emotion. Therefore, the objective of this review was to systematically appraise the literature examining ET or EEG during FER in individuals with ASD, providing an overview of the current state of the field.

## 2. Method

### 2.1. Study design

This systematic review was conducted in accordance with PRISMA guidelines for systematic reviews and meta-analyses (Moher et al., 2009). Six databases including Cinahl, Embase, Medline, Proquest, Psycinfo and Scopus were searched for full-length articles published up to the 20th (Psycinfo) or 27th (all other databases) of January 2016. Searches were conducted using a combination of MeSH terms and key words. The following is a sample of the expressions used: (“Autistic Disorder” OR “Child Development Disorders, Pervasive” OR, “Autism Spectrum Disorder”) AND (“Evoked Potentials”, OR “Electroencephalography” OR “Eye Movements”, OR “Fixation, Ocular”) AND (“Emotions”, “Expressed Emotion”, OR “Affect”). These search terms were tailored to match specific databases (refer to Appendix A) and limited to studies in the English language. The reference lists of included articles were manually searched for articles meeting the eligibility criteria.

### 2.2. Study inclusion criteria

Studies were included if they had a sample of individuals with ASD or individuals with high autistic symptomatology, broader autism phenotype or risk of ASD development. As the majority of studies (77%) were conducted prior to 2013, i.e. before the release of the latest version of the Diagnostic and Statistical Manual for Mental Disorders – 5th Edition (DSM-5) (American Psychiatric Association, 2013), the DSM-IV (American Psychiatric Association, 2010) was utilised to classify ASD in this review. Therefore, for the purposes of this review ASD was classified as Autism, Asperger syndrome (AS), Pervasive Developmental Disorder Not Otherwise Specified (PDD-NOS), and childhood disintegrative disorder (American Psychiatric Association, 2010). No specification was made as to whether the study included individuals with high functioning Autism (HFA; at least average IQ) or low functioning Autism (LFA; below average IQ). Studies primarily involving participants with Rett syndrome were excluded. No limits were placed on age, demographics or intelligence level of the sample with ASD. Studies were required to employ a facial emotion recognition paradigm with studies primarily investigating social scene perception, object recognition or non-emotionally relevant face processing excluded. Finally, studies were required to provide a measure of ET or EEG or a combination of both to be eligible for inclusion. Fig. 1 presents a flow chart of the method of data selection in accordance with the eligibility criteria.

### 2.3. Data extraction and synthesis

Data were extracted in accordance with the Cochrane handbook for

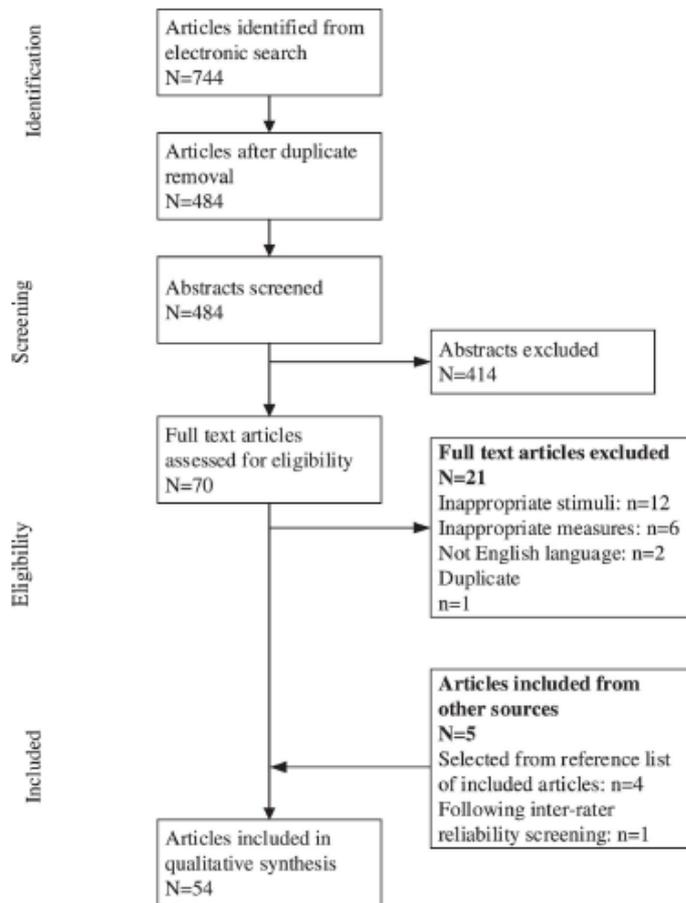


Fig. 1. Flow chart demonstrating method of study identification and screening.

systematic reviews (Higgins and Green, 2011). Participant demographic data was extracted in relation to clinical and comparison samples including number of participants, diagnosis, age and participant matching procedure. Information pertaining to the experimental design and stimuli were also extracted, this included the emotions utilised as well as whether the task was an explicit or implicit FER task. For the purposes of this review, implicit tasks were defined as tasks which required either the passive free-viewing of facial expressions or tasks that required the viewing of facial expressions while completing other recognition tasks (such as gender recognition, or target detection). Further distinction was made in regard to the type of emotion examined in the study. For the purposes of this review basic emotions have been defined as happy, anger, sad, fear, disgust, surprise in accordance with previous literature (Ekman, 1992) and complex emotions as any other emotions. Results extracted related to differences between groups in regard to ET, ERP or quantified EEG outcomes and pertinent within group differences. A summary of extracted data for each study is presented in Tables 1–3.

Initial extraction revealed clear trends in relation to the heterogeneity across studies owing to differences in sample ages, stimulus type, outcome measures and the reporting of results. This appeared to be particularly evident in the studies examining ET measures. Due to

the considerable variance observed across studies, a narrative review was deemed most appropriate to summarise and explore the findings in the various experimental paradigms. Data synthesis examined ET and EEG studies with respect to their various characteristics. For ET studies synthesis involved the number of fixations and duration of fixations to defined areas of interest as well as scan paths, with ET findings presented according to age and stimulus type. In synthesising EEG studies, ERP and EEG frequency features were extracted. Due to the large number of ERP and EEG measures examined within the studies, this review focused on the most frequently examined ERPs within each age category, such as the N170 and P100. Other less common components are discussed briefly. Due to the expected developmental changes studies were allocated to one of three sets. Studies with participants aged 0–12 years of age were classified as child studies, 13–17 years were classified as adolescent and adult pertained to studies of participants aged 18 and above.

#### 2.4 Study evaluation

Two reviewers independently assessed the quality of included studies according to the Kmet Form for quantitative analysis (Kmet et al., 2004). The Kmet form provides a means of appraising the quality of

**Table 1**  
Child Eye tracking and Electrophysiological studies.

Citation	Sample	Comparison		Mean age (SD)	N	Diagnosis	Task Format	Stimuli	Emotions	Key Findings	Methodology Quality											
		Diagnosis	N																			
Eye Tracking Nasik et al. (2014b)	Autism, ASD	19	3.97 (1.06)	TD	19	4.20 (0.60)	CA	Static photographs 30 ms, 300 ms and 2 s exposure times	Fear, Neutral	ASD fixation time on four face for 30 ms and 2 s condition < TD. ASD fixation time on eyes of fearful faces < TD. ASD fixation time to neutral face in 2 s condition < TD. ASD fixation time on eyes and mouth < TD for neutral faces. Fixation time not correlated with ASD symptomatology.	95% (22/24). Participants matched on CA. Correlations with IQ explored. Stimuli counterbalanced.											
												Autism, ASD	21	3.98 (1.05)	TD	21	4.27 (0.60)	CA	Dynamic, videos of familiar and unfamiliar faces expressing emotion. 4 s neutral followed by 4 s fearful expression exposure time.	Fear, Neutral	ASD # of fixations on fear = TD. ASD # of fixations on neutral < TD. ASD # of fixations on fear > neutral. TD # of fixations on fear = neutral. ASD fixation time on eye and mouth of neutral familiar and unfamiliar faces < TD.	87% (21/24). Participants matched on CA. Correlations with IQ explored. Counterbalanced exposure duration of stimuli.
De We et al. (2008)	AS, PDD-NOS, Autism	13	5.17 (.89)	TD	14	4.93 (1.11)	N/A	Static photographs 10 s exposure time.	Calm, Happy, Angry, Fear	ASD fixation time < TD. ASD fixation time on eye region = TD. Social and communication impairment scores negatively correlated with overall fixation time on the screen and fixation time on the mouth.	85% (20/24). Sample size small. Participant matching procedure unclear. Stimuli pseudo-randomized. Partial discussion of limitations.											
Falic-Yter et al. (2010). Study 1 + 2	Autism, AS, PDD-NOS	1115, 213	5.17 (.91)	TD	15	4.91 (.68)	N/A	Static photographs followed by dynamic videos, 4 s exposure time. Upright and inverted stimuli	Anger, Happy, Disgust, Fear, Neutral, Unlabeled Grimace	Study 1: ASD fixation time on eyes and mouth = TD. Social impairment positively correlated with fixation time on mouth and negatively correlated with fixation time on eyes. Communication impairment positively correlated with fixation time on eyes and negatively correlated with fixation time on mouth. Dynamic faces allowed same results but no correlation between communication impairment and fixation time on eyes. Same pattern as above also for each separate emotion	85% (20/24). Sample size small. Participant matching procedure unclear although estimate of developmental age calculated using PEP-R and GMDS. Partial stimuli randomization. Limitations not well described.											

(continued on next page)

Table 1 (continued)

Citation	Sample Clinical	Comparison		Matching procedure	Task Format	Stimuli	Emotions	Key Findings	Methodology Quality
		Diagnosis	N						
Falk-Ytter et al. (2010), Study 3	Autism, AS PDD-NOS	TD	12	6.58 (.67)	Implicit	Dynamic, videos, 4 s exposure time, upright and inverted stimuli.	Anger, Fear, Happy, Neutral	Positive correlation of fixation time on mouth and social impairment score on SCQ	At Above
Bul et al. (2010)	Autism, PDD-NOS	TD	26 (30 ET)	11.16 (2.89)	Implicit and Labelling (ET behavior obtained only during implicit task)	Dynamic, morphing stimuli Exposure time 15–30s	Anger, Disgust, Fear, Happy, Surprise, Sad	ASD fixation time on areas not eye and mouth = TD. ASD fixation time on nose/core/outside regions > TD when viewing fear. ASD children who had shorter fixation time on mouth and longer on eyes more accurate at disgust recognition. TD greater fixation time on eye and shorter fixation time on mouth more accurate at surprise recognition. Greater fixation time on eyes related to lower fear recognition in TD. ASD greater fixation time on not eye and mouth = slower surprise recognition.	90% (22/24), ASD sample for eye tracking analysis small. Results reported in partially sufficient detail.
Van der Gaag et al. (2002)	Autism, PDD-NOS	TD	17	10.1 (1.3)	Implicit	Static, Photographs 10 s exposure time.	Anger, Happy, Neutral, Surprise	ASD fixation time and # of fixations on all regions = TD. ASD first fixation location = TD.	90% (22/24) Stimuli randomized procedure unclear.
Loong et al. (2013)	autism, AS	TD	26	10.6 (1.3)	Matching	Static, pseudo photograph stimuli presented for 10s followed by whole face 'character' stimuli exposed until participant choice selected.	Anger, Happy, Surprise	ASD # fixations on whole face and pseudo stimuli = TD. ASD fixation time > TD regardless of area of stimuli.	86% (21/24). Participants matched only on CA. Stimuli not randomized.
Cravford	Autism, AS	1; FMS,	1;	11 (3.48)	Implicit	Static, photographs	Happy,	ASD and FMS fixation time to	90% (22/24). Sample size (continued on next page)



Table 1 (continued)

Citation	Sample Clinical	Comparison		Matching procedure	Task Format	Stimuli	Emotions	Key Findings	Methodology Quality				
		Diagnosis	N							Mean age (SD)	Diagnosis	N	Mean age (SD)
		N	Mean age (SD)							N	Mean age (SD)		
Vannings et al. (2010)	ASD	22	4 (0.1)	4.3 (0.2)	DD	17	4.3 (0.2)	CA, Gender, SON-R, WPPSI-R, MSEL, REP, Reynell Test for Language	Implicit	Static, photographs, High and low spatial frequencies, 500 ms exposure time.	Neutral, Fear	amplitude for neutral < fear, TD NSW amplitude to fear > neutral, ASD NSW to fear = neutral, ASD NC and P500 = TD.	90% (22/24). Analytic method partially described. Limited discussion of study limitations.
Wong et al. (2008)	Autism	10	8.5 (1.5)	8.5 (1.4)	TD	12	8.5 (1.4)	CA, RPM	Implicit and Labelling (control/ emotion)	Static, photographs, stimuli exposure time 750 ms	Happy, Sad, Angry, Fear, Neutral	ASD P100, N170 amplitude and latency = TD, ASD P200 amplitude to happy in right hemisphere > fear and neutral in right hemisphere. Dipole source at occipital, temporal, frontal and parietal regions in ASD weaker or delayed at sub-second latencies.	90% (22/24). Sample size small. Stimuli pseudo-randomized.
Yeung et al. (2014)	ASD	18	9.61 (3.13)	10.72 (3.61)	TD	18	10.72 (3.61)	CA, Gender, WISC IV (Hong Kong) CVT	Labelling	Static, photographs, stimuli presented until participant response.	Happy, Fear, Angry, Disgust, Surprise, Sad, Neutral	ASD lower right frontal theta coherence for sadness, disgust and surprise, TD higher theta coherence when viewing emotions (except anger) compared to neutral faces. ASD Theta not higher for emotional faces versus neutral. ASD increase in right frontal theta coherence associated with lower autistic symptomology.	96% (23/24). Stimuli pre-set randomized.
Apothia et al. (2012)	Autism	10	10.2	9.7	TD	12	9.7	N/A	Implicit	Static, photographs, 56 stimuli exposure time 850 ms.	Happy, Fear, Neutral	ASD ppN170 = TD.	71% (17/24). Sample size small. Limited discussion of participant characteristics or participant source. Participant matching procedure unclear. Results in partial detail. Limited discussion of limitations.
Bury et al. (2011)	Autism	15	10.55(3.31)	1; 7.70 (3.8), 2; 2; 10.51 (3.2)	1; TD, VF 2; TD CA	1; 15 2; 15	1; 7.70 (3.8), 2; 2; 10.51 (3.2)	CA (1), PPVT (French), RPM, WISC-III	Implicit	Static, photographs, 500 ms exposure time.	Happy, Angry, Disgust, Sad, Surprise, Fear	CA matched, ASD P100 amplitude < TD, ASD P100 lower than TD, ASD delayed N170, VE matched: ASD P100 amplitude < TD, ASD	90% (22/24). Sample size small. Limited discussion of study limitations.

(continued on next page)

Table 1 (continued)

Citation	Sample	Comparison		Matching procedure	Task Format	Stimuli	Emotions	Key Findings	Methodology Quality			
		N	Mean age (SD)									
De Jong et al. (2008)	Autism, ASD	30	10.7 (1.8)	TD	30	10.6 (1.6)	CA Gender WISC III	Implicit	Static and Dynamic, (morphing) High and low spatial frequency, direct and averted gaze. Stimuli with direct and averted gaze exposure time = 373 ms, morphing stimuli = 440 ms (40 ms, 11 frames)	Fear, Neutral	P100 latency = TD. ASD N170 amplitude for fear = neutral. TD N170 amplitude for fear > neutral. ASD N170 amplitude to fear < TD. Low spatial frequency versus high spatial frequency effect smaller in ASD group.	100% (24/24)
O'Connor et al. (2005)	AS	15	11.6 (1.9)	TD	15	11.2 (1.8)	CA, Gender	Labeling	Starks, photographs, Stimuli 1 s exposure time.	Happy, Sad, Angry, Fear	ASD N170, P100 and P200 amplitude and latency = TD. on CA.	92% (22/24). Sample size small. Participants matched on CA.
Tye et al. (2014)	1:ASD, autism, 2: ASD, + ADHD	1; 19, 2; 29	1; 11.69, 2; 10.53	1; TD, 2; ADHD	1; 26, 2; 18	1; 10.56 (1.79), 2; 10.48 (1.91)	CA, IQ	Implicit	Starks, photographs, exposure time 1.2s	Disgust, Fear, Angry, Joy, Neutral	ASD/ASD + ADHD N170 amplitude < TD. ASD/ASD + ADHD N170 amplitude to fear < neutral. TD and ADHD only N170 amplitude for fear = neutral. ASD + ADHD N170 shorter to angry compared to neutral. ASD shorter N170 to neutral compared to angry. ASD + ADHD longer N170 to happy compared to fear and ASD larger N170 latency to fear compared to happy. N400 latency shorter in ASD compared to TD and AS + ADHD.	92% (22/24). Participants matched only on CA and verbal IQ. Stimuli not randomized but randomized inter-stimuli period.

Abbreviations: ASD, Autism Spectrum Disorder, TD, Typically developing, CA, Chronological age, PDD-NOS, Pervasive Developmental Disorder Not Otherwise Specified, AS, Asperger Syndrome, K-BIT, Kaufman Brief Intelligence Test, WISC, Wechsler Scale of Intelligence, FSIQ, Full Scale IQ, Vineland Adaptive Behavior Scales, SEB, Socio-economic Status, MSEL, Mullen Scale of Early Learning, M-A, Mental age, SON-R, Stanford-Binet Nonverbal Intelligence Test - Revised, WPPSI-R, Wechsler Preschool and Primary Scale of Intelligence - Revised, PPVT, Psychometric Assessment of Vocabulary, WISC, Wechsler Intelligence Scale for Children, CVT, Chinese Vocabulary Test, PPVT, Peabody Picture Vocabulary Test, WI, Verbal Equivalent, ADHD, Attention Deficit Hyperactivity Disorder, N/A denotes areas where sufficient information was not provided by study.

**Table 2**  
Adolescent Eye Tracking and Electrophysiological Studies.

Citation	Sample	Clinic #	Comparison		Mean age (SD)	Matching procedure	Task Format	Stimuli	Emotions	Key Findings	Methodology Quality	
			N	Diagnosis								
Boels et al. (2013)	ASD	10	14.7 (1.1)	TD	10	14.6 (1.2)	CA	Labeling	Dynamic, VR avatars, 25–40 s exposure time of neutral face lip syncing followed by expression presented for 5s.	Enjoyment, Surprise, Contempt, Sad, Fear, Disgust, Anger	ASD fixation time on forehead > TD and fixation time on mouth < TD. ASD fixation time outside of face > TD. ASD fixation time on face < TD. Similar results for correct/incorrect trials.	92% (22/24). Small sample size. Participants only matched on CA
Boels et al. (2014)	ASD	10	14.7 (1.1)	TD	10	14.6 (1.2)	CA, DAS, SB, WISC (ASD), WISC (TD)	Labeling	Dynamic, VR avatars, 10–15 s exposure time of neutral face lip syncing followed by expression of varying intensity for 5s	Joy, Surprise, Contempt, Sad, Fear, Disgust, Anger	ASD fixation time to face eyes, nose and other = TD. ASD fixation time on mouth < TD. ASD fixation time on forehead > TD.	92% (22/24). Sample size small. Outcome measure partially described.
McCabe et al. (2013)	Autism, AS, PDD-NOS	14	14.71 (2.87)	1: TD, 2: 22q11DS	31, 2	1:16.55(3.3), 2: 16.75 (3.71)	CA	Labeling	Static, Photographs, 6 s exposure time.	Happy, Sad, Surprised, Disgust, Fear, Anger, Neutral	ASD and 22q11DS ≠ of fixations to face < TD. When IQ controlled for this effect was not significant. ASD fixation time on core features = TD.	88% (21/24). ASD sample small. Participants matched only on CA but IQ controlled for stimulus not randomized.
White et al. (2015)	ASD	15	14.88 (1.55)	TD	18	14.33 (1.52)	CA, Gender	Implicit	Static, photographs of single face and face pairs. Both presented for 4s	Face pairs: Disgust, Anger, happy, calm (instead of neutral), Single face: Happy, Sad, Surprise, Anger, Disgust, Fear, Analysis undertaken on Disgust, angry and happy only.	ASD fixation time on face and eyes = TD. After controlling for negative evaluation, ASD fixation time on eyes and face < TD. In ASD, Fear predicted fixation duration to face for anger and disgust. When stimulus presentation divided into 500 ms epochs, ASD fixation time on angry in 1st 500ms < TD. Progressive disengagement to disgust more apparent in ASD versus TD. ASD attention to disgust in 1st, 7th, and 8th 500 ms epochs < TD.	88% (21/24). Sample size small. Participants matched on CA.
Dalton et al. (2005)	Autism, AS	11	15.9 (4.7)	TD	12	17.1 (2.78)	CA	Labeling (neutral/ emotion)	Static, photographs, Dance and Averred Gnat, 3s exposure time.	Neutral, Happy, Fear, Anger	ASD fixation time on eyes < TD. ASD fixation time on mouth and face = TD.	75% (18/24). Sample size small. Participants matched on CA. Analytic method partially described. Stimuli not randomized. Partial discussion of limitations and confounders.
Dalton et al. (2008)	Autism, AS	14	15.9 (4.71)	1: FXS, 2: TD	1:9, 2: 15	1: 20.7 (2.77), 2: 16.8 (2.57)	WRIT (ASD = FXS only)	Labeling (neutral/ emotion)	As above.	Happy, Fear, Anger	ASD fixation pattern on eyes and mouth = FXS.	75% (18/24). Sample size small. IQ of TD group not assessed, although FXS and ASD group did not differ in IQ. Stimuli not randomized. RT results not

(continued on next page)

Table 2 (continued)

Citation	Sample	Matching procedure		Task Format	Stimuli	Emotions	Key Findings	Methodology Quality
		N	Mean age (SD)					
Wagner et al. (2013)	ASD	17	17.0 (2.5)	CA, KBIT-2	Static, photographs, 5s exposure time.	Anger, Fear, Neutral	ASD fixation time on face, eye and mouth = TD.	reported in sufficient detail. Good use of stimuli. 100% (24/24)
Torenham et al. (2014)	Autism, AS, PDD-NOS	26	17 (7)	WASI, PPVT-3	Static, photographs, 300 ms exposure time.	Anger, Neutral, Happy	ASD gaze towards eyes < TD for neutral. ASD gaze towards eyes of angry = TD. ASD participants who gave higher threat ratings to neutral faces produced less eye movements towards eyes. This was not seen for angry face or in TD.	100% (24/24).
Haxby et al. (2012)	AS	14	20.5	CA Gender, WASI	Static, photographs 5 conditions: isolated posed faces, isolated acid faces, isolated naturalistic faces, acted acid scenes and naturalistic social scenes 5s exposure time.	Happy, Fear, Sad, Excited, Disgusted, Angry, Romantic, Thinking, Bored, sorry	ASD Fixation time on posed and acted faces = TD. For naturalistic isolated faces, ASD fixation time on hair > TD. chance level or limited in description. Partial description of limitations on eyes < TD and fixation time on body > TD. For naturalistic scenes, ASD fixation time on eye and face < TD.	88% (21/24). Sample size small. Participant characteristics or limited in description. Partial description of limitations
ERG Lerner et al. (2013)	ASD	34	13.07 (2.07)	Age group Norms	Static, photographs of child and adult faces with high and low intensity, stimuli presented until participant response, maximum 3s.	Happy, Sad, Anger, Fear	N170 latency associated with decrease accuracy, after controlling for IQ and age no longer significant. Larger N170 amplitudes had faster responses. Shorter N300 latencies associated with faster response times for adult faces.	100% (24/24)
Alcibi et al. (2010)	Autism, AS, PDD-NOS	14	13.7 (2.3)	CA, Gender, WISC III (Japanese)	Static, direct and averted gaze, Stimuli exposure time 12s	Anger, Fear	ASD P100 amplitude = TD and VPP amplitude and latency = TD. ASD N170 latency = TD. ASD N170 amplitude to congruent ( fearful with averted gaze, anger with direct = incongruent stimuli. TD N170 amplitude to incongruent stimuli.	92% (23/24). Sample size small.
Gross et al. (2012)	ASD	10	14.1 (2.7)	1; TD, 2; ADHD 11, 2; 9	Static, photographs 300 ms exposure time.	Anger, Disgust, Fear, Sad	ASD had a lower induced gamma in emotion recognition task versus gender recognition. ADHD higher induced gamma in emotion recognition versus gender recognition. ADHD higher induced gamma than ASD in emotion recognition.	83% (20/24). Sample size small. It missed discussion of study limitations. Stimuli randomly selected. IQ measured however matching procedure unclear.
Wagner et al. (2013)	ASD	17	17 (2.5)	CA, KBIT-2	Static, photographs, 5s exposure time.	Anger, Fear, Neutral	ASD P100 amplitude = TD. ASD no difference of N170 between fearful,	100% (24/24)

(continued on next page)

Table 2 (continued)

Citation	Sample	Matching procedure	Task Format	Stimuli	Emotions	Key Findings	Methodology Quality
	Clinical						
	Diagnosis	N	Mean age (SD)	N	Mean age (SD)		
	Comparison	Diagnosis	N	Mean age (SD)			

Abbreviations: ASD; Autism Spectrum Disorder, TD; Typically Developing, CA; Chronological age, WI; Wechsler Intelligence Scale for Children, WASI; Wechsler Abbreviated Scales of Intelligence, AS; Asperger Syndrome, PDD-NOS; Pervasive Developmental Disorder Not Otherwise Specified PDS; Fragile X Syndrome, WRIT; Wide Range Intelligence Test, KBIT-2; Kaufman Brief Intelligence Test PVT1; Peabody Picture Vocabulary Test ADHD; Attention Deficit Hyperactivity Disorder. N/A denotes areas where sufficient information were not provided by study.

eight, neutral, TD N170 amplitude to fear > angry.

studies on 14 criteria relating to the research hypothesis, methods, study samples, reporting of results, and conclusions. Two criteria of the Kmet form did not apply to the studies included in this review (intervention blinding of assessor and subject), so the form used for the current systematic review included only 12 criteria (Appendix B). For each of the 12 criteria, the study is allocated a score of 2 (yes/addressed), 1 (partially addressed) or 0 (not addressed) according to the degree to which the criterion was met, therefore the maximum score that any study could achieve was 24 (e.g., 2\*12). Studies achieving a score of 80% or greater are rated as strong, 70–80% are good, 50–69% are adequate and scores of 50% or lower are considered limited.

3. Results

3.1. Search results

The search resulted in a total of 744 articles with the following distribution: Cinahl (40), Embase (189), Medline (171), ProQuest (15), Psycinfo (118), and Scopus (211). Duplicate removal resulted in a total of 484 eligible articles. The titles and abstracts of these articles were reviewed by the first author (MB), resulting in 70 articles being forwarded to full text review. The secondary review excluded an additional 15 articles and included an additional four (two EEG and two ET) from the reference lists of the included articles, one article was also included following inter-rater review (described in Section 3.2). In total, 54 articles were included in this review (31 ET, 22 EEG, 1 ET and EEG).

3.2. Inter-Rater reliability

A random selection of fifty articles identified from the electronic database search were reviewed by two researchers with a background in ASD and FER according to the inclusion and exclusion criteria in order to assess the inter-rater reliability of article assessment. The two reviewers reached consensus on 48 of the 50 articles (96%) and following discussion the reviewers reached agreement on all 50 articles (100%) with one additional article being included in the review (Fig. 1).

3.3. Study type

Fifty-two studies were case-control in nature whereby a sample of individuals with ASD was compared to a comparison group. Two studies did not have a comparison sample (Gayle et al., 2012; Lerner et al., 2013).

3.4. Methodological quality

The majority of included studies (k = 48) were of strong methodological quality (score of 80% or greater) and six were of good methodological quality (70–80%) as assessed by the Kmet form for quantitative analysis. Tables 1–3 outline the assessed methodical quality of the studies. Limitations primarily existed in the description of participant characteristics, process of matching or sample size (Tables 1–3).

3.5. Participant characteristics

As shown in Tables 1–3, Autism, HFA, AS and ASD were the most common clinical samples in this review. Some studies reported including participants with a PDD-NOS diagnosis (Akechi et al., 2013; Bal et al., 2010; Crawford et al., 2015; Dawson et al., 2004; de Wit et al., 2008; Falck-Ytter et al., 2010; Fujita et al., 2013; Magnée et al., 2008; McCabe et al., 2013; Tottenham et al., 2014; Van der Geest et al., 2002). Primarily, ASD participants were high functioning (at least average IQ) however, one study reported including a sample of

**Table 3**  
Adult Eye Tracking and Electrophysiological Studies.

Citation	Sample	Matching Procedure		Task Format	Stimuli	Emotions	Key Findings	Methodological Quality				
		N	Mean Age (SD)									
Eye Tracking Farr et al. (2015)	Clinical Diagnosis	N	Mean Age (SD)	Matching Procedure	Task Format	Stimuli	Emotions	Key Findings	Methodological Quality			
		12	19.5 (8.1)									
		Diagnosis	N	Mean Age (SD)								
		1: TD child, 2: TD adolescent	1; 12; 2; 12	1; 7.0 (2.2); 13.4 (0.9)	Dynamic, (morphing) Human Face and mechanical Face). 4 s exposure time.	Happy, Disgust, Fear, Surprise	ASD fixation time < TD. ASD fixation time on core features > non-core features. ASD fixation time on core features < TD for mechanical display. ASD fixation time on core features < TD for mechanical face < human face. ASD fixation time to mechanical motion > TD. ASD fixation time on core features = mechanical motion. TD fixation time on core features > mechanical motion.	86% (21/24). SD multi not randomized. Limitations partially discussed.				
Sawyer et al. (2012)	AS	29	21.6 (9.8)	CA, WAS	Matching and Labelling (ET obtained only during full face and perine viewing)	Static, photographs, 5 s exposure time. Happy, Sad, Surprised, Fear, Anger, Disgust, Scowling, Grin, Thoughtful, Amazing, Quizzical, Flirting, Bored, Interested, Arrogant, Embarrassed	ASD fixations on eyes and mouth = TD. ASD% of time first fixations to eyes = TD.	96% (23/24). Partial discussion of limitations.				
Neuman et al. (2006)	Autism	10	23 (2)	TD	10	28 (3)	CA, WAS, Gender	Labelling	Static, Whole Face and Gaussian Bubbles Upright and Inverted Faces. Whole face stimuli exposure time 1s. Bubbled stimuli presented until participant response or a maximum of 10s.	Rac, Happy (Gaussian Bubbles), happy, sad, anger, fear, disgust, surprise, neutral (whole face)	ASD viewing of upright whole face = TD. When faces whole and inverted, ASD fixation time on mouth > TD. In bubbled condition, ASD fixation time on mouth > TD and ASD fixation time on eyes < TD.	92% (22/24). Sample size small. What face stimuli viewed by 11 participants. Limited discussion of limitations.
Swanson et al. (2007)	Autism	10	23 (5.27)	1:TD, 2: Schizophrenia	10	22.4 (6.3); 28.1 (5.07)	CA, WAS	Labelling	Static, face and digitally erased faces, exposure time 3s.	Happy, Surprise, Rac, Anger, Sad, Disgust, Neutral	In face present condition: ASD fixation time on face < TD. ASD oriented to faces at the same speed regardless of face condition. ASD showed negative correlation between fixation time on face and recognition accuracy in face present condition. TD oriented faster to face in face present condition compared to face-absent.	83% (20/24). Sample size small. Stimuli not randomized. Partial discussion of limitations.
Spazio et al. (2007a)	Autism ET	9 (8 ET)	23 (6.75)	TD	10 (5 whole face)	28 (8.15)	CA, WAS	Labelling	Static Whole Face and Gaussian Bubbles. Stimuli displayed until participant response with maximum of 10s.	Rac, Happy (Gaussian Bubbles), Happy, Rac, Anger, Surprise, Disgust (whole face)	In bubbled condition, ASD fixation time and # of fixations to mouth > TD and ASD fixation time to right eye < TD. ASD fixation time for whole face	87% (21/24). Sample size small. Partial discussion of limitations.

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Table 3 (continued)

Citation	Sample	Matching Procedure		Task Format	Stimuli	Emotions	Key Findings	Methodological Quality		
		Comparison								
		Diagnosis	N							
		Mean Age (SD)	N	Mean Age (SD)						
Spiso et al. (2007b)	Autism	8 (7.11)	10	28 (8.15)	CA, WAS	Labeling	Whole face stimuli displayed for 1s. Static, Gaussian Bubbles Stimuli displayed until participant response with maximum of 10s.	Rest, Happy	When bubbles revealed more information in the left eye, ASD fixation time on mouth > TD. When bubbles revealed more information at the mouth, ASD fixation time on mouth < TD.	88% (20/24) Sample size small. Results not reported in sufficient detail. Partial discussion of limitations
Hernandez et al. (2009)	Autism	11 (8.31)	23	22.2 (3.6)	N/A	Implicit	Static, photographs, neutral face with direct and averted gaze, emotional face and avatars faces 4 s exposure time.	Happy, Sad, Neutral	ASD fixation time on core features = fixation time on non-core/outside features. TD fixation time on core features > fixation time on non-core/outside features. ASD fixation time on eyes < TD for neutral, happy, sad, neutral with averted gaze and avatars stimuli. ASD fixation time on nose < TD for neutral, happy, and sad and neutral with averted gaze stimuli. ASD fixation time on mouth = TD. ASD fixation time on outside regions/off screen > TD for all stimuli. ASD started exploration of face on eyes < TD and started exploration on mouth > TD.	79% (19/24). Sample size small. Participant matching procedure unclear. Participant source not described. Participant characteristics partially described. Limitations partially discussed.
Pdjhay et al. (2002)	HFA	5 (25.2)	5	28.2	N/A	Implicit and Labeling	Static, photographs, 2s exposure time	Happy, Rest, Anger, Disgust, Surprise, Sad	ASD fixation time and # of fixations on core regions < TD. ASD fixation time on eyes and nose < TD. ASD fixation time on mouth = TD. ASD # fixations and exploration of face on eyes < TD and started exploration on mouth > TD.	71% (17/24). Sample size small. Matching procedure unclear. Results not reported in sufficient detail. Stimuli not randomized.
Rutherford et al. (2008)	autism, AS	11 (6.09)	11	25.7 (8.87)	CA, Gender, WAS, Education	Labeling	Static, photographs, stimuli exposure time 2.5s	Happy, Surprise, Anger, Disgust, Sad, Fear, Disgust, Surprise, Shame, Contempt, Thoughtful, Flirting, Amused, Quizzical, Bored, Interested, Guilty, Arrogant.	ASD fixation time to eyes and mouth = TD. ASD # fixations on features of complex emotion < basic emotion. TD fixation time on features of complex emotion > basic emotion.	83% (20/24). Sample size small. Stimuli not randomized. Partial discussion of limitations
Fellmer et al. (2011)	AS	24 (10.8)	24	28.9 (10.6)	CA, gender	Matching	Static, Whole Face and Pseud. Pseud. stimuli exposure time 10s whole face stimuli displayed until participant response.	Happy, Anger, Surprise	Matched stimuli: ASD # of fixations on eyes < TD. ASD # fixations on mouth > TD. ASD # fixations on non-core/outside face = TD. ASD fixation time to eyes and non-core/outside of face = TD. Whole face stimuli: ASD # fixations on eyes < TD. ASD # fixations on	88% (21/24). Participant IQ not accounted for. Stimuli not randomized.

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Table 3 (continued)

Citation	Sample	Comparison		Mean age (SD)	N	Mean age (SD)	Matching Procedure	Task Format	Stimuli	Emotions	Key Findings	Methodological Quality
		Autism AS	TD									
Kirwan et al. (2012)	Autism AS	16	TD	30.44 (6.34)	17	30.47 (6.23)	CA, MWT Non-verbal strategic thinking (Lubi-Dingens System)	Labelling	Static, photographs, 150 ms exposure time.	Happy, Fear, Neutral	non-core/other parts of face > TD. ASD # fixations on mouth = TD. ASD fixations on non-core/other parts of face > TD. ASD fixation time on eyes and mouth = TD. ASD with higher recognition accuracy made more fixations on the eyes of punched stimuli, made fewer fixations on non-core/outside regions of whole face stimuli, had shorter fixation times on the eyes of punched stimuli and shorter fixation times to the mouth of whole faces compared to ASD participants with lower recognition accuracy.	96% (23/24). Partial discussion of limitations.
Kirwan et al. (2011)	Autism	20	TD	31.9 (7.6)	21	31.8 (7.4)	CA, gender, education, Wechsler test	Labelling	Static, photographs, 4.5s exposure time.	Complex Negative emotion from MFT (e.g., Sad, Angry)	ASD fixation time on eyes and mouth = TD. ASD fixation time on face < TD. Fixations on eye predictor of performance in ASD group and fixation time on mouth negative predictor of performance in ASD.	92% (22/24). 56 small counterbalanced.
Kirwan et al. (2010)	ASD	12	TD	35.4 (8.1)	11	27.1 (2.6)	Gender, MWT	Labelling	Static, photographs, 150 ms exposure time.	Happy, Fear, Neutral	ASD preference for eyes < TD. ASD tendency to gaze away from eyes downward to mouth when initially fixating on eyes > TD. TD tendency to gaze upward to eyes than downward to mouth for neutral and low ASD eye preference index positively correlated with performance, not seen in TD. Eye preference index negatively correlated with ADI-R social score. No correlation of ADI-R communication score, AQ or verbal IQ and gaze patterns.	96% (23/24). RT sample size small.
Cordes et al. (2008)	AS	18	TD	32.9 (13.35)	17	31.9 (11.30)	CA, Gender, WASH, DTVP	Implicit and Labelling	Static, photographs, 2.5s stimulus exposure	Happy, Sad, Fear, Surprise, Angry,	ASD fixations on eyes < TD. ASD fixations on face = TD. Fixation	100% (24/24).

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Table 3 (continued)

Citation	Sample	Matching Procedure		Task Format	Stimuli	Emotions	Key Findings	Methodological Quality
		Comparison						
		Diagnosis	N					
		Mean Age (SD)	Mean Age (SD)					
Boraston et al. (2008)	Autism, ASD/AS	11	11	CA, WAS	Static photographs, 2.5 s exposure time	Disgust Neutral, Genuine Smile, Pseud Smile	Time not associated with ASD symptom severity. Reduced recognition of fear in ASD associated with fewer fixations on eyes. High axial activity in ASD associated with reduced fixations on eyes.  ASD gaze time on eye regions < TD ASD fixations to the eye region < TD. No correlations found between gaze time or % fixations and performance.	90% (22/24). Sample size small. Partial discussion of limitations.
ERG Yang et al. (2011)	AS	5	7	N/A	Static photograph, 4 s exposure time	Anger, Happy, Neutral	Theta synchronization weaker in ASD. Beta2 and alpha desynchronization strong in ASD	71% (17/24). Sample size small. Limited discussion of participant characteristics and matching procedure. Control population not described. Limited estimate of variance.
Truong et al. (2015)	AS	10	10	Gender, WAS III	Static, Photograph and line drawing of face. Exposure time 1 s	Neutral, Happy, Anger	ASD N170 amplitude and latency = TD. In line drawing task ASD N400 amplitude = TD. In photograph task N400 amplitude in ASD < TD. ASD weaker delta/beta synchronization than TD in early and late stages of emotion recognition. ASD fewer distant left-hemispheric connections than TD in line drawing task.	90% (23/24). Sample size small.
Guyll et al. (2012)	AQ male	37	37	Implicit	Static photographs exposure time 150 ms	Neutral, Sad, Happy	rMMN amplitude to happy positively correlated with AQ score (smaller/more positive amplitude associated with higher AQ score).	90% (23/24) Limited discussion of participant characteristics. Small pseudo-randomized.
Lawrie et al. (2015)	High AQ	25	25	N/A	Static, Direct and averted gaze and upright and inverted Neutral face with direct gaze exposure time 500 ms, neutral face with averted gaze exposure time 200 ms, emotion face with averted gaze exposure time 300 ms.	Real, Happy	Effect of congruency on P100 significant in low but not high AQ groups. EDAN in high AQ = EDAN in low AQ. Laterality effect of ADAN present in low AQ group only.	90% (22/24). Participant matching procedure unclear, however, anxiety measured for all participants. Limited discussion of limitations.

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Table 3 (continued)

Citation	Sample	Matching Procedure		Task Format	Stimuli	Emotions	Key Findings	Methodological Quality			
		Comparison									
		Diagnosis	N								
		Mean Age (SD)	Mean Age (SD)								
Magnee et al. (2008)	PTSD	12	13	21.5 (4.0)	23.0 (2.9)	CA, WAIS III	Implicit	Static, photographs with congruent and incongruent auditory pairs. Face stimuli presented for 900 ms before auditory stimuli. Face stimuli remained until end of auditory presentation.	React, Happy	ASD N170 and P100 = TD. ASD N200 amplitude to fear voice < happy voice when presented with fear face. TD N200 amplitude to fear voice > happy voice when presented with fear faces.	88% (20/24). Sample size small. Analytic method partially described. Limited discussion of source of participant and discussion of limitations.
Magnee et al. (2011)	HFA	23	24	22.7 (5.8)	22.7 (1.9)	CA, WAIS III (Dutch) Gender	Implicit	Static, Congruent and incongruent Visual and Auditory Pairs. Face stimuli exposure time 100 ms, auditory stimuli presented for 500 ms.	React, Happy	No differences in N170 to visual stimuli. TD had significant congruency effects for N170 amplitude for divided attention condition (both auditory and visual input) in left hemisphere but not ASD group.	88% (21/24). Limited discussion of participant source. Analytic method partially described. Limitations partially described.
O'Connor et al. (2007)	AS	15	15	23.5 (5.2)	23.8 (4.4)	CA	Labelling	Static, photographs, stimuli exposure time 600 ms.	Neutral, Sad	ASD N170 amplitude = TD. ASD N170 latency to eyes and mouth > than TD. ASD latency to faces > TD. ASD N170 latency to faces = objects. TD N170 latency to faces shorter than to objects. ASD P100 = TD.	92% (22/24). Sample size small. Participants matched on CA.
O'Connor et al. (2005)	AS	15	15	24.6 (8.8)	23.8 (8.7)	CA, Gender	Labelling	Static, photographs, Stimuli 1 s exposure time.	Happy, Sad, Anger, Fear	ASD P100 amplitude = TD. ASD P100 and N170 latencies > than TD. ASD N170 amplitude < than TD. ASD P200 = TD.	92% (22/24). Sample size small. Participants matched on CA.
Cooper et al. (2013)	High AQ	10	10	25.4 (for both groups)	25.4 (for both groups)	N/A	Implicit	Dynamic, video of faces with hand movement. Stimuli exposure time 3s.	Happy, Anger, Neutral	High AQ greater low brain event related desynchronization to angry compared to happy. No group differences in alpha. Low AQ greater low brain event related desynchronization to happy compared to angry and neutral. Low AQ had greater low brain event related desynchronization to happy compared to high AQ.	88% (20/24). Sample size small. Limited discussion of participant source or participant characteristics. Group matching procedure unclear.
Fujita et al. (2013)	Autism, AS, PDD-NOS	9	10	31.5	26.8	CA	Implicit	Static, photographs, upright and inverted. 20 ms exposure time.	React, Neutral	ASD N100 amplitude for upright and inverted faces = upright and inverted objects. TD N100 amplitude to fear in upright > objects in upright. No subliminal (face effect in ASD (object – fear or neutral). TD subliminal (face effect with N100 amplitude for upright fear > inverted fear. ASD N100 amplitude subliminal face	88% (21/24). Sample size small. Participants matched on CA.

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Table 3 (continued)

Citation	Sample	Matching Procedure	Task Format	Stimuli	Emotions	Key Findings	Methodological Quality								
								Comparison							
	<table border="1"> <tr> <td>Classic</td> <td></td> </tr> <tr> <td>Diagnosis</td> <td>Mean age (SD)</td> </tr> <tr> <td>N</td> <td>N</td> </tr> <tr> <td>Mean age (SD)</td> <td>Mean age (SD)</td> </tr> </table>	Classic		Diagnosis	Mean age (SD)	N	N	Mean age (SD)	Mean age (SD)						
Classic															
Diagnosis	Mean age (SD)														
N	N														
Mean age (SD)	Mean age (SD)														

effect < TD for upright condition.  
ASD P300 = TD.

Abbreviations: LFA: Low Functioning Autism; TD: Typically Developing; CA: Chronological age; CPDI: Bayley Coloured Progressive Matrices; AS: Asperger Syndrome; WAS: Wechsler Abbreviated Scale of Intelligence; HFA: High Functioning Autism; WAS: Wechsler Adult Intelligence Scale; MW7: Math Multiple-Choice Vocabulary Test; DTP: Developmental Test of Visual Perception; AQ: Autism Spectrum Quotient; N/A denotes where no sufficient information was not provided by study.

individuals with LFA (Han et al., 2015).

In the majority of studies, comparison groups consisted of TD individuals. A subset of studies compared the ASD sample to groups of participants with other disabilities or conditions such as ADHD (Gross et al., 2012; Tye et al., 2014), developmental delay (Vlamings et al., 2010), Fragile X syndrome (FXS) (Crawford et al., 2015; Dalton et al., 2008), 22q11 Deletion Syndrome (22q11DS) (McCabe et al., 2013) and Schizophrenia (Sasson et al., 2007) while two studies included in this review did not include a comparison sample (Gayle et al., 2012; Lerner et al., 2013). Participant groups were primarily matched on chronological age and verbal or non-verbal intelligence (Tables 1–3).

### 3.6. Task format

Procedures requiring participants to overtly determine the presented emotion via labelling or matching tasks were employed in 31 studies. Implicit tasks, that is, those that did not require the explicit recognition of emotion or required only the passive viewing of stimuli, were used in 32 EEG and ET studies, with a number of studies employing both.

Stimuli consisted primarily of static photographs. Eight studies presented dynamic stimuli of facially expressed emotions (Bal et al., 2010; Bekele et al., 2014; Bekele et al., 2013; Cooper et al., 2013; de Jong et al., 2008; Falck-Ytter et al., 2010; Han et al., 2015; Nuske et al., 2014a). While whole face stimuli were presented in the majority of studies, some studies utilised experimentally manipulated stimuli including: revealing only certain features of the face via bubbles (Spezio et al., 2007a; Spezio et al., 2007b) or puzzle pieces (Falkmer et al., 2011; Leung et al., 2013), presenting upright and inverted stimulus orientation (Falck-Ytter et al., 2010; Fujita et al., 2013; Lassalle and Itier, 2015; Neumann et al., 2006), manipulating spatial frequencies (de Jong et al., 2008; Vlamings et al., 2010) or line drawings (Tseng et al., 2015), direct and averted gaze (Akechi et al., 2010; Hernandez et al., 2009; Lassalle and Itier, 2015; Van der Geest et al., 2002), familiar and unfamiliar faces (Nuske et al., 2014a), and digitally erased faces (Sasson et al., 2007).

The six basic emotions (happiness, anger, sadness, disgust, fear, surprise) or a subset of these six were presented in the vast majority of studies. For the purposes of this review 'neutral' was also considered a basic expression due to its potential in controlling for effect of emotional content on the outcomes. Complex emotions such as calm (de Wit et al., 2008), contempt (Bekele et al., 2014; Bekele et al., 2013), flirting, admiring, quizzical (Rutherford and Towns, 2008; Sawyer et al., 2012) and others were presented in a limited number of studies (Bekele et al., 2014; Bekele et al., 2013; Kirchner et al., 2011; Rutherford and Towns, 2008; Sawyer et al., 2012). Two studies used stimuli that consisted of posed and Duchenne smiles to determine differences in the eye gaze patterns when differentiating genuine and posed smiles in ASD (Boraston et al., 2008; Key et al., 2015).

## 4. Eye tracking

### 4.1. Children

#### 4.1.1. Static basic emotions (k = 6)

Findings of studies comparing children with ASD to TD samples were mixed in regard to eye gaze patterns to the core facial features. Van der Geest et al. (2002) not only reported a similar number of fixations to the eyes and mouth, but also found that children with ASD made the majority of their first fixations to the eyes, similar to TD populations, when completing a free viewing task of angry, happy, neutral and surprised expressions. de Wit et al. (2008) also failed to find reduced gaze to eyes in children with ASD during the viewing of happy, angry and fearful expressions. Similar findings were reported by Falck-Ytter et al. (2010) when examining the ratio of looking time to happy, angry, disgusted, fearful, neutral and unlabelled grimace emotions,

with children with ASD having similar looking times to both the eyes and mouth. Leung et al. (2013) reported comparable results in response to angry, happy, and surprised emotions. They presented children with ASD with whole face stimuli and puzzle pieces with eyes either bisected or whole. They postulated that the eyes bisected condition would not affect the recognition accuracy of children with ASD due to their purported lower reliance on the eyes in face and emotion processing. However, not only did the children with ASD make a similar number of fixations to the eyes as their TD counterparts, their accuracy in recognition was also impaired in the eyes bisected condition to a similar extent as in the control sample (Leung et al., 2013).

Nuske et al. (2014b) hypothesised that children with ASD would display differences in gaze behaviour in response to emotional faces, presented for either 30msec, 300msec, or 2 s. Consistent with this, children with ASD had shorter fixation durations to the eyes of fearful expressions and neutral faces across all stimuli exposure conditions (30 msec, 300 msec, 2 s) driven by differences in the longest exposure time (2 s). Children with ASD also made shorter fixations not only to neutral faces when presented for the longest exposure period (2 s), but also to fearful expressions when presented for 30 msec and 2 s (Nuske et al., 2014b). Furthermore, children with ASD made shorter fixations to the mouths of neutral, but not fearful faces across display conditions (driven by differences in the 2 s conditions). Van der Geest et al. (2002), reported no differences between children with ASD and TD children in either the number of fixations or the time spent on the face or non-core face areas. Nevertheless, de Wit et al. (2008) found that children with ASD had a shorter overall looking time compared to TD children. Similar to the findings in regard to the core features of the face, Leung et al. (2013) reported no differences in the number of fixations but reported longer fixation durations for children with ASD regardless of stimuli type, emotion or area of interest.

When examining correlations between social and communication abilities as measured by the Autism Diagnostic Interview-Revised (ADI-R), de Wit et al. (2008) found a negative correlation between these scores and looking time to the screen and percentage of looking time to the mouth. Similarly, when examining children with and without ASD, Falck-Ytter et al. (2010) found a positive correlation between social impairment and looking time to the mouth and a negative correlation between social impairment and looking time to the eyes, while the inverse was true for communication impairment.

When compared to children with FXS, children with ASD looked significantly more to the eyes of neutral expressions. However, dwell time on faces with happy, disgusted, and neutral expressions was similar in both groups, suggesting that attention to emotional faces is allocated similarly in these groups (Crawford et al., 2015).

#### 4.1.2. Static complex emotions ( $k = 1$ )

The complex emotion of calm was included in one free viewing task (de Wit et al., 2008). While this study did not conduct separate eye gaze analysis comparing basic and complex emotions, it was found that children with ASD had a shorter overall looking time to emotional faces compared to TD children, however no differences were reported in regard to fixation time on the eyes.

#### 4.1.3. Dynamic basic emotions ( $k = 3$ )

Reduced fixations to the eyes were reported for children with ASD in one study (Nuske et al., 2014a) that explored the effect of face familiarity on emotion perception. While children with ASD had divergent gaze to the eyes, these differences were present only in response to neutral, but not to fearful faces, with children with ASD making fewer fixations to the eyes regardless of familiarity of the face. In contrast to these findings, Falck-Ytter et al. (2010) reported no differences in the number of fixations children with ASD made to the eye regions of angry, happy, disgusted, fearful, neutral, and grimace facial expressions.

In regard to the other core facial features, ASD-linked differences

have been found, most notably in relation to gaze time towards the mouth. In Nuske et al. (2014a), TD children fixated more to the mouths of neutral expressions than children with ASD when viewing familiar and unfamiliar faces. However, Falck-Ytter et al. (2010) reported no group differences in time spent fixating on the mouth.

Children with ASD have also been found to spend less time looking at faces overall in comparison to their TD counterparts in two studies when viewing dynamic stimuli (Bal et al., 2010; Nuske et al., 2014a). Children with ASD had greater fixation duration percentages to regions other than the face when presented with fearful faces, but not other emotions (Bal et al., 2010). Nuske et al. (2014a) found a reduction in the number of fixations to neutral faces but not fearful faces in children with ASD. Correlations between the ADI-R and gaze behaviour to faces were reported in one study (Falck-Ytter et al., 2010). Similar to the findings with static faces, children with ASD showing high social impairment scores spent more time fixating on the mouth and less on the eyes when viewing dynamic stimuli compared to those with low social impairments. Higher communication impairment scores were associated with less looking time to the mouth, however, there were no correlations between gaze to the eyes and communication impairment. When using the Social Communication Questionnaire (SCQ), a measure of autism symptoms derived from the ADI-R, these findings relating to social impairment and the mouth were replicated. When examining dynamic stimuli presenting an action, those children with ASD who had increased looking time to the face as opposed to the action, had lower social impairment scores but higher communication impairment scores.

## 4.2. Adolescents

### 4.2.1. Static basic emotions ( $k = 6$ )

Adolescents with ASD were found to spend less time looking at faces expressing emotion compared to the TD counterparts (McCabe et al., 2013; White et al., 2015). McCabe et al. (2013) reported a lower number of fixations in adolescents with ASD across the six basic emotions compared to TD adolescents. However, when controlling for IQ, this difference was no longer significant. White et al. (2015) found no differences between their sample of adolescents with ASD and matched controls to disgust and angry expressions, however, when accounting for self-reported ratings on the fear of negative evaluation, the adolescents with ASD had shorter fixation durations on the face. When fixation durations were assessed in 500msec bins, adolescents with ASD reduced their fixation durations to disgust expressions more so than TD adolescents and had reduced fixation durations to angry expressions compared to TD adolescents during the first 500msec, suggesting differences in disengagement from disgust and angry expressions in ASD populations. In contrast however, Wagner (2013) reported no differences in the time adolescents with ASD spent viewing emotionally expressive faces.

In addition to a decrease in time spent fixating on the face, adolescents with ASD were also reported to spend less time fixating on the eyes of emotionally expressive faces (Dalton et al., 2005; Tottenham et al., 2014; White et al., 2015) with two studies reporting similar ET patterns to the eye region in adolescents with and without ASD (McCabe et al., 2013; Wagner et al., 2013). Tottenham et al. (2014) reported that adolescents with ASD made fewer eye movements towards the eyes of neutral but not angry expressions. Dalton et al. (2005) reported fewer fixations to the eyes for happy, fear, angry and neutral expressions. White et al. (2015) reported no differences in fixations to the eyes, however, when accounting for self-report scores of fear of negative evaluation, adolescents with ASD presented with shorter fixation durations to the eye region. In a similar vein, Tottenham et al. (2014) examined the correlations between how threatening adolescents perceived an emotion to be and their gaze patterns. Adolescents with ASD who perceived neutral faces as more threatening had a higher tendency to look away from the eyes, however, this was not seen in response to angry faces or in the TD adolescents.

None of the static simple emotion recognition studies in adolescents reported differences in the eye gaze patterns to the mouth between adolescents with and without ASD, a finding apparent across task formats, participant matching procedures and emotions (Dalton et al., 2008; Dalton et al., 2005; McCabe et al., 2013; Wagner et al., 2013).

#### 4.2.2. Static complex emotions ( $k = 1$ )

Hanley et al. (2012) sought to understand how adolescents process static stimuli with varying levels of social content, presenting adolescents with and without ASD with static images of posed, acted and naturalistic expressions as well as images taken from acted and naturalistic social scenes. Hanley et al. (2012) found no differences for posed or acted isolated expressions, however, adolescents with ASD spent significantly more gaze time viewing the hair of naturalistic isolated faces. When viewing items taken from social scenes, adolescents with ASD spent less time fixating on the eyes and more time on the body in acted social scenes and less time on the eyes and face in naturalistic social scenes (Hanley et al., 2012).

#### 4.2.3. Dynamic complex emotions ( $k = 2$ )

Dynamic complex emotions were used by two studies presented by the same authors (Bekele et al., 2014; Bekele et al., 2013). These studies attempted to evaluate the effect of immersive stimuli on emotion recognition in ASD using animated avatar faces expressing facial emotions. Both studies, examined emotion recognition as well as eye gaze patterns while the avatar was telling a story or talking with a neutral expression. Adolescents with ASD had a greater proportion of gaze time to the forehead and less to the mouth than TD adolescents in both studies (Bekele et al., 2014; Bekele et al., 2013). While there was agreement between the two studies in gaze time to the mouth and forehead, differences arose in other features. In Bekele et al. (2013) adolescents with ASD had a smaller gaze time on the face and a greater gaze time on non-face areas when both groups correctly identified the emotion along with shorter gaze time towards the mouth and longer gaze time towards the forehead. When adolescents with ASD were incorrect, only the difference in gaze time towards the forehead and mouth was significant (Bekele et al., 2013).

### 4.3. Adults

#### 4.3.1. Static basic emotions ( $k = 11$ )

In regard to ET patterns to the core facial features, the most apparent difference between adults with ASD and TD controls related to fixations to the eyes. The majority of studies found that adults with ASD allocated a smaller proportion of time to the eyes, fixated less to the eyes or gazed away from the eyes of emotionally expressive faces more often compared to their TD counterparts (Boraston et al., 2008; Gorden et al., 2008; Falkmer et al., 2011; Hernandez et al., 2009; Kliemann et al., 2012; Kliemann et al., 2010; Pelphrey et al., 2002). This difference was apparent regardless of emotion (Boraston et al., 2008; Gorden et al., 2008; Hernandez et al., 2009; Pelphrey et al., 2002) or whether the task was free viewing (Gorden et al., 2008; Hernandez et al., 2009; Pelphrey et al., 2002) or required active recognition (Boraston et al., 2008; Gorden et al., 2008; Falkmer et al., 2011; Kliemann et al., 2012; Kliemann et al., 2010; Pelphrey et al., 2002).

When considering the relationship between gaze to facial features and FER, Boraston et al. (2008) aimed to examine whether adults with ASD were able to differentiate natural from posed smiles, finding that adults with ASD had both a reduced gaze time and made fewer fixations to the eyes of the expressive faces. Gorden et al. (2008) found that in both free viewing and active recognition of the six basic emotions, adults with ASD had a smaller proportion of fixations to the eyes, despite both ASD and TD scanning different emotions in a similar manner.

Adults with ASD demonstrated no differentiation in eye gaze in relation to emotional expression, unlike TD adults who altered their eye gaze in response to the emotion presented (Kliemann et al., 2012;

Kliemann et al., 2010). Adults with ASD looked downward to the mouth from the eyes more often than TD adults (Kliemann et al., 2010), showing a decreased preference for the eyes of fearful and neutral expressions. This was consistent with Kliemann et al. (2012) who found that adults with ASD made more saccades away from the eye region than TD controls. Hernandez et al. (2009) found that when beginning the exploration of emotional faces, TD adults began their search in the eyes more often than adults with ASD.

Three studies found that individuals with ASD who made more fixations to the eyes had higher proficiency at emotion recognition than those who did not or looked more at other areas of the face (Falkmer et al., 2011; Kliemann et al., 2012; Kliemann et al., 2010). Gorden et al. (2008) found that those with ASD who looked less at the eyes had poorer recognition of fear and those who had higher scores of social anxiety fixated less on the eyes.

In regard to looking time to other core facial features findings are more mixed. Studies reporting on fixations to the nose, found that participants with ASD spent less time on the nose than TD adults (Hernandez et al., 2009; Pelphrey et al., 2002).

Falkmer et al. (2011) found that adults with ASD made a similar number of fixations and had similar duration of fixations on the mouth as TD adults when viewing whole faces. Similarly, despite adults with ASD having a smaller percentage of fixation time to the core features, Pelphrey et al. (2002) found no differences between groups in the proportion of time spent on the mouth. Hernandez et al. (2009) found similar results in their free-viewing task of happy, sad, neutral, neutral faces with averted gaze and avatars with no differences in looking time between groups. However, Hernandez et al. (2009) reported that adults with ASD were more likely to begin their exploration of emotional faces on the mouth compared to TD adults.

While some studies reported that adults with ASD fixated less to whole faces than their TD counterparts (Hernandez et al., 2009), others reported no differences between groups (Gorden et al., 2008; Neumann et al., 2006; Pelphrey et al., 2002). Hernandez et al. (2009) found that adults with ASD spent more time on regions peripheral to the face than TD adults and while TD spent more time on the core facial features than peripheral regions.

A number of studies used other experimental paradigms involving the manipulation of facial stimuli in order to investigate the differential effect of top down and bottom up visual processing strategies (Falkmer et al., 2011; Neumann et al., 2006; Sasson et al., 2007; Spezio et al., 2007a, 2007b). Manipulations included examining the effect of Gaussian bubbles (Neumann et al., 2006; Spezio et al., 2007a, 2007b) or puzzle pieces (Falkmer et al., 2011), inverted faces (Neumann et al., 2006) and digitally erased faces (Sasson et al., 2007). When viewing inverted stimuli, Neumann et al. (2006) found that adults with ASD had longer fixation times to the mouth compared to the TD group. When examining bubbled or puzzled stimuli, adults with ASD looked more at the mouth and less at the eyes than TD adults in four studies (Falkmer et al., 2011; Neumann et al., 2006; Spezio et al., 2007a, 2007b). Spezio et al. (2007b) found that when information was available in the eyes that could assist in the recognition of emotion, adults with ASD looked more towards the mouth than TD adults. Sasson et al. (2007) presented adults with and without ASD and schizophrenia with static images of social scenes with the faces present or digitally erased, hypothesizing that the performance of the clinical populations would be more impacted by the face-present condition. The adults with ASD had a shorter fixation duration to faces in the face present condition in comparison to TD adults with TD adults orientating to the face faster when the face was present versus absent while ASD did not differentiate in orientation speed (Sasson et al., 2007). In contrast to the findings of increased eye fixations and performance (Falkmer et al., 2011; Kliemann et al., 2012; Kliemann et al., 2010), Sasson et al. (2007) found the opposite effect, with adults with ASD having a negative correlation between recognition accuracy and fixation duration to the face.

#### 4.3.2. Static complex emotions ( $k = 3$ )

When viewing static complex emotions, a single study reported that adults with ASD made fewer fixations to faces expressing complex emotions (Kirchner et al., 2011). However, a decrease in looking time to the eyes (Kirchner et al., 2011; Rutherford and Towns, 2008; Sawyer et al., 2012) or divergent eye gaze patterns to other core features of the face, including the mouth (Kirchner et al., 2011; Rutherford and Towns, 2008; Sawyer et al., 2012) was not found. Similar to the findings with static basic emotions (Falkmer et al., 2011; Kliemann et al., 2012; Kliemann et al., 2010), Kirchner et al. (2011) found a positive association with looking time to the eyes and a negative association with looking time to the mouth for recognition performance of complex negative stimuli in their ASD populations.

Two studies compared the time spent viewing the features of complex emotions in comparison with basic emotions (Rutherford and Towns, 2008; Sawyer et al., 2012). One study reported no differences in time spent examining the eyes and mouth of complex compared to basic emotions in their ASD and TD groups (Sawyer et al., 2012), while Rutherford and Towns (2008) found that adults with ASD spent more time on the eyes and mouth of faces expressing basic emotions compared to complex emotions, while the opposite was true for TD adults.

#### 4.3.3. Dynamic basic emotions ( $k = 1$ )

Dynamic representations of simple emotions were presented to adults in one study. Han et al. (2015) examined a sample of adults with ASD who presented with a comorbid intellectual disability. This study used morphing facial expressions as well as mechanical displays representing emotional expressions with the aim of determining whether motion processing was more enhanced in ASD as opposed to the processing of emotion. Adults with ASD had a lower percentage of fixation time; however fixations to the eyes and mouth of human emotional stimuli were similar to that of their TD control groups. To the mechanical display, adults with ASD made fewer fixations to the core features of the face, differentiating their gaze to the robotic setup from that to the emotional display, a difference not seen in the TD control group. This suggests that adults with ASD may process motion rather than emotion when viewing dynamic facial expressions.

### 5. EEG evoked potentials

EEG evoked potentials were examined by 18 of the studies included. Of these studies, the most reported components were N170 and P100.

#### 5.1. Children

##### 5.1.1. N170 ( $k = 6$ )

Children with ASD were found to be atypical in both the latency and amplitude of the N170 component in three studies (Batty et al., 2011; de Jong et al., 2008; Tye et al., 2014). Delayed N170 latencies in children with ASD were found in one study (Batty et al., 2011) with another study finding differences in the latencies between children with ASD and ASD with comorbid ADHD (Tye et al., 2014). Batty et al. (2011) found that across basic emotions, children with ASD had slower N170 latencies compared to children matched for chronological age. In regard to the amplitude of the N170, de Jong et al. (2008) reported reduced amplitude of the N170 in children with ASD compared to TD children in response to fearful expressions. Furthermore, fearful expressions elicited larger N170 responses in TD children when compared to neutral with no modulation effect seen in children with ASD (de Jong et al., 2008).

ADHD comorbidity has also been associated with divergent N170 latencies and amplitudes in ASD populations. Tye et al. (2014) found that children with ASD had shorter N170 latencies to neutral faces compared to angry faces and longer latencies to fearful expressions in comparison to happy faces while children with co-occurring ASD and ADHD had the opposite response to these emotions. In addition,

children with ASD and ASD/ADHD comorbidity had decreased N170 amplitude across happy, angry, fearful and disgusted expressions in comparison to TD controls. In contrast to the findings of de Jong et al. (2008), the amplitude of the N170 was modulated by emotion in the ASD group with fear eliciting larger amplitudes compared to neutral. This same modulation effect was not seen in TD children or children with ADHD.

##### 5.1.2. P100 ( $k = 4$ )

Two child studies reported that children with ASD and TD matched controls had similar P100 ERPs in response to emotional faces (O'Connor et al., 2005; Wong et al., 2008). In contrast, two free-viewing studies reported differences in both latency and amplitude of the P100 ERP (Batty et al., 2011; Vlamings et al., 2010). Batty et al. (2011) compared children with ASD to two groups of TD children, one matched for chronological age and one matched on verbal equivalent age, and compared to both, children with ASD had smaller P100 amplitudes in response to the six basic emotions, but slower latencies only in comparison to chronologically age matched controls.

The effect of spatial processing bias in ASD was examined in one study using neutral and fearful faces presented in high and low spatial frequencies. Vlamings et al. (2010) postulated that high spatial frequencies represented more detail supporting local orientated processing and low spatial frequency related to global pattern processing. Fear faces presented in high spatial frequency elicited larger P100 amplitudes compared to neutral faces in children with ASD aged 3–4 years. Conversely, IQ matched TD control children were found to show larger P100 amplitudes to neutral faces compared to fear faces presented in low spatial frequency (Vlamings et al., 2010).

##### 5.1.3. Other ERPs

The P200 ERP was examined in three child studies (Dawson et al., 2004; O'Connor et al., 2005; Wong et al., 2008). Of these, one reported differences with children with ASD having smaller and slower P200 responses to neutral faces during an implicit recognition task compared to chronologically age matched children (Dawson et al., 2004). When matched on verbal equivalent age, however, children with ASD had larger P200 amplitudes than TD children in the midline and central regions only (Dawson et al., 2004).

Within the child ERP studies, other not as commonly explored components included the N300 (Dawson et al., 2004), P300 and P500 (Dawson et al., 2004), N400 (Key et al., 2015), P400 (Key et al., 2015), Negative Slow Wave (NSW) (Dawson et al., 2004), N290 (Key et al., 2015) and Nc (Dawson et al., 2004; Key et al., 2015).

Children with ASD were found to have no differentiation in the amplitude of the N300 and NSW while TD children showed larger amplitudes to fear compared to neutral faces (Dawson et al., 2004). Differences in P300 emerged with ASD children having larger amplitudes to neutral compared to fear expressions while verbally equivalent aged children showed the opposite (Dawson et al., 2004). Infants at a high risk of developing ASD showed altered differentiation of P400 and Nc ERPs in response to neutral, small and large smiles compared to low risk infants (Key et al., 2015).

#### 5.2. Adolescents

##### 5.2.1. N170 ( $k = 3$ )

The amplitude and latency of the N170 component may not be modulated by emotion in adolescents with ASD. Adolescents with ASD were found to show no modulation of the N170 amplitude in response to fear and angry faces while TD adolescents showed different N170 amplitudes as a function of emotion (Wagner et al., 2013). A similar effect was seen when Akechi et al. (2010) examined the effect of eye gaze on emotion processing. It was proposed that the processing of gaze and emotion are not independent and gaze direction may facilitate the processing of emotion whereby approach orientated emotions such as

happiness are processed faster with direct gaze while avoidant orientated emotions are processed faster with indirect gaze. It was found that TD adolescents displayed larger N170 amplitudes to stimuli showing congruent emotions and gaze direction (fear faces with indirect gaze, angry with direct gaze) compared to incongruent emotions and gaze direction while the adolescents with ASD did not show this difference, indicating that adolescents with ASD may experience difficulty integrating gaze and expression cues.

A single group experimental study examined the correlation between N170 and the accuracy of adolescents with ASD at recognising emotions (Lerner et al., 2013). This study found that adolescents diagnosed with ASD who had longer latencies and smaller amplitudes of the N170 were less likely to correctly identify emotion accurately and had longer response times (Lerner et al., 2013).

#### 5.2.2. P100 ( $k = 2$ )

Two studies examined the P100 component in adolescents with ASD (Akechi et al., 2010; Wagner et al., 2013). One of these studies reported negligible differences in both the latency and the amplitude of the P100 in adolescents with and without ASD in response to the six basic emotions (Wagner et al., 2013). The sole difference between ASD and TD adolescents was found in response to angry and fear expressions. The P100 latency differed between O1 and O2 electrodes in TD participants but not ASD participants (Akechi et al., 2010).

### 5.3. Adults

#### 5.3.1. N170 ( $k = 5$ )

Three studies reported differences between adults with ASD and controls (Magnée et al., 2011; O'Connor et al., 2007; O'Connor et al., 2005) while two studies did not find between group differences (Magnée et al., 2008; Tseng et al., 2015). O'Connor et al. (2005) found that adults with ASD had smaller and delayed N170 ERPs to happy, sad, angry and scared expressions compared to controls. In a later study, O'Connor et al. (2007) found that when examining emotional faces in comparison to objects, N170 in adults with ASD did not differentiate face from object processing while TD controls had earlier N170 responses to faces when compared to objects. Furthermore, TD individuals had earlier N170 responses to faces and the eye and mouth regions of emotionally expressive faces compared to adults with ASD.

Difficulty with the integration of multisensory information was evident in two studies (Magnée et al., 2011, 2008). When presented with only visual input, the ASD groups did not differ from TD adults in regard to the N170 (Magnée et al., 2011, 2008), however, when required to divide attention, adults with ASD did not show differentiation based on the congruency of auditory and visual stimuli as seen in TD adults (Magnée et al., 2011).

#### 5.3.2. P100 ( $k = 4$ )

The P100 component was examined in four ERP studies in adults (Lassalle and Itier, 2015; Magnée et al., 2008; O'Connor et al., 2007, 2005). Adults with ASD were found to have longer latencies to happy, sad and angry expressions in one study (O'Connor et al., 2005). TD individuals with high autistic traits were also found to differ in P100 with gaze and emotion having a congruency effect on the P100 of TD adults with low autistic symptomatology, but not in adults with high autistic symptomatology (Lassalle and Itier, 2015).

#### 5.3.3. Other ERPs

Other ERPs examined in adult populations were the N100 (Fujita et al., 2013), P300 (Fujita et al., 2013), N200 (Magnée et al., 2008), N400 (Tseng et al., 2015), Visual Mismatch Negativity (vMMN) (Gayle et al., 2012), Early Directing Attention Negativity (EDAN) and Anterior Directing Attention Negativity (ADAN) (Lassalle and Itier, 2015). N100 amplitudes were not modulated by emotional faces or objects in adults with ASD while TD adults showed larger N100 ERPs in response to

emotional faces compared to objects (Fujita et al., 2013). Similarly, the N400 ERP was similar in TD and ASD adults when shown line drawings of expressions, however the N400 was not apparent in adults with ASD when shown photographs of expressions (Tseng et al., 2015). In regard to vMMN, TD adults with high autistic traits showed smaller vMMN amplitudes to happy faces compared to TD adults with low autistic traits (Gayle et al., 2012). Lassalle and Itier (2015) examined both EDAN and ADAN, EDAN occurring 200ms–300 ms after stimulus presentation and ADAN, occurring 300–500 ms after stimulus presentation have previously been associated with the orientation of attention and the maintenance of attention, respectively. These authors examined the effect of stimulus inversion and gaze direction on the processing of emotional stimuli, finding an effect of gaze direction on ADAN in individuals with low but not high autistic traits on the Autism Spectrum Quotient (AQ).

### 5.4. Quantitative EEG ( $k = 6$ )

Quantitative methods of examining EEG were used in six studies. Alpha, theta and beta frequencies were the most explored followed by delta and gamma. The particular methods used varied across studies and included dipole source analysis, phase synchronization, desynchronization, coherence, mu suppression and oscillations. All studies reported atypical cortical activation in ASD populations with differences being reported across the frequency spectrum.

The theta wave occurring between 4 and 7.5 Hz has been previously associated with the processing of affect, and was examined in three studies (Tseng et al., 2015; Yang et al., 2011; Yeung et al., 2014). Children with ASD were found to have lower right frontal theta coherence compared to TD children and did not show the same increase in theta coherence observed in TD children in response to emotional faces compared to neutral faces (Yeung et al., 2014). In addition, children with higher theta coherence appeared to have lower autistic symptomatology (Yeung et al., 2014). Tseng et al. (2015) found similar results with adolescents and adults with ASD displaying weaker delta/theta synchronization than typically developing controls in both early and late stages of emotion recognition. Weaker theta synchronization in ASD was also reported by Yang et al. (2011).

ASD populations were found to have greater beta 2 synchronization and alpha desynchronization in posterior regions compared to TD populations (Yang et al., 2011), however, these findings were not consistent across studies (Tseng et al., 2015).

Mu rhythm activity, the suppression of which is believed to be associated with mirror neuron function (Pineda, 2005), was investigated in one study. Cooper et al. (2013) examined event related desynchronization in the low beta and alpha bands, postulated to reflect mirror neuron activity in the motor cortex and somatosensory cortex respectively. TD adults with low autistic traits presented with greater low beta desynchronization compared to adults with high autistic traits when examining happy faces, reflecting reduced activation of the mirror neuron system to happy faces in individuals with high autistic traits on the AQ. Furthermore, while low trait autism individuals showed greater low beta desynchronization to happy as compared to angry faces, the inverse was true for the high autism trait group, also suggesting divergent mirror neuron activity. No group differences emerged in the alpha mu component, indicating divergent mu rhythm activity may arise in the motor cortex (Cooper et al., 2013).

Gamma oscillations were explored in one study of adolescents with ASD compared to a group of adolescents with ADHD and a group of TD adolescents in emotion and gender recognition tasks. Adolescents with ASD were shown to have lower gamma power to anger and disgust emotions when compared to gender recognition tasks while TD adolescents showed a smaller differentiation of gamma power between these two tasks (Gross et al., 2012).

## 6. General discussion

Evidence from both ET and EEG studies included in this review suggests that the attentional and cognitive processes involved in FER are atypical in ASD populations. Eye tracking studies reported atypical gaze to the emotional faces and core facial features in individuals with ASD during FER while EEG studies most consistently reported atypical modulation of the N170 ERP. In addition, while less examined, findings in the frequency domain also indicate atypical cortical activity during FER in ASD samples.

It seems somewhat surprising that the pattern of ET results was not more consistent across studies. Reduced gaze to the eyes is frequently cited as observed in ASD and is generally considered a key characteristic of the diagnosis (American Psychiatric Association, 2013; Baron-Cohen et al., 2000). However, a number of studies in this review failed to find any significant difference in the gaze behaviour of individuals with ASD in comparison to TD controls and there appeared to be a clear effect of age on between group differences in gaze behaviour. Only two of the nine child studies that compared children with ASD to TD children, reported a reduced number of fixations or duration of time spent looking at the eyes (Nuske et al., 2014a; Nuske et al., 2014b). Similarly, of the eight adolescent studies, only half reported reduced gaze to the eyes in individuals with ASD (Dalton et al., 2005; Hanley, 2012; Tottenham et al., 2014; White et al., 2015). When examining the adult studies, results were more consistent with 11 of the 16 studies reporting reduced use of information presented in the eyes by persons with ASD (Boraston et al., 2008; Corden et al., 2008; Falkmer et al., 2011; Han et al., 2015; Hernandez et al., 2009; Kliemann et al., 2010; Neumann et al., 2006; Pelphrey et al., 2002; Spezio et al., 2007a, 2007b). This apparent change of gaze behaviour across the developmental trajectory may have several potential origins. The failure to find stable, significant differences between ASD and TD children, may in part be explained by the stimuli or tasks used and their inability to adequately capture attention in either group. It is possible that the stimuli presented do not engage children sufficiently, and thus were not capable of eliciting divergent gaze behaviour. Those child studies which did find reduced gaze in children with ASD varied exposure time (30 ms, 300 ms, 2secs) (Nuske et al., 2014b) or used familiar and unfamiliar faces (Nuske et al., 2014a) whereas the study reporting increased gaze to the eyes in ASD children used very unusual puzzle piece stimuli (Leung et al., 2013). The remaining child studies typically examined gaze to stimuli that were presented for longer durations (4–10 s) and utilised prototypical static and dynamic faces. It is possible that the additional complexity offered by the varied exposure times, face familiarity or puzzled stimuli required greater cognitive processing, resulting in altered eye gaze.

Adult studies reported reduced gaze in response to basic emotions (Corden et al., 2008; Falkmer et al., 2011; Han et al., 2015; Hernandez et al., 2009; Kliemann et al., 2010; Neumann et al., 2006; Pelphrey et al., 2002; Spezio et al., 2007a, 2007b), with significantly reduced gaze to the eyes being found with prototypical static faces (Corden et al., 2008; Kliemann et al., 2010; Pelphrey et al., 2002), dynamic faces (Han et al., 2015) and experimentally manipulated stimuli (Hernandez et al., 2009; Neumann et al., 2006; Spezio et al., 2007a, 2007b). Given that the development of basic emotion recognition typically reaches maturity in late childhood (Tonks et al., 2006), it appears unlikely that the increased consistency to document reduced eye gaze in adults with ASD was due to the increased complexity of the stimuli used in adult populations. It is possible that this difference in gaze behaviour becomes more apparent in adult populations as a result of divergent development of facial emotion processing in late childhood or adolescence.

Two accounts have been offered to explain divergent eye gaze patterns in ASD, the social salience and the eye avoidance accounts. The social salience account proposes that the eye region may provide particularly salient information assisting in the decoding of facial information and emotional expressions (Baron-Cohen et al., 1997;

Langton et al., 2000). A lack of orientation or focus on the eyes in ASD populations may therefore suggest that individuals with ASD do not perceive the eyes as being socially salient or meaningful (Baron-Cohen et al., 1997; Baron-Cohen et al., 2001). As a result, individuals with ASD may select to look at more physically salient features, such as the mouth which has greater variability and motion than the eye region, perhaps capturing the attention of individuals with ASD to a greater degree. Reduced saliency of social information for individuals with ASD, may be indicative of possible altered function of a number of structures within the social brain such as the fusiform face area (FFA) (Kanwisher et al., 1997), amygdala (Rudrauf et al., 2008; Santø et al., 2011), orbitofrontal cortex and temporal poles (Rudrauf et al., 2008). These structures have been shown to engage in feedback processes with visual processing streams, influencing visual attention during emotion processing (Rudrauf et al., 2008). Atypical eye gaze in ASD individuals, particularly to the eye regions may suggest that the pathways involved in the rapid evaluation and processing of emotional stimuli are altered in ASD. The eye avoidance hypothesis (Tanaka and Sung, 2016) postulates that individuals with ASD may present with over-arousal of the amygdala and hyper-physiological arousal in response to social stimuli. As a result, reduced gaze to the eyes in individuals with ASD may be an attempt to self-regulate and mediate the level of threat perceived from the eyes (Dalton et al., 2005; Tanaka and Sung, 2016).

On a related note, anxiety or fear of negative evaluation appeared to have an effect on gaze towards the eyes in a number of ET studies included in this review. Comorbid anxiety is common within ASD populations (Maddox and White, 2015) and atypical gaze to faces, particularly resulting in a reduction in fixation towards the eyes has been reported in anxiety disorders (Daly, 1978; Wang et al., 2012). Moreover, anxiety disorders when combined with ASD, have been shown to exacerbate ASD symptoms (Farrugia and Hudson, 2006). Few studies have examined the impact of co-occurring anxiety in ASD populations and most have failed to control for anxiety in their clinical and control populations. Those that have included a measure of social anxiety or threat rating found that those with ASD who had higher anxiety scores, or who rated emotions as more threatening, looked at the eyes significantly less than their TD counterparts (Corden et al., 2008; Tottenham et al., 2014; White et al., 2015).

Atypical gaze to other core facial features such as the mouth, was also observed in some studies (Bal et al., 2010; Bekele et al., 2014; Corden et al., 2008; Leung et al., 2013; Nuske et al., 2014a; Nuske et al., 2014b). As a result, atypical gaze to faces during FER may also indicate atypical processing of information from the mouth region, however, findings overall remain inconclusive.

There was also a clear tendency in the ET literature towards the report of non-significant trends, with the majority of these trends reporting results consistent with the significant findings (Bal et al., 2010; Bekele et al., 2013; Boraston et al., 2008; Corden et al., 2008; de Wit et al., 2008; Kliemann et al., 2012; Kliemann et al., 2010; Rutherford and Towns, 2008; Tottenham et al., 2014). This tendency for reports of trends to corroborate significant findings may be seen to provide additional, although weak, support for the notion of reduced gaze towards the eyes during FER. While it is noted that these findings are not statistically significant, the tendency for these trends to be reported and for conclusions to be based on them can make the interpretation and integration of the results reported in the literature problematic. It is, for instance, not clear whether the report of trends is selective, i.e., whether trends are reported only if they are seen to be consistent with an expected pattern of results. Such a bias may help to strengthen a presumed pattern of results that has a less solid empirical base as originally thought. Methodological issues associated with some studies, such as small sample size, may have contributed to this tendency to find and report statistical trends. Future research may benefit from larger scale studies to more accurately determine the gaze behaviour of individuals with ASD.

It should also be noted that across ET studies a number of different

outcome measures are reported. For example, studies may examine the duration of the first fixation, the total fixation time, number of fixations, scan paths or location of first fixations and the rationale for choosing one over the other is not always clear. The range of outcome measures examined may impact the resultant findings. For example, it was found that adults with ASD may differentiate their gaze depending on the location of their first fixation, indicating a reduced preference for the eyes compared to TD adults (Kliemann et al., 2012; Kliemann et al., 2010).

Across studies reporting ERPs, the N170 was consistently smaller, delayed and slower in ASD populations. The N170 ERP has been shown to be largest in response to faces (Blau et al., 2007), suggesting its involvement in the processing of facial information. While the face-specific nature of the N170 ERP is well accepted (Eimer, 2011, 2000; Eimer et al., 2011), the precise function of the N170 ERP continues to be debated. The N170 ERP has been suggested to reflect the early encoding of facial stimuli (Eimer, 2000), whereas other studies have indicated that the N170 can also be modulated by the emotional content of the faces (Batty and Taylor, 2003; Blau et al., 2007). Given the debate in the current literature regarding the processes reflected in the N170 ERP, it is unclear whether FER impairment in ASD reflects altered encoding of facial information, resulting in difficulty processing facial configurations (O'Connor et al., 2007) or altered function in a possible parallel system specific for emotion processing (Blau et al., 2007). Nevertheless, consistently smaller and slower N170 ERPs in the ASD populations indicate altered function of early visual processing during FER.

An important caveat is that differences in ERPs in ASD populations may also be indicative of heterogeneity in the ASD population. It could be the case that only a subset of individuals with ASD are impacted by FER deficits (Nuske et al., 2013) or that there is more universal disorganisation and variability in neural pathways involved in FER in ASD.

Studies of frequency domain measures of EEG provide further evidence for atypical activation of cortical regions during FER in ASD. Increased theta synchronization has been demonstrated to reflect information encoding and episodic memory (Klimesch, 1999), and a reduction in theta synchronization and reduced right frontal theta coherence in ASD populations (Tseng et al., 2015; Yang et al., 2011) may reflect poor encoding of facial emotion. The hippocampus and amygdala have been shown to be involved in the encoding of emotional memory (Richardson et al., 2004) and the amygdala has been found to have atypical structure and function in ASD (Baron-Cohen et al., 2000; Balle et al., 2015; Dalton et al., 2005). Reduced theta synchronization may be indicative of atypical connectivity between neural networks involving the amygdala and hippocampus resulting in less efficient encoding and memory retrieval of facial expression. A phasic suppression of alpha during task performance has been shown to reflect increasing attention demands (Klimesch, 1999; Klimesch et al., 1998), thus, greater alpha de-synchronization in ASD may suggest increased concentration or attention to the task, possibly reflecting decreased efficiency of structures involved in FER (Yang et al., 2011). Changes in the frequency domain can be reflective of a number of different cognitive processes (Basar et al., 2001), therefore, caution must be observed when inferring the particular cognitive processes involved in FER.

Yang et al. (2011) and Tseng et al. (2015) both postulated that the observed reduction in the lower frequency bands in people with ASD may be indicative of impaired automatic processing of emotion while increased alpha desynchronization and beta may be reflective of increased conscious control of visual processing. This is possibly indicative of the use of compensatory strategies accounting for weaknesses in the typical automatic processes involved in emotion recognition (Tseng et al., 2015).

While only examined in one study, the role of the mirror neuron system in FER is important to note (Cooper et al., 2013). The mirror neuron network is postulated to be involved in the understanding of

movement and imitation (Rizzolatti and Craighero, 2004). For this reason, the function of this system in understanding the movement of others has been proposed to be linked to the understanding of social situations, theory of mind (Gallese, 2007; Schulte-Rüther et al., 2007; Williams et al., 2001) and facial expressions (Enticott et al., 2008). Suppression of mu rhythm has been suggested to reflect mirror neuron activity (Pineda, 2005; Rizzolatti and Craighero, 2004). Atypical patterns of mu activity found in individuals with high autistic symptomatology (Cooper et al., 2013) suggest that the mirror neuron system involved in the understanding of actions may contribute to an FER impairment in ASD and warrants further investigation (Hickok, 2009).

The effect of emotion per se as well as of specific emotions on the differences reported between groups was difficult to elucidate from the extant literature. A number of studies reported differences in ET and ERP responses to neutral faces in addition to differences in response to emotional expressions. Therefore, it is unknown whether impairments in face recognition in general result in a FER deficit, or whether there are additional impairments in ASD related specifically to the processing of facially expressed emotion. Previous reviews have suggested that individuals with ASD have a deficit in face processing (Tang et al., 2015; Weigelt et al., 2012), and diminished fixations to the eyes during tasks such as face recognition have been identified in ASD (Harms et al., 2010; Senju and Johnson, 2009; Tanaka and Sung, 2016). Certainly, atypical gaze to faces would also manifest in FER tasks. A number of studies across the developmental trajectory reported that while ERPs were modulated by emotion in TD samples, this modulation was absent in ASD samples. This suggests that whereas TD display differentiated neural activity based on the emotional content of faces, persons with ASD may not display this same differentiation, suggesting that while general face processing in ASD is impaired, there may be an additional or compounding impairment in the processing of emotion.

## 7. Future directions and challenges

Facial emotion recognition is a complex task drawing on a number of neural networks (Adolphs, 2002). Given the complexity of these processes, a significant body of research has emerged across diverse areas to elucidate the nature of FER impairment in ASD. However, the large degree of heterogeneity in the studies included in this review owing to differences in experimental paradigms and tasks makes synthesising results difficult. The methodological differences across studies may affect the findings. Participant factors, for example sample size, ASD population characteristics or matching procedure may also result in differing outcomes. ERPs have been shown to be influenced by the experimental paradigm selected. For example, a P100 elicited by a target following an emotional face (Lassalle and Itier, 2015) may reflect a different process as does a P100 elicited by the emotional face (O'Connor et al., 2005). Thus, caution must be used when interpreting the available results. The complexity of this field renders the synthesis of results across studies difficult and will continue to challenge researchers.

One option to generate more clarity to the pattern of FER results in ASD might be subgroup analyses. While attempts have been made to determine subtypes of ASD (Beglinger and Smith, 2001; Georgiades et al., 2013; Ousley and Cermak, 2015), the phenotype of ASD remains heterogeneous (Georgiades et al., 2013) changing across the developmental trajectory and in response to intervention or treatment. Comparison of different samples and different individuals with ASD may not provide an accurate representation of FER in ASD. Falck-Ytter et al. (2010) found differences in the way in which social impairment and communication impairment scores on the ADI-R correlated with gaze behaviour, possibly providing some evidence to suggest that the individual profiles of individuals with ASD may inform the gaze behaviour elicited by FER. Future research may take into account the individual developmental profile of ASD participants and conduct longitudinal studies to determine how the attentional and neurological

processes involved in FER may develop across the lifespan.

In addition to the variable diagnosis of ASD itself, ASD often presents with co-occurring diagnoses (Joshi et al., 2010). Social anxiety and ASD can present with similar symptomology, particularly in high functioning individuals (Tyson and Cruess, 2012) and anxiety may present with atypical gaze to faces (Daly, 1978; Wang et al., 2012). Approximately 30 percent of the ASD population have an ADHD diagnosis (Simonoff et al., 2008). Behavioural studies have shown that ASD with comorbid ADHD results in reduced recognition of facial emotion (Sinzig et al., 2008). A recent study suggests that variability in FER performance may be explained in part by the attentional distractibility profile of the individuals with ASD (Berggren et al., 2016). To date, few studies have accounted for comorbid diagnoses when examining FER performance in ASD. Subsequently, it is difficult to conclude if FER impairment is resultant of ASD itself, or can be explained by co-occurring conditions, such as social anxiety or ADHD. Future research may be able to extricate to what extent atypical gaze and brain activity are due to co-occurring diagnoses or cognitive profiles.

A number of outcome related questions arose from this review. Firstly, the P100 and N170 were the most commonly explored ERPs in both child and adult studies with the majority of studies reporting both slower latencies and smaller amplitudes of the N170 in ASD populations. The P100 and N170 represent both the early processing of visual information and the intermediate stages whereby configural and emotional encoding of faces occurs (Zhu et al., 2015). There was limited research investigating later components including N300 (Dawson et al., 2004), N400 (Tseng et al., 2015), P400 (Key et al., 2015), N250 and Late Stage Positive Potential (LPP). As these later occurring components are reflective of more cognitive processing (Sur and Sinha, 2009), future research may benefit from examining these later components in ASD to determine the extent and nature of the emotion processing differences.

Secondly, while the EEG and ET studies in isolation provide valuable insights into the neurophysiological and attentional processes underlying emotional face processing in ASD only one study examined them together (Wagner et al., 2013). However, this study only examined the two measures in parallel and did not integrate them. The integration of ET with other neuroimaging measures such as fMRI is more common, and contributes to advances in knowledge, such as the finding that the amygdala activity is moderated by fixations to the eyes (Dalton et al., 2005). EEG provides superior temporal resolution to fMRI, therefore combining EEG and ET may provide greater insights into the very precise electrophysiological mechanisms which may be

moderated by specific gaze behaviours.

The findings of this review also have potential clinical utility. ET patterns and specific electrocortical activity related to the processing of emotionally expressive faces may prove valuable as markers from both a diagnostic or predictive standpoint as well as a potential target for treatment. ET and EEG markers when used in combination may prove clinically significant as markers for diagnosing ASD, treatment outcome or predicting emotion recognition or social skills.

These EEG and ET markers may also lead to effective intervention methods in themselves. The findings that fixations to the eyes was associated with greater proficiency in FER in ASD populations may indicate that if these patterns are modified, proficiency in these tasks may improve. Biofeedback is an intervention which involves the training of the self-regulation of certain physiological processes with the aim of modifying behaviour. EEG and ET biofeedback has proved effective in increasing attention in children with ADHD and ASD, therefore, if biomarkers exist for FER, biofeedback may assist individuals with ASD to enhance their ability to detect and recognize facially expressed emotion (B & Ite et al., 2015; Holtmann et al., 2011; Kouijzer et al., 2013).

## 8. Conclusion

The ET and EEG results summarized in this review suggest that the attentional and cognitive processing of emotional faces is atypical in ASD across the developmental trajectory. Atypicalities in eye gaze, while not conclusive, indicate altered visual attention to facial emotions in individuals with ASD. A clear developmental effect was evident in the ET findings, indicating altered gaze to the eyes during FER is more apparent in adult populations. Atypical activation of cortical areas associated with the processing of facially expressed emotion is supported by the findings of EEG studies reporting differences in the elicitation of ERPs across the developmental trajectory.

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## Appendix A. Search Terms Used for Each Database

Database	Date of Search	Results returned	MeSH Terms or key words*
ProQuest	27 January 2016	15	"Autistic Disorder" "Child Development Disorders, Pervasive" "Autism Spectrum Disorder" "Evoked Potentials" "Electroencephalography" "eye movements" "fixation, ocular" "Emotions" "expressed emotion" "affect"
Medline	27 January 2016	171	"Autistic Disorder" "Child Development Disorders, Pervasive" "Autism Spectrum Disorder" "Asperger Syndrome" "Electroencephalography" "evoked potentials"

			<ul style="list-style-type: none"> <li>"evoked potentials, visual"</li> <li>"eye movements"</li> <li>"eye movements, measurements"</li> <li>"fixation, ocular"</li> <li>"Emotions"</li> <li>"facial expression"</li> <li>"social perception"</li> <li>"Affect"</li> </ul>
PsychInfo	20 January 2016	118	<ul style="list-style-type: none"> <li>"autism"</li> <li>"pervasive developmental disorder"</li> <li>"Aspergers syndrome"</li> <li>"Evoked Potentials"</li> <li>"Electroencephalography"</li> <li>"eye movements"</li> <li>"eye fixation"</li> <li>"visual perception"</li> <li>"visual tracking"</li> <li>"visual search"</li> <li>"emotions"</li> <li>"emotional states"</li> <li>"expressed emotion"</li> <li>"social perception"</li> </ul>
Scopus	27 January 2016	211	<ul style="list-style-type: none"> <li>"autistic disorder"</li> <li>"child development disorders pervasive"</li> <li>"autism spectrum disorder"</li> <li>"Asperger"</li> <li>"evoked potential"</li> <li>"EEG"</li> <li>"Electroencephalography"</li> <li>"eye tracking"</li> <li>"eye movement"</li> <li>"fixation, ocular"</li> <li>"eye fixation"</li> <li>"visual tracking"</li> <li>"emotion"</li> <li>"expressed emotion"</li> <li>"social perception"</li> </ul>
CINAHL	27 January 2016	40	<ul style="list-style-type: none"> <li>"Autistic Disorder"</li> <li>"Child Development Disorders, Pervasive"</li> <li>"Electroencephalography"</li> <li>"Evoked Potentials, Visual"</li> <li>"Evoked Potentials"</li> <li>"Eye movements", "Eye Movement Measurements"</li> <li>"Emotions"</li> <li>"Affect"</li> <li>"Facial Expression"</li> </ul>
Embase	27 January 2016	189	<ul style="list-style-type: none"> <li>"autism"</li> <li>"Asperger syndrome"</li> <li>"childhood disintegrative disorder"</li> <li>"pervasive developmental disorder not otherwise specified"</li> <li>"electroencephalography"</li> <li>"eye movement"</li> <li>"eye tracking"</li> <li>"eye fixation"</li> <li>"emotion"</li> <li>"facial expression"</li> <li>"affect"</li> </ul>

## Appendix B. Criteria from the Kmet Form for Quantitative Analysis Used to Assess Methodological Quality of Included Studies

Criteria	Yes (2)	Partial (1)	No (0)
1 Question/objective sufficiently described?			
2 Study design evident and appropriate?			
3 Method of subject/comparison group selection or source of information/input variables described and appropriate?			
4 Subject (and comparison group, if applicable) characteristics sufficiently described?			
5 If interventional and random allocation was possible, was it described?			
6 Outcome and (if applicable) exposure measure(s) well defined and robust to measurement/misclassification bias? Means of assessment reported?			
7 Sample size appropriate?			
8 Analytic methods described/justified and appropriate?			
9 Some estimate of variance is reported for the main results?			
10 Controlled for confounding?			
11 Results reported in sufficient detail?			
12 Conclusions supported by the results?			

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<b>Journal:</b>	Neuroscience and Biobehavioral Reviews
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## **APPENDIX C**

Supporting documentation tables for Chapter Seven (Paper IV)

Table 1. Attributes selected using Wrapper Methods for EEG-based classification

Classifier	Attributes selected	
	Positive	Negative
Naïve Bayes	Beta_FZ	Theta_FT7
SMO	Theta_FP1	Theta_F3
	Alpha_FT9	Theta_FT7
		Theta_P4
MLP	Beta_FP1	Theta_FP1
		Theta_F3
		Beta_FT10
Decision Stump		Theta_F3
Random Forest	Theta_O1	Theta_T6
	Beta_FT10	Beta_CP4

---

Random Tree

Theta\_CPZ

Alpha\_FZ

Beta\_FT10

---

Table 2. Attributes selected using Wrapper Methods for classifications based on EEG and SRS-2 data

Classifier	Attributes selected		
	Positive	Negative	SRS-2 included
Naïve Bayes	Alpha_TP7	Theta_FT7	Yes
	Beta_T5		
	Beta_O2		
SMO	Alpha_TP8	Theta_F3	Yes
	Alpha_FT9	Alpha_PZ	
MLP		Theta_F3	Yes
		Theta_T4	
		Beta_T3	
		Beta_CP3	
Decision Stump			Yes

---

Random Forest	Theta_T3	Theta_T6	Yes
	Beta_CP3		
Random Tree	Theta_CPZ	Alpha_FZ	No
	Beta_FT10		

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## **APPENDIX D**

Authorship contribution forms for papers submitted as part of this thesis (Papers I – IV)

## Chapter Two (Paper I)

### Author Contribution Statement

To whom it may concern,

I, Melissa Heather Black contributed the following to the paper entitled ‘Mechanisms of Facial Emotion Recognition in Autism Spectrum Disorder: Insights from Eye Tracking and Electroencephalography ‘

- Conceptualisation and design of the research;
- Data collection, analysis and interpretation;
- Writing the manuscript and critical appraisal of the findings
- Corresponding author responsible for communication with the journal

Signed:  Melissa H Black Date: 6/8/18.

I, as a co-author, endorse that this level of contribution by the candidate as indicated above is appropriate.

Signed:  Nigel TM Chen Date: 6/8/18

Signed:  Kartik K Iyer Date: 20/08/2018

Signed:  Ottmar V Lipp Date: 10/8/18

Signed:  Sven Bölte Date: 10/08/2018

Signed:  Marita Falkmer Date: 8/8 2018

Signed:  Tele Tan Date: 10/8/2018.

Signed:  Sonya Girdler Date: 03/08/18

## Chapter Three (Paper II)

### Author Contribution Statement Paper

To whom it may concern,

I, Melissa Heather Black contributed the following to the paper entitled 'More than valence? Using a dimensional and discrete approach to investigate complex facial emotion processing'

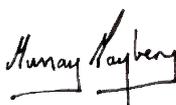
- Conceptualisation and design of the research;
- Data collection, analysis and interpretation;
- Writing the manuscript and critical appraisal of the findings
- Corresponding author responsible for communication with the journal

Signed:  Melissa H Black Date: 3/8/18

I, as a co-author, endorse that this level of contribution by the candidate as indicated above is appropriate.

Signed:  Nigel TM Chen Date: 3/8/18

Signed:  Ottmar V Lipp Date: 10/8/18

Signed:  Murray Maybery Date: 14/8/18

Signed:  Sven Bölte Date: 10/8/2018

Signed:  Marita Falkmer Date: 3/8 2018

Signed:  Sonya Girdler Date: 3/8/18

## Chapter Four (Paper III)

### Author Contribution Statement

To whom it may concern,

I, Melissa Heather Black contributed the following to the paper entitled 'Brief report: Complex facial emotion recognition and atypical gaze patterns in autistic adults'

- Conceptualisation and design of the research;
- Data collection, analysis and interpretation;
- Writing the manuscript and critical appraisal of the findings
- Corresponding author responsible for communication with the journal

Signed:  Melissa H Black Date: 3/8/18

I, as a co-author, endorse that this level of contribution by the candidate as indicated above is appropriate.

Signed:  Nigel TM Chen Date: 3/8/18

Signed:  Ottmar V Lipp Date: 10/8/18

Signed:  Sven Bölte Date: 10/08/2018

Signed:  Sonya Girdler Date: 3/8/18

## Chapter Five (Paper IV)

### Author Contribution Statement

To whom it may concern,

I, Melissa Heather Black contributed the following to the paper entitled 'Altered reactivity to complex facial emotion: A study of EEG spectral power in autistic adults'

- Conceptualisation and design of the research;
- Data collection, analysis and interpretation;
- Writing the manuscript and critical appraisal of the findings
- Corresponding author responsible for communication with the journal

Signed:  Melissa H Black Date: 3/8/18

I, as a co-author, endorse that this level of contribution by the candidate as indicated above is appropriate.

Signed:  Kartik K Iyer Date: 20/08/18

Signed:  Matthew Albrecht Date: 20/08/18

Signed:  Ottmar V Lipp Date: 10/8/18

Signed:  Nigel TM Chen Date: 3/8/18

Signed:  Sven Bölte: Date: 10/08/2018

Signed:  Tele Tan Date: 10/8/18.

Signed:  Sonya Girdler Date: 3/8/18.

## Chapter Six (Paper V)

### Author Contribution Statement

To whom it may concern,

I, Melissa Heather Black contributed the following to the paper entitled 'Altered connectivity in autistic during complex facial emotion recognition: A study of EEG imaginary coherence'

- Conceptualisation and design of the research;
- Data collection, analysis and interpretation;
- Writing the manuscript and critical appraisal of the findings

Signed:  Melissa H Black Date: 3/8/18

I, as a co-author, endorse that this level of contribution by the candidate as indicated above is appropriate.

Signed:  Tahani Almabruk Date: 21/08/2018

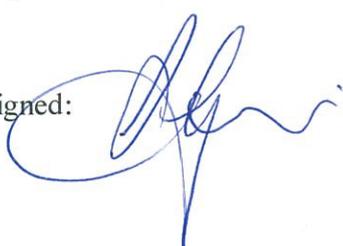
Signed:  Matthew Albrecht Date: 14/08/2018

Signed:  Ottmar V Lipp Date: 10/4/18

Signed:  Nigel TM Chen Date: 3/8/18

Signed:  Sven Bölte Date: 14/08/2018

Signed:  Tele Tan Date: 10/8/18,

Signed:  Sonya Girdler Date: 3/8/18.

## Chapter Seven (Paper VI)

### Author Contribution Statement

To whom it may concern,

I, Melissa Heather Black contributed the following to the paper entitled 'Can EEG-based biomarkers during facial emotion recognition provide an effective means of classifying ASD in adulthood?'

- Conceptualisation and design of the research;
- Data collection, analysis and interpretation;
- Writing the manuscript and critical appraisal of the findings
- Corresponding author responsible for communication with the journal

Signed:  Melissa H Black Date: 3/8/18

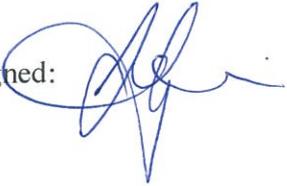
I, as a co-author, endorse that this level of contribution by the candidate as indicated above is appropriate.

Signed:  Tele Tan Date: 10/8/18.

Signed:  Sven Bölte: Date: 20/08/2018

Signed:  Nigel TM Chen Date: 6/8/18

Signed:  Ottmar V Lipp Date: 10/8/18

Signed:  Sonya Girdler Date: 3/8/18

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## **APPENDIX E**

Curtin University Human Research Ethics Committee Approval letter

**Memorandum**

<b>To</b>	Dr Chiara Horlin, School of Occupational Therapy and Social Work
<b>From</b>	Professor Stephan Millett, Chair, Human Research Ethics Committee
<b>Subject</b>	Protocol Approval <b>HR 52/2012</b>
<b>Date</b>	6 June 2012
<b>Copy</b>	Professor Torbjorn Falkmer, School of Occupational Therapy and Social Work Associate Professor Tele Tan, School of Electrical Engineering and Computing

Office of Research and Development  
**Human Research Ethics Committee**

**TELEPHONE** 9266 2784  
**FACSIMILE** 9266 3793  
**EMAIL** hrec@curtin.edu.au

Thank you for your application (4260) submitted to the Human Research Ethics Committee (HREC) for the project titled "Looking, seeing and hearing social information". Your application has been reviewed by the HREC and is approved.

- You have ethics clearance to undertake the research as stated in your proposal.
- The approval number for your project is **HR 52/2012**. Please quote this number in any future correspondence.
- Approval of this project is for a period of twelve months **05-06-2012** to **05-06-2013**. To renew this approval a completed Form B (attached) must be submitted before the expiry date **05-06-2013**.
- Your project has the following special conditions: NIL

**Applicants should note the following:**

It is the policy of the HREC to conduct random audits on a percentage of approved projects. These audits may be conducted at any time after the project starts. In cases where the HREC considers that there may be a risk of adverse events, or where participants may be especially vulnerable, the HREC may request the chief investigator to provide an outcomes report, including information on follow-up of participants.

The attached **FORM B** should be completed and returned to the Secretary, HREC, C/- Office of Research & Development:

When the project has finished, or

- If at any time during the twelve months changes/amendments occur, or
- If a serious or unexpected adverse event occurs, or
- 14 days prior to the expiry date if renewal is required.
- An application for renewal may be made with a Form B three years running, after which a new application form (Form A), providing comprehensive details, must be submitted.

Yours sincerely,



Professor Stephan Millett  
Chair Human Research Ethics Committee

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## **APPENDIX F**

Example information and consent forms

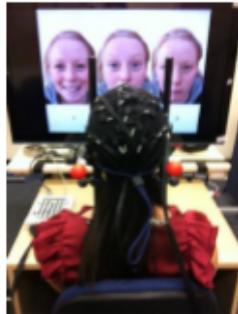


Melissa Black/Julia Tang

School of Occupational Therapy & Social Work  
Curtin University  
GPO Box U1987  
Perth, Western Australia, 6845  
Telephone +61409 109 816 /+61433 599 877  
Email melissa.black@curtin.edu.au  
julia.tang@curtin.edu.au

### Looking, Seeing and Hearing Social Information

In most everyday situations objects and environments are perceived through our senses and we receive information from more than one sense at any given time. The way we process and integrate this information is essential to how we engage in all activities in daily life. This experiment will explore visual ('seeing') and auditory ('hearing') processing of social information (faces and voices) using eye tracking (ET) and electroencephalography (EEG).



Your participation in this study will take approximately 2 hours and will involve completing a series of computer tasks whilst wearing an EEG cap (left). The EEG cap will be fitted to your head like a loose swimming cap. This process is completely safe and non-invasive and after the experiment you will be able to shower to remove the gel paste from your hair. The eye tracker (pictured right) will be used to record your eye movements. You will also be asked to complete some cognitive tasks that involve verbal questions, looking at picture puzzles and building patterns from blocks.



Eye Tracker

All information collected in this study will be recorded without names or any other identifying information. Only the researcher will have access to the completed tasks, and your individual results will not be reported. To assist us with this study, access your diagnostic reports. No individual results/information will be published and group data will only be published as scientific papers or conference presentations. Participation in this study is entirely voluntary, and you will be free to withdraw from the research at any time, without providing reason or justification. In this case, any results or records of your participation will be destroyed, unless you agree otherwise.

As a reimbursement for your time and participation, you will receive either 2 adult movie tickets OR a \$40 Coles/Myer gift card.

Please do not hesitate to contact the researchers, Melissa Black or Julia Tang (details above) or Associate Prof. Sonya Girdler (+618 9266 3630) if you have any questions regarding the research project.

Melissa Black  
PhD Candidate  
School of Occupational Therapy and  
Social Work

Julia Tang  
PhD Candidate  
School of Occupational Therapy and  
Social Work

Sonya Girdler  
Associate Professor  
School of Occupational Therapy and  
Social Work

This research has been reviewed and given approval by the Curtin University Human Research Ethics Committee (approval number SMEC-73-10, OTSW-03-2011 and OTSW-10-2011). Should you wish to make a complaint on ethical grounds, please contact the Human Ethics Committee (Secretary), phone: 9266 2784, email: hrec@curtin.edu.au, mail: C/- Office of Research and Development, Curtin University of Technology, GPO Box U1987, Perth WA 6845



Melissa Black/Julia Tang

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GPO Box U1987  
Perth, Western Australia, 6845  
Telephone +61409 109 816 /+61433 599 877  
Email melissa.black@curtin.edu.au  
julia.tang@curtin.edu.au

CONSENT FORM

Looking, Seeing and Hearing Social Information

I .....have read the information provided concerning this study, and any questions I have asked have been answered to my satisfaction.

- I agree to participate in this activity, realising that I may withdraw at any time without reason and without prejudice.
- I understand that all information provided will be treated as strictly confidential, and will not be released by the investigator unless required by law. I have been advised as to what data are being collected, what the purpose is, and what will be done with the data upon completion of the research.
- I agree that research data gathered for the study may be published provided that neither my name, nor other identifying information, is used.
- I agree to allow access to my medical record where the diagnosis of Asperger's syndrome/Autism Spectrum Disorder is confirmed.

Name & Signature : .....  
Contact number : .....  
Email address : .....  
Date : .....

This research has been reviewed and given approval by the Curtin University Human Research Ethics Committee (approval number HR 52/2012). Should you wish to make a complaint on ethical grounds, please contact the Human Ethics Committee (Secretary), phone: 9266 2784, email: hrec@curtin.edu.au, mail: C/- Office of Research and Development, Curtin University of Technology, GPO Box U1987, Perth WA 6845

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