Individual differences in recogn-eye-zing faces: Behavioural and neural underpinnings of face recognition in neurotypical and autistic adults

by

Karisa B. Parkington

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Examining Committee Membership

The following served on the Examining Committee for this thesis. The decision of the Examining Committee is by majority vote.

External Examiner	Dr. James Tanaka, PhD Professor, Psychology University of Victoria
Supervisor	Dr. Roxane Itier, PhD Associate Professor, Psychology University of Waterloo
Internal Member	Dr. Britt Anderson, MD, PhD Associate Professor, Psychology University of Waterloo
Internal Member	Dr. Heather Henderson, PhD Professor & Chair, Psychology University of Waterloo
Internal-External Member	Dr. Laura Middleton, PhD Assistant Professor, Kinesiology University of Waterloo

Author's Declaration

I hereby declare that I am the sole author of this thesis. This a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Statement of Contributions

Karisa B. Parkington was the sole author of all chapters in this dissertation, written under the mentorship of Dr. Roxane J. Itier and the internal examining committee.

Preliminary findings from Chapters 2, 4, and 5 have been presented at peer-reviewed academic conferences; Chapter 3 results have been accepted as a poster presentation at the upcoming International Society for Autism's 2021 virtual conference.

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The experiments included in this dissertation were conducted by Karisa B. Parkington under the supervision of Dr. Roxane Itier at the University of Waterloo.

Karisa B. Parkington contributed to experiment conceptualization and design, programming, data collection, and training 15 research assistants who assisted with data collection (Chapter 2) and processing (Chapters 2-5). She also led all participant recruitment efforts, collected data for all neurocognitive assessment sessions (Chapters 3-5), and was responsible for data cleaning, analysis, interpretation, dissemination of findings, and manuscript preparation. Dr. Roxane Itier provided intellectual input and guidance in experiment conceptualization and design, data analysis and interpretation, as well as editing conference abstracts.

Abstract

Attention to another's eyes and face recognition are necessary building blocks for efficient social communication. Neurotypical adults show an attentional bias for the eye region and strong face recognition performance. In contrast, adults with an autism spectrum disorder (ASD) often have pervasive difficulties looking at the eyes and recognizing others. These behavioural tendencies have led researchers to propose the eye avoidance and indifference theories of face recognition: implicating disruptions in eye sensitivity as a potential source of face recognition difficulties, although a direct link has yet to be established at the individual level. Holistic integration also plays a key role in neurotypical face recognition, although the temporal neurodynamics of autistic holistic integration remain unclear. Addressing this clinically relevant gap in the literature and acknowledging the within-group heterogeneity reported for both autistic and neurotypical adults, this dissertation presents four empirical studies evaluating feature saliency during face perception and its relationship with face recognition accuracy in adults with and without an ASD. Chapter 2 presents one of the first evaluations establishing direct associations between fixations to internal facial features during face encoding and recognition accuracy (*d′*) across incidental and intentional task demands. Results demonstrate incidental recognition accuracy is positively associated with left eye and nasion fixation patterns but is negatively impacted by increased fixations to the nose. Intentional recognition accuracy, on the other hand, negatively correlates with fixations directed towards non-core features and sub-clinical autistic traits. Chapter 3 then extends this research into a clinical ASD population and neurotypical control adults, evaluating face recognition performance from a neurodiversity perspective. Despite between-group analyses revealing autistic adults spend less time looking at faces during encoding, neurotypical and autistic adults' eye movements do not differ in their fixation patterns towards internal features nor in their recognition accuracy scores. Within-group analyses for adults with an ASD reveal a negative association between autism symptomology and intentional face recognition accuracy. To clarify the temporal neurodynamics of early face perception in autism, two ERP experiments were completed by a subset of participants from Chapter 3. N170 peak amplitudes and latencies were measured in response to upright/inverted faces and cars, isolated eye regions, and isolated mouths (Chapter 4) and in response to intact faces with fixation enforced to the left eye, right eye, nasion, nose, or mouth (Chapter 5). Consistent with neurotypical patterns, autistic adults demonstrate preserved markers of eye sensitivity and holistic integration at the N170 level when fixation is enforced. Collectively, this research signifies the importance of the eyes and nasion in supporting neurotypical and autistic face recognition accuracy and emphasizes the importance of accounting for individual differences from a neurodiversity perspective in social cognition research. Considerations for monitoring visual attention to faces and moving towards more individualized methods in neuroimaging studies are also discussed. This research has important clinical implications for the advancement and assessment of face recognition and social cognition abilities in ASD.

Keywords: face recognition, eye saliency, holistic integration, neurodiversity, individual differences, autism spectrum disorder, eye-tracking, N170

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Dedication

This dissertation is dedicated in loving memory of my Nana, Loreen Corkum.

A strong and passionate woman from simple upbringings, Nana instilled a passion for helping others and a sense of female-empowerment from a young age, supporting me in countless ways throughout my childhood, education, and research journey. Always eager to listen and learn more about what I was doing (even if she didn't always understand what I was talking about) Nana provided the love and unconditional support that only a grandparent could. She was ostensibly proud when I received my BSc from Dalhousie in 2013 and again in 2017 at my MA convocation, beaming from ear to ear that her little princess was on her way to become a doctor. Sadly, Nana passed away in October 2017 and is not here today to witness the completion of my PhD, but her memory and spirit live on and I know how proud she would be for me to fulfill my lifelong dreams.

I love you forever and always, Nana.

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Chapter 1: General Introduction

> *"…to recognise autism as an example of diversity in the set of all possible brains, none of which is 'normal' and all of which are simply different."*
> -Simon Baron-Cohen (p. 3, 2017)

1.1 Face Recognition and Social Communication

Face recognition is a crucial building block for successful social communication and interaction: we behave differently with people we know than with people we do not know. Humans are highly social beings with a propensity for social engagement and interaction (Emery, 2000; Itier & Batty, 2009; Kleinke, 1986) and are generally considered face experts. In fact, empirical research demonstrates that the ability to recognize faces develops across the lifespan (Bruce & Young, 1986; Crook III & Larrabee, 1992; O'Hearn, Schroer, Minshew, & Luna, 2010; O'Toole, 2011; Wilmer et al., 2010) and is a skill that is dissociable from word and object recognition, as well as from general memory and intelligence (Bainbridge, Isola, & Oliva, 2013; Palermo et al., 2011; Peterson & Miller, 2012; Yovel, Wilmer, & Duchaine, 2014).

For most neurotypical[1] adults, face recognition occurs relatively naturally with little or no conscious effort, although a full spectrum of abilities exists (Russell, Duchaine, & Nakayama, 2009; Tardif et al., 2019). Difficulties or errors in recognizing someone's face can result in awkward or socially inappropriate consequences and in fact, many adults with an autism spectrum disorder (ASD) report difficulties recognizing and identifying faces in their everyday lives (Grandin, 2008; Hendrickx, 2015; Just & Pelphrey, 2013; Robinson, 2008). These claims are substantiated by

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[1] For the purposes of this manuscript, *neurotypical* refers to an individual with no reported psychiatric or neurological conditions.

empirical investigations demonstrating sub-standard face recognition performance relative to neurotypical peers (for reviews see Tanaka & Sung, 2016; Weigelt et al., 2012), despite intact or superior memory for patterns, objects, or other categories of expertise (e.g., history, dates, sports, etc.; Boucher & Anns, 2018; Caron, 2004; Hedley, Brewer, & Young, 2011; Kuusikko-Gauffin et al., 2011; Ozonoff & Strayer, 2001; Shalom, 2003; Trepagnier, Sebrechts, & Peterson, 2002). Notably, autistic adults have been found to perform within the prosopagnosic range on standardized assessments of face recognition (Cygan et al., 2018; Kirchner et al., 2011; O'Hearn et al., 2010). Less severe (but still impactful) decrements in performance have also been shown in a variety of immediate and delayed face recognition paradigms (Faja, Webb, Merkle, Aylward, & Dawson, 2009; Falkmer et al., 2010; McPartland, Webb, Keehn, & Dawson, 2011; Schauder et al., 2019; Scherf, Behrmann, Minshew, & Luna, 2008; Trepagnier et al., 2002; Williams, Goldstein, & Minshew, 2005). The development of face recognition across the lifespan for individuals with ASD remains unclear, although some studies implicate an altered or delayed trajectory relative to same-aged neurotypical peers (Fedor et al., 2017; O'Hearn et al., 2010; O'Hearn, Larsen, Fedor, Luna, & Lynn, 2020).

1.2 Theories of Autistic Face Recognition

Several theories have been proposed to elucidate neurotypical and autistic face recognition mechanisms (Moriuchi, Klin, & Jones, 2017; Senju & Johnson, 2009; Tanaka & Sung, 2016; Weigelt et al., 2012). Qualitative theories focus on understanding how faces are initially processed and encoded (e.g., eye sensitivity/avoidance, holistic processing) and if disruptions in these early perceptual stages are the antecedent to subsequent recognition difficulties and impairments. Quantitative models focus on how well faces are remembered and high-order cognitive processes (e.g., memory consolidation, retrieval) as the root of face recognition abilities. This dissertation will focus on elucidating the *eye indifference/avoidance* and *holistic integration* qualitative theories of autistic face recognition.

1.2.1 Theories of Eye Avoidance and Sensitivity Indifference

1.2.1.1 The Eyes are Important for Neurotypical Face Recognition

Empirical evaluations demonstrate that the eye region (i.e., the left eye[2], nasion[3], and right eye) is markedly diagnostic[4] for neurotypical face recognition and identification (Henderson, Williams, Castelhano, & Falk, 2003; Henderson, Williams, & Falk, 2005; Hills, Ross, & Lewis, 2011; Hills, Cooper, & Pake, 2013; Schyns, Bonnar, & Gosselin, 2002). In fact, focusing just below the left eye within the first two fixations of seeing a face has been associated with strong face recognition accuracy (Hsaio & Cottrell, 2008; Peterson & Eckstein, 2012; Peterson & Eckstein, 2013; van Belle, Ramon, Lefèvre, & Rossion, 2010). Overall, memory for faces is generally higher when elements of the eye region (especially the left eye) are visible (Haig, 1985; Hsaio & Cottrell, 2008; Peterson & Eckstein, 2012, 2013; Royer et al.,

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[2] *Left eye* refers to the eye position from the observer's perspective (i.e., eye on the left side of the face from frontal view).

[3] *Nasion* refers to the region between the left and right eyes of the face, at the nose bridge (see Figure 1B).

[4] Recognition *diagnosticity* refers to the idea that specific visual cues (in this case the eyes) are used to make specific perceptual and cognitive categorizations (such as face recognition and identification; Hills et al., 2011; Lowe, Gallivan, Ferber, & Cant, 2016).

2018; Schyns et al., 2002; Sormaz, Andrews, & Young, 2013; Tardif et al., 2019). Occluding or removing eye information tends to impair recognition performance (Sadr, Jarudi, & Sinha, 2003; Sekuler, Gaspar, Gold, & Bennett, 2004), although altering other internal facial features (e.g., nose or mouth) does not impact face recognition to the same degree (McKelvie, 1976; Tanaka & Farah, 1993; Tanaka & Simonyi, 2016).

Notably, neurotypical adults' gaze fixation patterns tend to form a T-shaped arrangement when viewing faces, with the majority of fixations directed towards the eye region, some fixations allocated along the midline of the face (towards the nose and mouth), and few-to-no fixations assigned to non-core features such as the forehead, chin, or cheeks (Barton, Radcliffe, Cherkasova, Edelman, & Intriligator, 2006; Henderson et al., 2005; Hills et al., 2013; Janik, Wellens, Goldberg, & Dellosso, 1978; Malcolm, Lanyon, Fugard, & Barton, 2008; Rollins, Bertero, & Hunter, 2019; Shepherd, Davies, & Ellis, 1981; Walker-Smith, Gale, & Findlay, 1977; Yarbus, 1967). In fact, strong face-recognizers (identified based on a median-split) spend more time looking at, and make more fixations between, the eyes than weak face-recognizers (Sekiguchi, 2011). Attentional cueing to the eye region has also been found to improve recognition performance for upright, but not inverted, faces (relative to mouth- or no-cueing conditions; Hills et al., 2011, 2013). This research collectively highlights a distinct sensitivity to the eye region (especially the left eye) in supporting neurotypical face recognition.

1.2.1.2 Eye Indifference and Avoidance in Autism

In contrast to neurotypical adults, many adults with an ASD experience pervasive difficulties initiating and maintaining eye contact with others (American Psychiatric Association, 2013; Lord et al., 2012), resulting in disorganized and irregular face scanning patterns (Cygan et al., 2018; Pelphrey et al., 2002; Spezio, Adolphs, Hurley, & Piven, 2006; Wang et al., 2019; Yi et al., 2013, 2014). Atypicalities in visual attention are primarily constrained to the eye region (Yi et al., 2013, 2014) and are often apparent within the first year of infancy (Jones & Klin, 2013; Osterling, Dawson, & Munson, 2002; Wolff et al., 2012; Zwaigenbaum et al., 2005). Rather than directing their attention towards the eyes, autistic adults often spend more time looking at other facial features (such as the mouth), a person’s body, or the background environment (Chita-Tegmark, 2016; Dalton et al., 2005; Ewing et al., 2018; Falkmer et al., 2010; Fedor et al., 2017; Frazier et al., 2017; Klin et al., 2002; Spezio et al., 2006; Sterling et al., 2008; Wang et al., 2019).

Stemming from these empirical findings, the eye indifference and avoidance theories postulate that reduced attention to the eyes may result in the observer missing critical social cues, leading to cascading influences on social cognition performance (including face recognition; Moriuchi et al., 2017; Senju & Johnson, 2009; Tanaka & Sung, 2016). More specifically, the eye indifference hypothesis proposes that the eye sensitivity observed in neurotypical adults may be reduced or absent in ASD, resulting in a relative indifference to feature saliency (Moriuchi et al., 2017; Senju & Johnson, 2009). The eye avoidance perspective suggests that divergent visual patterns may reflect autistic individuals' active avoidance of the eye region due to an elevated state of arousal (Tanaka & Sung, 2016). Collectively, these theories suggest that autistic face recognition difficulties are likely due to disruptions in eye saliency during the initial stages of face processing.

1.2.2 Theory of Holistic integration

1.2.2.1 Primary Mechanism of Face Processing: Holistic Integration

Holistic processing is a face-sensitive[5] neurocognitive mechanism in which the shape, spacing, and configuration of individual features are integrated into a cohesive, indecomposable whole (Maurer et al., 2002; McKone & Yovel, 2009; Nemrodov, Anderson, Preston, & Itier, 2014; Rossion & Gauthier, 2002). By assimilating facial features into a single face percept for a quick "snapshot", holistic processing expedites processing speed and reserves cognitive resources for more socially relevant information (e.g., gaze perception, emotion recognition, identification). This mechanism also allows for the relatively automatic processing of identifying attributes that are unique to each person's face (feature shape, size, spacing, symmetry, etc.) during the earliest stages of face processing. This is most evident from neurotypical adults' superior recognition capabilities for faces when they are presented in their established, upright alignment (Bruce & Young, 1986; Jenkins, Dowsett, & Burton, 2018; O'Toole, 2011; Wilmer et al., 2010; Yovel et al., 2014).

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[5] Holistic processing is not unique to faces; it occurs for any category of expertise (Brams et al., 2019; Campbell & Tanaka, 2018; Tanaka & Curran, 2001; Vogelsang, Palmeri, & Busey, 2017). However, it is most commonly studied in relation to face processing.

Alternatively, when face configuration is disrupted and features are altered or impoverished (e.g., through face inversion or feature isolation), the canonical face template is not triggered and visual processing becomes more serial and part-based, resulting in slower processing speeds, increased cognitive demands, and impaired recognition memory (Barton et al., 2006; Haxby et al., 1999; Hills et al., 2011; Hills et al., 2013; Leder & Bruce, 2000; Rossion & Gauthier, 2002; Tanaka & Farah, 1993; Tanaka & Simonyi, 2016; Valentine, 1988; Xu & Tanaka, 2013; Yin, 1969). Object recognition is not affected by inversion to the same degree, highlighting that faces are disproportionately affected by feature configuration.

1.2.2.2 Holistic Processing in ASD

In contrast to the wealth of knowledge for neurotypical adults, the implications of holistic processing for autistic face recognition are less clear. Until more recently, it has been generally accepted that holistic processing is systematically impaired in autistic individuals, evidenced by smaller differences between upright and inverted faces (Hobson, Ouston, & Lee, 1988; Rose et al., 2007) and in recognition performance between isolated features and complete faces (Joseph & Tanaka, 2003; Lahaie et al., 2006; Langdell, 1978; see Tanaka & Sung, 2016 and Weigelt et al., 2012 for review). These findings have led researchers to suggest that autistic individuals may be disadvantaged at face recognition accuracy due to an increased reliance on less efficient part-based perceptual mechanisms for face recognition, in line with the theory of weak central coherence (Frith & Happe, 1994; Happé & Frith, 2006; Hill & Frith, 2003). From this perspective, a piecemeal face processing bias is likely to contribute to a degraded identity percept and, therefore, weaker recognition performance. However, this view has been challenged more recently in light of emerging evidence demonstrating intact holistic processing mechanisms in autistic adults (Faja et al., 2009; Lahaie et al., 2006; Nishimura, Rutherford, & Maurer, 2008; Scherf, Behrmann, Minshew, & Luna, 2008). Adults with an ASD perform similarly to their neurotypical peers on measures of face inversion (Lahaie et al., 2006b; Scherf et al., 2008) and feature isolation (Faja et al., 2009), demonstrating degraded recognition performance when face configuration is disrupted relative to the recognition of upright, intact faces. Autistic adults have also been shown to engage in holistic processing strategies when they are cued towards features relevant for face matching (López, Donnelly, Hadwin, & Leekam, 2004). These findings suggest that whilst neurotypical individuals tend to rely predominantly on holistic mechanisms for face processing, autistic individuals may have a weaker holistic bias, instead relying on featural or holistic mechanisms under different task demands.

Autistic disruptions in holistic face processing are most apparent during childhood, suggesting that the development and refinement of holistic mechanisms may simply be delayed or divergent in ASD, rather than impaired altogether. Adults with an ASD may default to featural mechanisms when unconstrained, but likely develop holistic processing strategies across development which can be implemented when instructed to do so (e.g., behavioural assessments). With an increasing awareness of the diversity and malleability of holistic strategies within autistic adults, additional research is required to verify the integrity of holistic mechanisms in ASD and elucidate the neurocognitive underpinnings of autistic face processing.

These theories (i.e., eye indifference/avoidance and holistic integration) provide a strong theoretical basis for the hypothesis that disruptions during the earliest stages of face processing are a root cause of neurotypical and autistic face recognition abilities. It is imperative to consider, however, that these theories are based predominantly on group averages and often overlook heterogeneity between participants in face recognition performance. Nevertheless, a distinct spectrum of face recognition abilities is present across both the neurotypical and autism populations (e.g., Yovel et al., 2014), ranging from pervasive difficulties in recognizing faces (i.e., developmental prosopagnosia; Duchaine & Nakayama, 2006; Palermo et al., 2011) to superior abilities in which a face is never forgotten (Bobak, Bennetts, Parris, Jansari, & Bate, 2016; Russell et al., 2009; Tardif et al., 2019; Wilmer et al., 2010). Within-group variability amongst neurotypical adults has been described since the first seminal investigations of gaze patterns to faces (Haig, 1985; Janik et al., 1978; Walker-Smith et al., 1977), although the evaluation of individual differences within visual processing and social cognition research has only taken heed more recently.

1.3 Individual Differences in Face Recognition Accuracy

Individual difference approaches compliment and extend group-level findings by providing additional insights into the patterns underlying the overall group averages (Wilmer et al., 2010; Yovel et al., 2014). Critically, averages derived from empirical studies may be consistent with a behavioural effect but may not be associated with it. For example, if adults with an ASD spend less time looking at others' eyes relative to neurotypical adults, this does not necessarily mean that autistic adults actively avoid the eyes; it could instead indicate that reduced eye contact leads to what researchers qualify as autistic traits (directionality problem) or it could indicate that a third variable, such as neurodevelopmental trajectory, impacts an individual's autistic symptomology and eye contact. Thus, it is critically important for social cognitive research to explore the underlying patterns and heterogeneity in cognitive and behavioural performance between individuals (for discussion see Yovel et al., 2014). By focusing the analytical lens in a different way, within-group analyses allow for independent evaluations of the theories derived from group-level studies in ways that may not otherwise be possible. For example, holistic processing has long been theorized to facilitate face recognition performance based on an expertise for upright, but not inverted, faces (Itier, 2015; Maurer et al., 2002; Richler & Gauthier, 2014; Rossion & Gauthier, 2002; Rossion, 2009; Yin, 1969). Examination of individual differences in holistic processing and face recognition abilities have extended this theory further by revealing a direct association between these visual-cognitive processes at the individual level (DeGutis, Wilmer, Mercado, & Cohan, 2013; Richler, Cheung, & Gauthier, 2011; Wang, Li, Fang, Tian, & Liu, 2012; although see Konar, Bennett, & Sekuler, 2010 and Richler, Floyd, & Gauthier, 2015). Furthermore, individual-based approaches have revealed that whilst holistic processing accounts for a notable degree of performance variability in neurotypical face recognition (approximately 20%; DeGutis et al., 2013; Yovel et al., 2014), a large proportion of variability remains unexplained, indicating that other neurocognitive mechanisms (such as eye sensitivity) must also play a role in facilitating face recognition abilities.

The importance of implementing within-group approaches in clinical ASD research is further underscored by the neurodiversity framework – the idea that natural variation and diversity in cognitive, emotional, and behavioural traits fall along a spectrum of abilities (Baron-Cohen, 2017; Mandy, 2018; Masataka, 2017; Silberman, 2017). Moving away from a deficit-based model, the neurodiversity perspective embraces variability in cognitive and behavioural profiles, viewing the phenotypes of neurodevelopmental disabilities (such as those with ASD) as essential components of the full continuum of human ability. The eye sensitivity/avoidance and holistic integration theories of neurotypical and autistic face recognition have not yet been explored from a neurodiversity perspective at the individual level. Therefore, one of the main goals of the current research is to address this clinically relevant gap in the literature.

1.4 Dissertation Overview

The broad objective of this dissertation is to evaluate the relationship between gaze fixation patterns to facial features and recognition accuracy from a neurodiversity perspective, evaluating neurotypical and autistic adults' performance at the between- and within-group levels. Specifically, can individual (within-group) differences in autistic traits and/or gaze patterns to facial features explain some of the heterogeneity in face recognition accuracy? This was accomplished by conducting a large-scale, neurocognitive assessment of face recognition in neurotypical adults and adults with an ASD (**Appendix A**). This body of work represents a first step towards a more comprehensive understanding of the role of the eyes and gaze fixation patterns in face recognition abilities and the impact of individual differences in neurotypical adults and those living with an ASD.

Replicating and extending group-level findings, the present research also incorporates correlational and comparative metrics (i.e., subtraction measures) to explore individual differences in neurotypical and autistic face processing at the behavioural and neural level. First, direct associations between fixation patterns to facial features and face recognition accuracy were evaluated in a large sample of neurotypical adults under incidental and intentional task demands (Chapter 2). These methods were subsequently extended to a group of adults with an ASD and age-, gender-, ethnicity-, and IQ-matched neurotypical control adults (Chapter 3) and followed up with assessments of early face perception in a subset of participants, using co-registered eye-tracking and electroencephalography (EEG) recordings (Chapters 4 & 5). Findings will be discussed in relation to the prominent qualitative theories of face recognition implicating a saliency indifference and/or hyper-arousal to the eyes in autism.

Chapter 2: Neurotypical Gaze Patterns During Face Encoding and Their Relationships to Incidental and Intentional Face Recognition Accuracy

> *"Ut imago est animi voltus sic indices oculi."*
> *The face is a picture of the mind as the eyes are its interpreter.*
> -Cicero (143-106 BC)

2.1 Introduction

When we encounter people in our everyday lives, the way in which we look at and examine the person's face will invariably affect our ability to recognize that person later. However, very little is known about how eye movement patterns during face encoding are related to recognition accuracy at the individual level. The first experiment addressed this gap in the literature by evaluating the relationship between individual differences in fixation patterns to internal (left eye, right eye, nasion, nose, and mouth) and non-core facial features during face encoding and subsequent recognition accuracy. Associations were examined for both incidental and intentional recognition to determine if the use of facial features differs across task demands. The influence of sub-clinical autistic tendencies was also examined to determine the impact of autistic traits in visual-cognitive mechanisms.

2.1.1 Eye Saliency

In neurotypical adults, the present state of the literature implicates a sensitivity to the eye region in face recognition, such that use of eye information during intentional recognition and identification improves accuracy (Haig, 1985; Hsaio & Cottrell, 2008; Peterson & Eckstein, 2012, 2013; Rollins et al., 2019; Schyns et al., 2002; for review see Itier, 2015). There is also significant credence to suggest that attending to the eyes during face encoding (when a face is first encountered) is an important strategy for optimizing face recognition performance (Henderson et al., 2005; Hills et al., 2011, 2013; Sekiguchi, 2011; although see Rollins et al., 2019). For instance, face recognition accuracy is higher when attention is cued to the eye region during encoding, compared to mouth- or no-cueing conditions (Hills et al., 2011; 2013). Likewise, strong face-recognizers tend to spend more time looking at people's eyes when they first see videos of unfamiliar people introducing themselves than do poor face-recognizers (Sekiguchi, 2011). However, a direct link between free-viewing fixation patterns during the encoding of previously unfamiliar faces and subsequent recognition accuracy has yet to be established at the individual level.

2.1.2 Individual Differences in Feature Reliance

Despite reports of variability in fixation patterns from the earliest studies of face recognition (e.g., Haig, 1985; Janik et al., 1978; Walker-Smith et al., 1977), studies have only recently begun to explore the role of gaze fixation patterns in face recognition mechanisms from an individual (within-in group) perspective. This research focuses primarily on occluding the majority of the face and only presenting a small section, large enough for one facial feature (i.e., Bubble technique; Schyns et al., 2002; Vinette, Gosselin, & Schyns, 2004). These studies reveal that the left eye is most diagnostic for optimizing neurotypical face recognition performance (Royer et al., 2018), an effect that extends across the full range of recognition abilities (Tardif et al., 2019). Individual-level approaches have also revealed that the T-shaped face fixation pattern commonly reported throughout the neurotypical literature (i.e., majority of fixations directed towards the eye region, with fewer fixations directed towards the mouth and nose; Henderson et al., 2005; Walker-Smith et al., 1977; Yarbus, 1967) is largely a biproduct of averaging idiosyncratic visual strategies across participants (Arizpe, Walsh, Yovel, & Baker, 2017; Mehoudar, Arizpe, Baker, & Yovel, 2014). In fact, Arizpe and colleagues (2017) found four distinct feature-dominant subgroups based on peak eye movement spatial densities during old/new recognition of unfamiliar faces (i.e., left eye-, right eye-, nasion-, and nose/mouth-reliant), with each subgroup accounting for 20-30% of participants. These findings demonstrate adults may have developed individualized gaze strategies that are the most effective in supporting the optimal extraction of face information, rather than all neurotypical adults employing the same visual processing strategies during face recognition (Arizpe et al., 2017; Mehoudar et al., 2014; Peterson, Lin, Zaun, & Kanwisher, 2016; Peterson & Eckstein, 2012, 2013; Tsank & Eckstein, 2017; Yovel et al., 2014). Notably, a significant association between idiosyncratic eye movement patterns and recognition performance has not yet been found (Arizpe et al., 2017; Mehoudar et al., 2014), although this may be attributed to the limited sample sizes (*Ns* ≤ 50) in these studies, limiting their ability to detect within-group effects in the neurotypical population. Overall, these discoveries highlight the importance of examining fixation patterns at the individual level and signal a need for segregating the eye region into separate components (i.e., left eye, nasion, right eye) in order to determine the unique contribution of each feature and understand the dynamics of face recognition more fully.

2.1.3 The Impact of Task Demands

It also remains unclear how the relationships between gaze patterns and face recognition accuracy vary across task demands. When we encounter unfamiliar people in our daily lives, our focus is often directed to socially pressing cues directly affecting one's safety and/or social behaviours (e.g., trustworthiness). In this case, referred to as *incidental encoding,* face attributes essential for identifying faces (e.g., feature shape and size, inter-featural distance) are passively encoded during the earliest stages of face perception (Zheng, Mondloch, Nishimura, Vida, & Segalowitz, 2013). In contrast, most empirical investigations implement paradigms relying on the explicit encoding and recognition of faces (i.e., *intentional* recognition), where identifying details are actively encoded as the observer focuses on remembering the face for a later encounter. Although most everyday encounters arguably rely on more incidental mechanisms, the degree to which this passive featural encoding relates to recognition accuracy remains unknown. Gaze fixation patterns have been shown to differ depending on a participant's awareness of task-relevant information (Boutet, Lemieux, Goulet, & Collin, 2017). When participants are aware of task demands (e.g., all trials within a block require the same type of response) gaze fixation patterns are primarily directed towards the centre of the face. Alternatively, when participants are unaware of task requirements (e.g., task-relevant information is randomized throughout a block), gaze fixations are biased towards the eye region. Gaze patterns also appear to be relatively consistent across social judgements (e.g., trustworthiness vs. dominance; Hermens, Golubickis, & Macrae, 2018), although further examination of this phenomenon is required, particularly in relation to the connection with incidental and intentional face recognition accuracy.

2.1.4 Sub-clinical Autistic Traits and Face Recognition

Face recognition difficulties are common amongst individuals with an ASD (Kirchner et al., 2011; McPartland et al., 2011; O'Hearn et al., 2010; Weigelt et al., 2012; see Chapter 1). Interestingly, these behavioural patterns have been shown to extend to the general population as well, with autistic-like cognitive and behavioural traits being implicated in face recognition performance at the sub-clinical level (Davis et al., 2017; Halliday, MacDonald, Scherf, Sherf, & Tanaka, 2014; Morgan & Hills, 2019; Rhodes, Jeffery, Taylor, & Ewing, 2013; Valla, Maendel, Ganzel, Barsky, & Belmonte, 2013). Face recognition difficulties can extend to neurotypical first-degree relatives of autistic probands, albeit to a lesser degree (Adolphs, Spezio, Parlier, & Piven, 2008; Kuusikko-Gauffin et al., 2011; Sucksmith, Allison, Baron-Cohen, Chakrabarti, & Hoekstra, 2012; Wallace, Sebastian, Pellicano, Parr, & Bailey, 2010; Yucel et al., 2015). Additionally, neurotypical adults with a high degree of sub-clinical autistic traits also have trouble recognizing others when individual differences are considered (Halliday et al., 2014; Rhodes et al., 2013; Valla et al., 2013). Collectively, empirical research demonstrates negative associations between sub-clinical autistic traits and face recognition abilities, such that individuals with more autistic tendencies tend to have poorer recognition scores than individuals with fewer autistic traits.

2.1.5 Study Aims and Research Questions

The first goal of this dissertation was to examine the associations between fixation patterns to internal facial features and face recognition accuracy in neurotypical adults. To this end, a within-subjects design was implemented in which eye movements were recorded in a large sample of adults engaged in incidental and intentional recognition tasks with unfamiliar faces. To determine the relative attentional importance afforded to each feature, featural saliency was measured for core (left eye, right eye, nasion, nose, and mouth) and non-core (forehead, cheeks, and chin) features of the face using area-normalized eye-tracking measures . Group-level analyses evaluated the effects of encoding task demands on fixation measures and recognition accuracy (*d'*). Within-group differences were subsequently explored for each task through correlations focused on the associations between gaze patterns and recognition accuracy scores.

Overall, it was predicted that the classic T-shaped fixation pattern would be replicated at the group level during face encoding and would not vary across task demands. Specifically, participants were expected to direct the majority of their fixations towards the eye region (with a particular bias for the left eye and nasion) during incidental encoding, in line with previous studies demonstrating an increased eye-reliance in conditions where participants are unaware of the primary task demands (Boutet et al., 2017) and when making trustworthiness judgements (Hermens et al., 2018). Furthermore, if attention to the eyes is in fact essential for optimizing face recognition, then an increased awareness of task-relevant information should also lead neurotypical adults towards an eye region bias during intentional encoding in order to optimize the extraction of identity-relevant cues. At the behavioural level, face recognition accuracy was expected to be higher following intentional encoding (due to increased cognitive resources dedicated to identity-coding) than during incidental encoding. Idiosyncratic fixation patterns were anticipated across the neurotypical sample, with significant heterogeneity in feature reliance. It was predicted that increased fixation to the eyes would be positively associated with recognition accuracy (on the respective task), whereas fixations to the nose, mouth, and non-core features were not expected to relate to face recognition accuracy. Here, the eye region was separated into three segments (left eye, nasion, and right eye) to directly evaluate the validity of the left eye superiority reported in the literature (e.g., Haig, 1985; Schyns et al., 2002; van Belle et al., 2010); if the left eye is particularly salient for face encoding and recognition then associations should be strongest for the left eye.

Once these gaze-behaviour associations were established, featural fixation patterns and recognition accuracy were correlated with self-reported autistic traits (for sub-scale analyses see **Appendix C**). It was anticipated that sub-clinical autistic traits would be negatively correlated with looking time and fixation counts to the eyes (especially the left eye), such that neurotypical adults with more autistic traits would spend less time attending to the eyes than adults with fewer autistic tendencies. Nose fixations were not expected to be associated with autistic traits, although a positive correlation was predicted for mouth fixations, such that adults with higher AQ scores would attend to the mouth more often than their peers with lower AQ scores. Autistic tendencies were also expected to relate to face recognition accuracy (with poorer face recognition performance observed for neurotypical adults self-reporting more autistic traits), although any potential differences between incidental and intentional tasks were exploratory in nature.

2.2 Method

2.2.1 Participants

A total of 124 neurotypical adults with no history of epilepsy or seizures, psychiatric disorders, neurological disease, head injury, or concussion participated for course credit or cash payment. All participants self-identified as White/Caucasian,[6] reported normal or corrected-to-normal vision, and were not taking antidepressant, antipsychotic, or cortisone medications at the time of testing. Data from twelve participants were subsequently excluded due to equipment malfunction (3), unreliable eye-tracking recordings[7] (3), or for performing at or below chance levels ($d' \leq 0$) on both face recognition tasks[8] (4). Thus, 112 neurotypical adults

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[6] To reduce other-race perceptual and memory confounds on face recognition performance, only participants identifying with a primary White/Caucasian racial background were included in the present study.

[7] One participant yielded poor calibrations on all eye-tracking recordings, and two participants' data consisted solely of shaky, unreliable fixations (< 100ms) due to movement and/or weak pupil contrast.

[8] This *a priori* exclusion criterion was implemented to ensure that neurotypical recognition abilities were not confounded by developmental prosopagnosia, other visual/face processing difficulties, or non-compliance with task instructions. Participants were only required to achieve above-chance levels on one task to be included in the analyses reported here, so as not to penalize participants for potential floor-effects on one task. Six participants in the current sample demonstrated chance-level accuracy ($d' \leq 0$) on one task (3 incidental; 3 intentional); however, these participants performed above chance-level on the other task and were not flagged as influential outliers. Therefore, these participants are included in the present analyses.

(60 female, 50 male, 1 non-binary, 1 unspecified; M_{age} = 20.44 years, SD_{age} = 4.41) were included in the analyses reported here.

This study was reviewed and approved by a University of Waterloo Human Research Ethics Committee and, in accordance with the Declaration of Helsinki, all participants provided informed written consent at the beginning of the experimental session.

2.2.2 Stimuli

A collection of 120 White/Caucasian faces (60 men, 60 women) from the Chicago Face Database set (Ma, Correll, & Wittenbrink, 2015) were separated into four stimulus sets (each with 15 men and 15 women). All faces depicted a neutral facial expression and included models who did not have facial hair or glasses. Photographs were greyscaled and cropped to only include the internal facial features (i.e., eyes, nose, and mouth). Face stimuli were then air-brushed to remove any identifying marks (e.g., scars, acne), makeup, jewelry, and/or hair, and were sized to a horizontal visual angle of 8.53^{o} (for the *Encoding Phases*) and 6.52^{o} (for the *Test Phases*)[9]. Finally, faces were centered on an axis passing through the tip of the nose on a pixel-scrambled background (12.64^{o} x 12.88^{o} visual angle, see **Figure 1**).

2.2.3 Procedure

After obtaining informed consent, eye dominance was established using the Miles test (Miles, 1930). Participants were then seated at a table with their heads

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[9] Different sized faces were used at encoding and test to ensure that behavioural markers of face recognition best captured *identity* encoding, rather than *pictorial* memory from the same image (Bruce & Young, 1986).

supported in a chinrest 70 cm from a ViewPixx monitor (120 Hz refresh rate). The experimental tasks were presented in a fixed order with the *Incidental Face Recognition Task* always preceding the *Intentional Face Recognition Task*.[10] At the end of each session, each participant completed the Autism-Spectrum Quotient questionnaire, a validated and reliable measure of autistic social-cognitive behaviours (AQ; Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001).

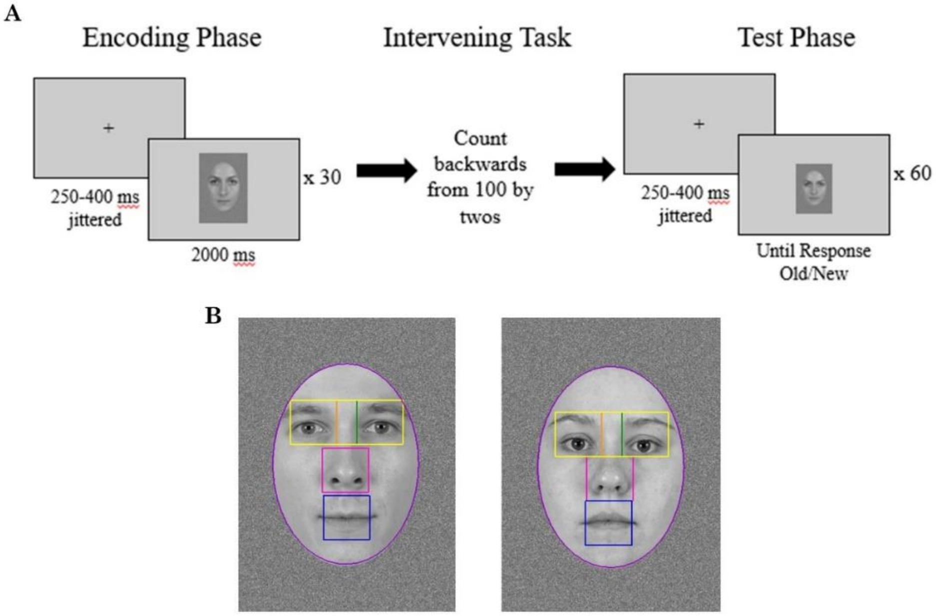

Figure 1. *Panel A:* Trial progression for the *Encoding* and *Test Phases* of the *Incidental and Intentional Face Recognition Tasks*. Note that both tasks proceeded in the same manner (with different face sets), with the exception that in the incidental task participants were asked to mentally judge the trustworthiness of each face during encoding, whereas participants were instructed to explicitly study/memorize each face during the intentional encoding phase. *Panel B*: Stimulus exemplars with feature regions of interest (ROIs) overlaid for the left and right eyes, nasion, nose, mouth, and non-core facial features (i.e., chin, cheeks, and forehead).

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[10] Although I acknowledge that potential order effects on the data outcomes cannot be ruled out, this order was preserved across all participants to maximize the unexpected nature of the face recognition test during the *Incidental Face Recognition Task* and to ensure that participants' eye movement patterns and behavioural responses remained as natural and unbiased in this condition as possible. Set-task mappings were counterbalanced across tasks and participants.

2.2.3.1 Incidental Face Recognition Task

The old/new recognition task used here was comprised of an *Encoding Phase,* a *Test Phase,* and a *Rating Phase.* For the purposes of this manuscript, the *Rating Phase* will not be discussed further.

In the *Encoding Phase,* participants viewed 30 faces (15 men, 15 women) one at a time, in a random order, and were instructed to mentally judge the trustworthiness of each face as it appeared on the screen (i.e., "Think to yourself, 'How trustworthy does this person look to me?'"). On each trial, a central fixation cross was presented (jittered presentation time: 250 – 400 ms), followed by a face stimulus (subtending 8.53^{o} horizontal visual angle). The face remained on-screen for 2000 ms before the next trial began (**Figure 1A**); no overt responses were required during this phase of the experiment. Face set was randomized across participants.

Once the *Encoding Phase* was complete, participants were instructed to count backwards from 100 by increments of two (e.g., 100, 98, 96, and so on) for a duration of 30 seconds. The researcher started a stopwatch once participants started counting and stopped the participant after 30 seconds had passed. This intervening task was included to ensure participants had sufficient time to transfer all face memory traces to long-term memory prior to starting the *Test Phase.*

Participants were then told they would be tested on their memory for the faces they had just seen. In this surprise *Test Phase*, participants were instructed to indicate, as accurately as possible, whether each face was *old* (i.e., they had seen this face and mentally assessed this person's trustworthiness) or *new* (i.e., they had never seen this face before) using the left and right trigger keys on a standard game controller. Response buttons were counterbalanced across participants. Here, participants viewed 60 sequential faces (30 men, 30 women; all target faces from the *Encoding Phase* set, as well as 30 new distractor faces from one of the remaining face sets) in a random order. Each trial began with a central fixation cross (jittered presentation time: 250 – 400 ms), followed by a face stimulus which remained on the screen until a response was registered (**Figure 1A**).

2.2.3.2 Intentional Face Recognition Task

This task proceeded in much the same manner as that explained above for the *Incidental Face Recognition Task*, except that participants were explicitly instructed to study/memorize each face carefully during the *Encoding Phase* for an upcoming (expected) memory test (*Test Phase*). All other instructions and response options remained the same.

The two stimulus sets not used in the *Incidental Face Recognition Task* were used here (30 faces for the *Encoding Phase* and 60 faces (30 target, 30 distractor) for the *Test Phase*). Participants were aware that all faces presented in the *Intentional Face Recognition Task* were different from those in the previous task (i.e., *old* responses indicated that the face was just studied/memorized, not that the face had ever been judged on its trustworthiness; *new* responses indicated that they had never seen the face before).

2.2.3.3 Autism-Spectrum Quotient (AQ)

The AQ is a 50-item self-report questionnaire commonly used to assess cognitive and behavioural tendencies associated with the autistic phenotype (Baron-Cohen et al., 2001) and has been validated in both clinical and non-clinical adult samples (Austin, 2005; Hoekstra, Bartels, Cath, & Boomsma, 2008; Hurst, Mitchell, Kimbrel, Kwapil, & Nelson-Gray, 2007; Ruzich et al., 2015; Sucksmith, Roth, & Hoekstra, 2011; Woodbury-Smith, Robinson, Wheelwright, & Baron-Cohen, 2005). Here, respondents completed a computerized version of the questionnaire, indicating their level of agreement or disagreement ("definitely disagree", "slightly disagree", "slightly agree", "definitely agree") with statements tapping into the five cognitive-behavioural domains (attention to detail, attention switching/flexibility, social skills, communication, imagination/theory of mind). Each item was then scored on a scale of 1 – 4, with higher scores indicating more autistic-like tendencies[11]; Total AQ scores were summed across all items. Subscale scores were also calculated for each of the five sub-domains (see **Appendix C**).

2.2.4 Eye-Tracking Recordings

An Eyelink 1000 remote eye-tracking system (SR Research, http://sr-research.com) recording at a sampling rate of 1000 Hz was used to monitor monocular eye movements from each participant's dominant eye[12]. Nine-point calibration and

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[11] The four-point scoring system was adopted here because these methods have been shown to yield stronger internal consistency and test-retest reliability metrics compared to studies implementing Baron-Cohen et al.'s (2001) traditional binary scoring system (Austin, 2005; Stevenson & Hart, 2017). This scoring technique is also recognized to be a more suitable method of capturing individual variations in behavioural heterogeneity (a key aspect of autistic symptom presentation).

[12] The non-dominant eye was recorded for four participants due to difficulties tracking the dominant eye.

validation sequences were initiated at the beginning of each phase, marking the participant's eye gaze position relative to a series of targets placed equidistant around an invisible square border.

2.2.5 Data Processing

Six non-overlapping region of interest (ROI) templates (corresponding to the left eye, right eye, eye region, nose, mouth, and full face; **Figure 1B**) were created for each face. Individualized templates were generated for each face model, as opposed to one generalized template, to account for variations in internal feature structure and distances across identities. Post data collection, these individualized ROI templates were applied to all experimental trials.

Fixation reports detailing the location (featural ROI[13]) and duration (in milliseconds) of each fixation during the *Encoding Phase* were extracted using DataViewer software (version 2.6.1; SR Research, http://sr-research.com). Fixations falling within the eye region but not within the left or right eye boundaries were coded as landing within the nasion ROI. Likewise, fixations falling within the face but not within the boundaries of any core feature were categorized as landing on non-core features. Fixations less than 100 ms were removed[14] (7.46% of all fixations) using custom-made R scripts, in line with standards from the face processing literature

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[13] In the rare event the centroid of a fixation landed on the border(s) between two or more core feature ROIs, the fixation was coded as landing on the upper-most feature (i.e., eyes > nose > mouth). Fixations on eye-nasion borders defaulted into the respective eye's ROI, and fixations on the border of core feature ROIs were coded as falling within the ROI (rather than being labelled as a fixation towards a non-core feature).

[14] Fixations less than 100 ms are confounded by irrelevant oculomotor activity (e.g., saccadic velocities) and are more likely to include small eye movements more indicative of false saccade planning and/or attentional redirection rather than higher-order cognitive processes of interest to the present study (Manor & Gordon, 2003; Rayner & Pollatsek, 1989).

(Falkmer et al., 2010; Goldinger, He, & Papesh, 2009; Hills & Pake, 2013; Manor & Gordon, 2003). Fixation counts and total time spent looking at each ROI were calculated. Trial-wise proportion values were then computed for looking time (relative to the 2000 ms viewing time) and fixation counts (relative to the total number of fixations made during the trial).

Next, to maximize our confidence that results would reflect the relative *interest* or *salience* of each feature (rather than being confounded by differences in the size and boundaries of each feature's ROI), proportional area values were calculated for each feature (**Equation 1**) relative to the full image (including the face and the pixel-scrambled background; 12.64° x 12.88°).

Equation 1:

$$proportion_{ROI\ area} = \frac{ROI\ area\ (in\ pixels)}{image\ size\ (in\ pixels)}$$

These area proportion values were then used to transform the proportional looking time and fixation outcome measures into area-normalized values (*A;* **Equations 2 & 3**).

Equation 2:

$$A_{dwell\ time} = \frac{proportion\ of\ dwell\ time\ to\ the\ ROI}{proportion\ of\ ROI\ area}$$

Equation 3:

$$A_{fixation\ count} = \frac{proportion\ of\ fixations\ made\ to\ the\ ROI}{proportion\ of\ ROI\ area}$$

Following this transformation, values ≥ 1 indicate that a region was visually targeted due to the region's relative salience or interest. Alternatively, area-normalized values closer to 1 suggest that fixations were directed to the region randomly.

To calculate behavioural memory sensitivity scores (d'), the proportion of hits (correctly identified targets) and false alarms (incorrectly identified distractors) were calculated for each recognition task. Next, task-specific d' values were computed using the dprime() function in R, by subtracting the standardized distribution for false alarms from the standardized distribution for hit responses[15] (**Equation 4**).

Equation 4: $$d' = z(hits) - z(false\ alarms)$$

Using this metric, d' scores index an individual's ability to accurately detect the test signal (in this case target faces) amongst cognitive "noise" (incorrectly recognized faces). Higher d' values denote greater discernment between signal and noise and, therefore, better recognition accuracy. Chance threshold is denoted by d' values equal to 0 (i.e., equal proportions of hits and false alarms); values below zero indicate a higher degree of perceptual noise than recognition signal (i.e., false alarm rate > hit rate).

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[15] The dprime() function applies logarithmic-linear corrections to extreme proportional values (i.e., hit or false alarm values equal to 0 or 1; Hautus, 1995). No such instances were observed in these experiments.

2.2.6 Data Analysis

All statistical analyses were conducted using SPSS v26 (IBM Statistics).

First, to quantify the differences in viewing patterns between features, and to evaluate the impact of encoding demands, a 6 (Feature: left eye, right eye, nasion, nose, mouth, and non-core regions) x 2 (Task: incidental and intentional) repeated measures analysis of variance (ANOVA) was conducted using area-normalized looking time and fixation count values as outcome variables. Greenhouse-Geisser corrections were applied where Mauchley's test of sphericity was violated ($p < .05$); group-level follow-up analyses and pairwise comparisons were Bonferroni-corrected. Second, to evaluate the impact of task demands on recognition accuracy, a paired-sample t-test was conducted with Task (incidental or intentional face recognition) as the within-subject variable and d' as the dependent variable.

Next, the relationship between fixation patterns and recognition accuracy (d') using an individual differences perspective. To this end, a series of Pearson correlations were implemented evaluating the relationship between fixation patterns to facial features (left eye, right eye, nasion, nose, mouth, non-core features) and task-specific d' values. Correlations were computed for each feature-task relationship (e.g., left eye & incidental recognition, mouth & intentional recognition, etc.; 6 features x 2 tasks) and for both outcome measures (area-normalized looking time and fixation counts). Correlation analyses were also used to evaluate the relationships between self-reported autistic traits (AQ) and fixation patterns as well as recognition accuracy. Bootstrapping simulations[16] (with 5000 iterations; Efron & Tibshirani, 1994) were applied to all correlation analyses to define 95% confidence intervals, thereby determining the likelihood of the observed relationships yielding a non-existent ($r = 0$) association and to provide protection against multiple comparisons (Efron & Tibshirani, 1994; Romano, Shaikh, & Wolf, 2008; Vasilopoulos, Morey, Dhatariya, & Rice, 2015; Westfall, 2011).

2.3 Results

2.3.1 Descriptives and Distribution Normality

Descriptive statistics for eye-tracking and behavioural measures are presented in **Appendix D**. Initial inspection of the data confirmed that most underlying distributions fell within normality threshold standards (skewness < 3, kurtosis < 10; Kline, 1998). However, looking time and fixation counts to non-core features during intentional encoding yielded non-normal distributions (*Looking time:* skewness = 2.84, kurtosis = 11.18; *Fixation Frequency:* skewness = 3.29, kurtosis = 14.46) when the full sample was considered. This was found to be driven by four outlying cases (±2.5 *SD*). Exclusion of these instances resolved normality issues (Kline, 1998; see **Appendix D**) and were henceforth removed from analyses evaluating viewing patterns to non-core features.

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[16] Bootstrap simulations estimating 95% confidence intervals were conducted for each correlation, rather than the more classically implemented Bonferroni correction, in line with recommendations for data with interdependent variables (Vasilopoulos et al., 2017), as is the case here. Therefore, although some associations may not survive correction at the conservative Bonferroni threshold, the corrections applied here sustain the credibility of the reported effects.

2.3.2 Fixations to Facial Features During Incidental and Intentional Encoding

Fixation patterns did not differ between encoding tasks (Task main effects and interactions: ps $\geq .13$).

Regardless of encoding task, participants focused on the core internal features (left eye, right eye, nasion, nose, and mouth) for longer periods of time, and more often, than expected by chance alone (As ≥ 2.91; **Figure 2**). Alternatively, fixations to non-core features (e.g., forehead, cheeks, chin) occurred more randomly (As = 0.50 – 0.59). The 2 (Task) x 6 (Feature) repeated measures ANOVAs confirmed main effects of Feature, such that participants fixated on the nasion more often, and for longer periods of time, than any other core or non-core facial features (area-normalized looking time: $F(2.74, 300.97) = 85.09$, $MSE = 55.01$, $p < .001$, $\eta_p^2 = .44$; area-normalized fixation counts: $F(2.56, 281.76) = 116.47$, $MSE = 66.08$, $p < .001$, $\eta_p^2 = .51$; paired comparisons: ps $\leq .001$). The left eye was also looked at significantly more than the right eye and mouth (ps $\leq .02$), although left and right eye fixations did not differ from the nose (ps $\geq .21$). The mouth was looked at the least of all internal features (ps $\leq .001$).

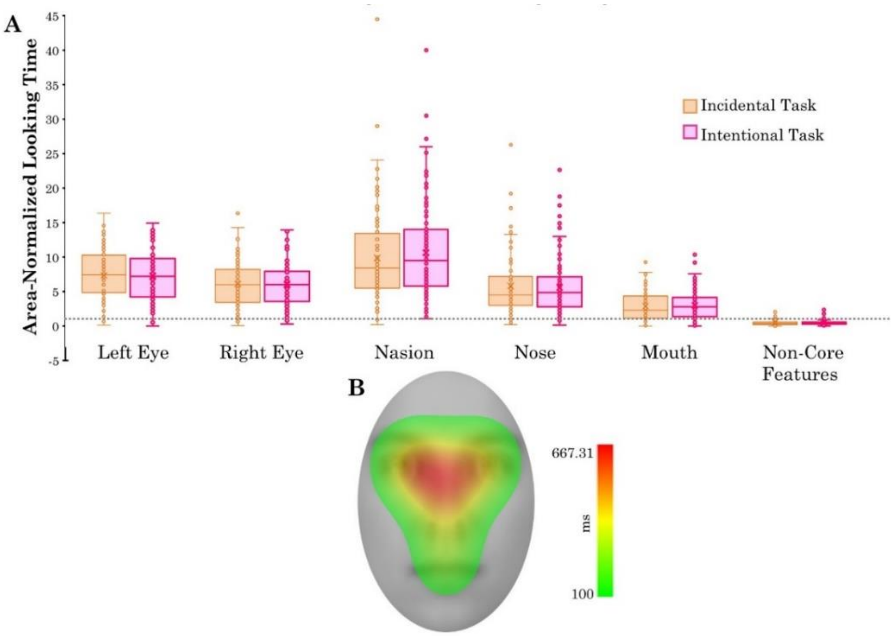

Figure 2. *Panel A:* Area-normalized looking time to internal facial features during incidental (orange) and intentional (pink) encoding. The dotted line marks the threshold for random-intentional eye movements (1.0) a. Median scores are represented by the horizontal lines and whiskers extend to the minimum and maximum points within the interquartile range. *Panel B:* Heat map illustrating average fixation durations during intentional encoding overlaid on a composite face comprised of all face identities.

2.3.3 Incidental and Intentional Face Recognition Accuracy

Contrary to the initial hypothesis, face recognition accuracy did not differ between the incidental and intentional recognition tasks ($t(111) = -0.40$, $p = .69$; **Figure 3**).

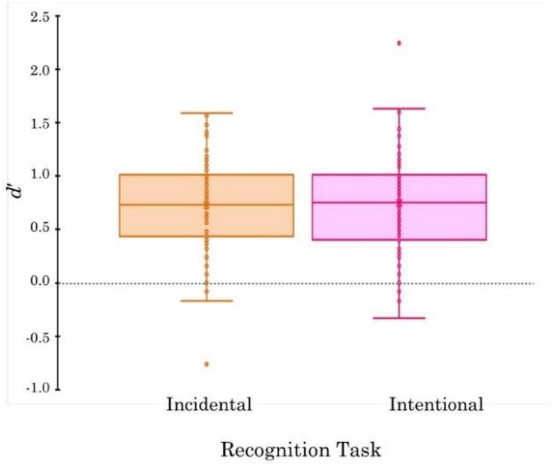

Figure 3. Incidental and intentional recognition accuracy (d') scores. The dotted line ($d' = 0$) indicates chance level and whiskers extend to the minimum and maximum points within the interquartile range. Median scores are represented by the centre line.

2.3.4 The Relationship Between Encoding Fixation Patterns and Face Recognition Accuracy

2.3.4.1 Incidental Face Recognition Task

Correlation analyses revealed significant positive associations between left eye fixation metrics and incidental recognition accuracy scores (*Looking Time*: $r = .23$, $p = .01$, $CI_{95\%}$: [0.02 – 0.41]; *Fixation Count:* $r = .23$, $p = .02$, $CI_{95\%}$: [0.03 – 0.42]; **Figure 4A**), such that increased fixation to the left eye during encoding was related to higher incidental recognition accuracy (d'). Participants who made more (area-normalized) fixations on the nasion also demonstrated significantly higher incidental recognition accuracy than participants who made fewer nasion fixations ($r = .19$, $p = .05$, $CI_{95\%}$: [-0.01 – 0.36]; **Figure 4C**), although time spent looking at the nasion did not reach statistical significance ($p = .19$). In contrast, nose fixations were negatively correlated with incidental recognition accuracy scores (*Looking Time:* $r = -.22$, $p = .02$, $CI_{95\%}$: [-0.38 – -0.03]; *Fixation Count:* $r = -.22$, $p = .02$, $CI_{95\%}$: [-0.39 – -0.06]; **Figure 4B**), such that participants who spent more time look at, and/or made more fixations towards, the nose during encoding performed more poorly than participants who attended to the nose less often**.** All other correlations were non-significant (ps $\geq .19$).

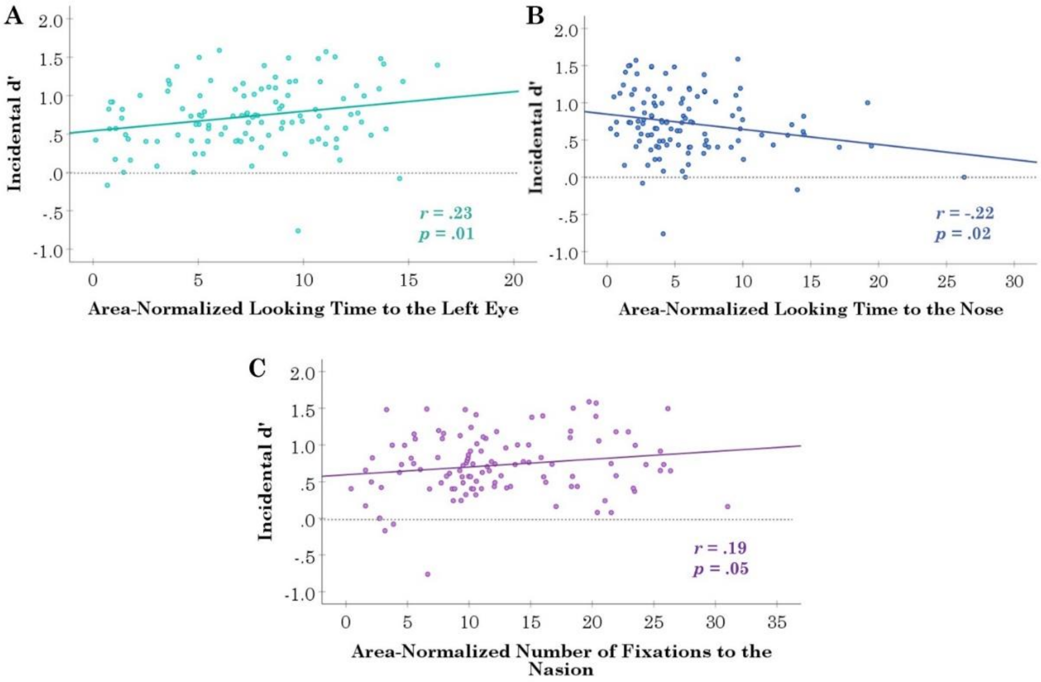

Figure 4. Scatterplots depicting the significant correlations identified between area-normalized looking time to the left eye (*Panel A*) or nose (*Panel B*), as well as nasion fixation counts (*Panel C*) during face encoding and subsequent incidental recognition accuracy (d'). The dotted line ($d' = 0$) indicates chance level.

2.3.4.2 Intentional Face Recognition Task

For this task, reduced looking time and fewer fixations to non-core features of the face were associated with higher intentional face recognition scores (*Looking time:* $r = -.25$, $p = .009$, $CI_{95\%}$: [-0.40 – -0.10]; *Fixation Frequency*: $r = -.25$, $p = .01$, $CI_{95\%}$: [-0.40 – -0.08]; **Figure 5A**). No other correlations were statistically significant (*p*s ≥ .31).

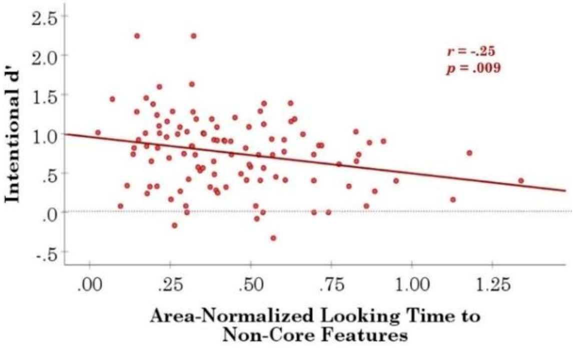

Figure 5. Scatterplot depicting the significant association between area-normalized looking time to non-core features and intentional recognition accuracy. The dotted line ($d' = 0$) marks chance level.

2.3.5 The Role of Sub-Clinical Autistic Traits

Pearson correlations were implemented to assess the relationships between AQ scores and fixation patterns (area-normalized looking time and fixation counts), as well as between autistic traits and incidental/intentional recognition accuracy. AQ scores were not available for one participant; thus, analyses reported here were conducted with 111 neurotypical adults. Descriptive and normality statistics for all AQ factors are displayed in **Appendix C** along with exploratory analyses across AQ sub-scales.

Contrary to initial hypotheses, fixation patterns were largely unrelated to self-reported autistic traits (*p*s ≥ .08). Total AQ scores were, however, significantly correlated with intentional recognition accuracy ($r = -.21$; $p = .03$; $CI_{95\%}$: [-.39 – -.01]), such that individuals with higher AQ scores performed more poorly than their counterparts with fewer autistic traits (**Figure 6B**). Total AQ scores were not significantly related to incidental recognition accuracy scores ($r = -.16$; $p = .09$).

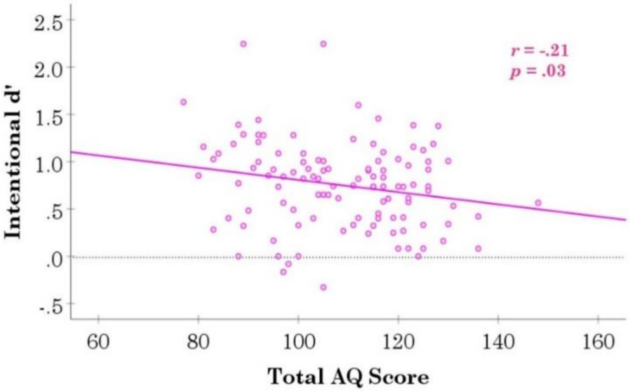

Figure 6. Scatterplot depicting the significant negative correlation between Total AQ scores and intentional accuracy (*d*′) scores.

2.4 Discussion

This research study aims to evaluate the relationship between gaze fixation patterns to internal facial features and face recognition accuracy in a large sample of neurotypical adults. Here, area-normalized looking time and fixation counts to core (left eye, right eye, nasion, nose, and mouth) and non-core (forehead, cheek, chin) features were monitored during incidental and intentional face encoding. Group-level analyses focused on quantifying potential task differences in gaze patterns and recognition accuracy. Correlation analyses then evaluated the relationship between individual differences in fixation patterns to features and variability in face recognition accuracy. Overall, group level results demonstrate increased visual attention towards core internal features of the face relative to non-core features, replicating previous reports throughout the neurotypical literature (Andrews, Davies-Thompson, Kingstone, & Young, 2010; Haig, 1985; Longmore, Liu, & Young, 2015; Shepherd et al., 1981; Yarbus, 1967). Critically, this bias towards the internal features of the face was prominent, even when accounting for the visual area of each feature, thereby highlighting the relative saliency of these features for face encoding. Supporting the initial predictions and the eye region sensitivity for recognition reported throughout the literature (Henderson et al., 2005; Hills et al., 2013; Janik et al., 1978; Rollins et al., 2019; Royer et al., 2018; Shepherd et al., 1981; Sormaz et al., 2013), these results demonstrate that the eye region (left eye, nasion, and right eye) is fixated on longer and more often than other parts of the face. Here, we also see that within the eye region, the nasion itself appears to be the most salient area, with substantially more fixations directed towards this small region than would be expected based on its size and lack of detail alone. Therefore, this region of the face must emanate some form of relative importance or interest for neurotypical adults – an idea we will revisit in Chapter 5. Fixation patterns were also noticeably biased towards the left and right eyes of the face, signifying these features' salience in the eye region as well. It is worth noting that here, the left and right eyes of the face were looked at the same degree overall, and this was true for both tasks.

Interestingly, gaze fixation patterns to the eyes were not significantly different from fixations directed towards the nose. The relative saliency of the nose observed here admittedly came as an initial surprise, given that this feature is not particularly diagnostic for face recognition (Schyns et al., 2002; Shepherd et al., 1981). However, closer examination of the raw data revealed that many nose-based fixations were clustered towards the upper-left quadrant of the ROI (close to the left eye and nasion; see the heatmap in **Figure 2**) and not towards the base of the nose[17] (as would be expected if the nose feature itself was essential for face encoding). Given that this fixation cluster falls at the intersection of multiple features, this indiscriminate area of the face may be classified as part of the eye region, nasion, nose, or non-core features across studies depending on how the featural ROIs are defined (Hessels, Kemner, van den Boomen, & Hooge, 2016). With this understanding, the present results are no longer at odds with the eye sensitivity literature as initially thought – the base of the nose itself (what we commonly consider to be the nose feature) does not contain diagnostic information for face recognition. Instead, the region below each eye appears to capture visual attention to a significant degree during face encoding. These results compliment existing research indicating that fixations just below the

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[17] This observation also confirms that nose metrics were not disproportionately influenced by fixations carrying over from the preceding fixation cross (centred on the nose) but rather that these measures include intentionally directed fixations (> 100 ms).

left eye are related to improved face identification (Hsaio & Cottrell, 2008; Peterson & Eckstein, 2012, 2013) and extends our understanding further by demonstrating these patterns are also seen during face encoding. The subjectiveness of feature ROI application discussed here also speaks to the importance of analyzing x- and y-gaze coordinates and/or implementing standardized ROIs to improve translation and generalizability across research studies and samples (see Hessels et al., 2016).

The left-eye bias is not supported at the group level in this large sample of neurotypical adults with a range of gaze fixation patterns and recognition abilities. Rather, the distributed saliency observed across multiple facial features is consistent with Arizpe et al.'s (2017) gaze-reliant sub-groups: left eye-, right eye-, nasion-, and nose-mouth-reliant and support the view that neurotypical adults' fixation patterns may be better classified based on preferred feature clusters – the subject of a future investigation. Taken together, the current research highlights the importance of the eye region in face encoding and signifies the need for social cognition studies to analyze the eye region in more detail (i.e., segregating the left eye, right eye, and nasion into individual components and/or analyzing x- and y-gaze coordinates) to more fully understand what it is about the eyes and nasion that make them particularly salient.

Although recognition accuracy (*d'*) did not differ between tasks on average, correlation analyses revealed that variability in gaze fixation patterns were related to incidental (but not intentional) recognition accuracy. Consistent with initial predictions, the left eye and nasion were positively correlated with recognition accuracy, supporting the position that the left eye and nasion are the most salient features for successful recognition. Although it is important to keep in mind that the eye sensitivity hypothesis was only supported for incidental recognition. Even though participants looked at the eyes and nasion similarly regardless of encoding tasks, fixations directed towards the eyes during intentional encoding were not significantly related to subsequent face recognition accuracy. The consistency of associations across area-normalized looking time and fixation count metrics indicates that neurotypical adults not only look at the left eye for longer periods of time to support efficient recognition, but it also appears that a strategy in which the left eye and nasion are returned to frequently (i.e., higher fixation counts) is equally beneficial for optimizing incidental recognition. These findings extend our understanding of the importance of the eye region in incidental face recognition and provide evidence in support of the eye region as an anchored reference point for face processing.

Fixation counts and time spent looking at the nose were also found to be negatively associated with incidental recognition accuracy, such that adults with an increased reliance on the nose demonstrated poorer recognition scores than adults who did not rely on this feature to the same degree. This extends our general understanding that the nose does not typically portray key identifying details to include the realization that increased reliance on this feature may in fact *impair* recognition performance. It is also interesting to consider this pattern in light of the earlier finding that fixations tend to be directed towards the bridge of the nose and underneath the eyes. Although left eye and nasion fixations yielded positive associations with recognition accuracy, nose fixations elicited the opposite response. In line with previous research (Hsaio & Cottrell, 2008; Peterson & Eckstein, 2012, 2013), the current study suggests that the eccentricity of fixations from the eyes and nasion may also be critical for recognition efficiency. Specifically, fixations closer to the eyes appear to be optimal for neurotypical performance, whereas less-precisely targeted fixations on the (adjacent) bridge of the nose may not be in sufficient range of the "optimal zone" to maximize accuracy. The precise nature of these relationships cannot be addressed by the present study alone and require further investigation.

Intentional face recognition accuracy was not associated with gaze fixation patterns to core facial features, although a negative correlation was apparent with time spent looking at non-core features (forehead, cheeks, chin). These findings stress the importance of directing visual attention towards internal core features during face encoding to optimize face recognition accuracy. This relationship was further mediated by autistic-like *imagination* traits (see **Appendix C**), indicating that adults with an increased awareness of another's thoughts and intentions (i.e., perspective taking) may be more cognisant of the social (identity) cues portrayed by the internal features of the face, thereby directing their fixations towards these features more often and optimizing recognition accuracy. Alternatively, adults with a weaker understanding of others' intentions and how social cues are portrayed seem to be less likely to direct fixations towards internal features, instead spending more time attending to less relevant parts of the face, resulting in poorer recognition accuracy (for further discussion see **Appendix C**). Once neurotypical adults direct their fixations to the internal features of the face, however, reliance on certain features does not necessarily benefit intentional recognition.

Intentional recognition accuracy also systematically decreased as a function of Total AQ score (**Figure 6**), whereas sub-clinical autistic traits were not significantly related to incidental recognition accuracy. These results add to the body of literature demonstrating differences in recognition performance as a function of sub-clinical autistic traits (Davis et al., 2017; Halliday et al., 2014; Morgan & Hills, 2019; Rhodes et al., 2013; Valla et al., 2013) and extend the field's understanding to demonstrate that this pattern is specific to intentional recognition and does not translate to all measures of face recognition performance. Therefore, autistic traits differentially impact face recognition performance at the sub-clinical level based on task demands, with the most significant influence observed when explicit memorization and recognition is required. These results mirror evidence from outside the face literature indicating weaker learning trajectories for individuals with high AQ scores when executive functioning demands are required, but not when visual perception strategies are beneficial to learning performance (Ferraro, Hansen, & Deling, 2018; Parkington, Clements, Landry, & Chouinard, 2015; Reed, Lowe, & Everett, 2011).

This first experiment demonstrates that although faces appear to be looked at in similar ways across task demands at the group level, the way in which facial features are *used* for face recognition is fundamentally different across tasks and individuals. Using an individual differences approach, this study reveals that the left eye and nasion are particularly salient during face encoding and incidental recognition, supporting the eye region sensitivity of neurotypical face processing and recognition. Fixations clustered towards the bridge of the nose also appear to be important for incidental face encoding, although increased reliance on this region has a negative impact on recognition accuracy. Alternatively, intentional face recognition is largely unrelated to gaze fixations to core facial features and is instead influenced more so by non-core features and autistic traits, indicating a cognitive-behavioural impact on memory abilities at the sub-clinical level.

Chapter 3: Autistic Gaze Patterns During Face Encoding and Face Recognition Accuracy

> *"The face is the mirror of the mind and eyes without speaking confess the secrets of the heart."*
> -St. Jerome (347 – 420 A.D.)

3.1 Introduction

Now that associations between face encoding fixation patterns and recognition accuracy have been established in neurotypical adults (Goal #1; Chapter 2), these methods were extended into a clinical autism population to assess neurodivergent face recognition abilities (Goal #2).

3.1.1 The Role of Visual Attention in Autistic Face Recognition

One of the most noticeable behavioural characteristics of autism is a propensity for reduced attention to the eyes and difficulties maintaining and integrating eye contact during social overtures (American Psychiatric Association, 2013). Although the stereotypical schema of autistic gaze behaviours is often similar to that depicted in the media (e.g., Rain Man, Dr. Murphy from The Good Doctor): an autistic adult who looks away from the face all together and focuses on the person's body or the background, it is essential to recognize that, like any other cognitive or behavioural trait, gaze behaviours vary widely in ASD. While it is true that some autistic adults, particularly men, spend more time attending to non-social elements in their environment relative to neurotypical adults (Chita-Tegmark, 2016; Hendrickx, 2018), other autistic adults may constrain their focus to the face but on other core facial features (e.g., nose or mouth), non-core parts of the face (e.g., forehead, cheeks), or the person's hair (Just & Pelphrey, 2013; Klin et al., 2002; Pelphrey et al., 2002). In stark contrast to the stable, systematic fixation patterns observed when neurotypical adults view faces (see Chapters 1 & 2), individuals with an ASD often display irregular and disorganized gaze patterns –allocating attention in a seemingly random fashion, or towards the mouth and body of another person (Chita-Tegmark, 2016; Klin et al., 2002; McPartland et al., 2011; Pelphrey et al., 2002; Rollins et al., 2019; Snow et al., 2011; Spezio et al., 2016; Wang et al., 2019). These findings suggest that many adults with an ASD are less strategic in distributing their visual attention to facial features within a face, due to a reduced awareness or saliency for diagnostic cues within the eye region (*eye indifference*; Moriuchi et al., 2017) and/or an increased reliance on other features (e.g., nose, mouth) for social information as a result of active avoidance of the eyes (*eye avoidance;* Tanaka & Sung, 2016).

Some autistic adults develop camouflaging strategies (e.g., mimicking mutual eye gaze or fixating close to the eyes)[18] to mask their autistic behaviours, whereas others may not experience as much, or any, difficulty integrating eye contact, thereby showing typical attention to another's eyes (Green, Travers, Howe, & 2019; Hendrickx, 2015; Hull et al., 2020; Ratto et al., 2018; Schuck et al., 2019). However, this diversity in visual attention is under-recognized within the scientific literature. To date, only a handful of studies have reported similar eye movement patterns

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[18] Recent investigations have unveiled that autistic girls/women and non-binary individuals tend to engage in more camouflaging behaviours and mutual eye contact than autistic boys or men (Hendrickx, 2015; Hull et al., 2020; Schuck et al., 2019).

between autistic and neurotypical adults at the group level (Fletcher-Watson, Leekam, Benson, Frank, & Findlay, 2009; Hedley, Young, & Brewer, 2012; Schauder et al., 2019). These reports demonstrate that, in some cases, autistic adults do attend to, and use, eye information in a similar way as neurotypical adults. Closer examination of studies reporting group-level impairments also reveals that preserved gaze patterns are present in autism but are often missed or undermined by group-level effects and analyses (Wilmer et al., 2010; Yovel et al., 2014). Likewise, although face recognition difficulties and impairments are prevalent amongst autistic adults, several reports of typical face recognition have also been documented (Hedley et al., 2012; Kanner, 1943; Klin et al., 1999; Nishimura et al., 2008; Schauder et al., 2019). In fact, face recognition abilities are likely related to autistic behavioural expression and social functioning (Kirchner et al., 2011; McPartland et al., 2011), although it remains unclear which aspects of autistic symptomology contribute to face recognition abilities (e.g., perspective taking, attention to detail) – an important facet to understand in order to effectively develop therapies, interventions, and workshops that address core social symptoms in autistic adults.

Collectively, this research signifies that despite the perpetuation of deficit-based views of ASD, not all autistic gaze patterns and face recognition abilities deviate from the neurotypical range. Instead, the true reflection of autistic face processing abilities may be better characterized along an extension of the neurotypical spectrum, highlighting the importance of adopting a neurodiversity framework in relation to autistic social cognition (Baron-Cohen, 2017; Mandy, 2017;

Masataka, 2017; Silberman, 2017). While it is critical that we understand the underlying roots of disrupted and impaired performance, it is equally important to determine how preserved attention to the eyes influences face processing mechanisms in autism by recognizing the full spectrum of abilities. One possibility is that similar to neurotypical adults, attention to the eyes may play a key role in accounting for autistic face recognition abilities (Moriuchi et al., 2017; Senju & Johnson, 2009; Tanaka & Sung, 2016). For instance, Snow and colleagues (2011) reported that face recognition accuracy was related to the number of fixations autistic adults made to faces during encoding, although a direct link between attention to specific features within the face (especially the eyes) and face recognition accuracy has yet to be evaluated.

3.1.2 Study Aims & Research Questions

The second goal of this dissertation was to examine the associations between fixation patterns to internal facial features and face recognition accuracy in autistic and neurotypical adults. Consequently, the same within-subjects design described in Chapter 2 was implemented in a diverse sample of adults with an ASD and matched neurotypical control adults. Once again area-normalized fixation metrics captured attentional saliency for each feature (left eye, right eye, nasion, nose, mouth, and non-core regions) and a combination of group-level and within-group analyses explored the impacts of task demands and gaze patterns on face recognition accuracy. Autistic behavioural symptomology (as measured by the Autism Diagnostic Observation

Schedule, ADOS-2; Lord et al., 2012) was also correlated with gaze fixation patterns and recognition accuracy.

A range of gaze fixation patterns and recognition abilities were anticipated for both groups, although it was hypothesized that autistic adults would fixate on the eyes less during face encoding and would perform more poorly on measures of face recognition, than neurotypical controls. In line with studies indicating a potential over-reliance on the mouth during autistic face processing (Klin et al., 2002; Pelphrey et al., 2002; Spezio et al., 2013), it was also predicted that adults with ASD would fixate on the mouth or non-core facial features more than their neurotypical counterparts. At the individual level, it was anticipated that autistic symptomology would be associated with face recognition accuracy and gaze fixation patterns. In particular, it was predicted that eye and nasion fixations would be negatively correlated with ADOS-2 scores, such that autistic adults with milder symptomologies would attend to the eyes more than autistic adults with greater social difficulties. Alternatively, fixations to the mouth and non-core features were predicted to be associated with higher ADOS-2 scores. The nose was hypothesized to be unrelated to autistic symptom presentation.

In terms of gaze-behaviour relationships, positive associations between eye fixation patterns (especially to the left eye) and face recognition accuracy were anticipated, in accordance with Chapter 2 results and eye indifference/avoidance theories (Moriuchi et al., 2017; Tanaka & Sung, 2016). Furthermore, if adults with ASD do in fact rely on the mouth or non-core features for face recognition, then an association should be seen between mouth fixation patterns and *d′* scores for autistic participants.

3.2 Method

3.2.1 Participants

All eligible participants from the neurocognitive assessment (**Appendix A**) completed this experiment. Following data processing, 1 neurotypical participant was excluded because she performed below chance levels on both face recognition tasks[19]. This resulted in 24 autistic and 21 neurotypical adults providing complete data for this experiment (**Table 1**).

Table 1. Demographic information for autistic and neurotypical adults included in the Incidental and Intentional Face Recognition Task analyses. Mean values and ranges are shown here with standard deviations in parentheses.

	Autistic Adults **n = 24**	**Neurotypical Adults** **n = 21**	***t(43)***	***p***
Gender	12 female, 9 male, 2 non-binary, 1 transgender	10 female, 9 male, 2 non-binary	-	-
Ethnicity	22 White, 2 Asian	19 White, 2 Asian	-	-
Age	29.54 (9.70) 18 – 52 years	27.95 (10.12) 19 – 50 years	0.54	.59
Full Scale IQ	115.88 (15.57) 91 – 157	115.74 (8.94) 101 – 128	0.03	.97
Verbal IQ	117.04 (13.92) 100 – 160	115.32 (9.25) 95 – 134	0.47	.65
Performance IQ	111.46 (17.10) 83 – 154	112.05 (9.92) 94 – 128	-0.13	.89

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[19] Similar to Chapter 2, this chance-level criterion was implemented for neurotypical adults to ensure that this group represented individuals with typical face recognition abilities not confounded by developmental prosopagnosia or other face recognition difficulties.

3.2.2 Stimuli, Procedure, & Data Processing

All stimuli and *Incidental and Intentional Recognition Task* procedures were identical to those described in Chapter 2. These recognition tasks were completed at the beginning of Session 2 of the neurocognitive assessment (**Appendix A**).

To quantify clinical autistic behaviours and confirm ASD diagnosis, adults with a suspected or previously diagnosed autism spectrum disorder completed Module 4 of the ADOS-2; Lord, Luyster, Gotham, & Guthrie, 2012) at the end of the first experimental session. This interactive collection of activities and interview questions was administered by KBP in accordance with research-reliable training standards and took approximately one hour to complete. To receive an *autism spectrum* classification, respondents must have a Communication sub-scale score of at least 2, a Social Interaction sub-scale score of at least 4, and a cumulative Communication and Social Interaction score above 7. Alternatively, respondents with Communication scores above 3, Social Interaction scores above 6, and a combined Communication and Social Interaction score above 10 receive an *autism* classification. Restricted, repetitive behaviour indices are included as part of the total ADOS-2 score but are not used when considering diagnostic classifications (Lord et al., 2012). All autistic participants scored at or above the *autism spectrum* ADOS-2 classification (range: 6 – 17; **Appendix E**) and thus were included in the ASD group.

3.2.3 Data Analysis

To quantify the differences in featural fixation patterns between groups, and to evaluate the impact of encoding demands, 6 (Feature: left eye, right eye, nasion, nose, mouth, non-core) x 2 (Task: incidental, intentional) x 2 (Group: ASD, neurotypical) mixed model ANOVAs were conducted using area-normalized looking time and fixation count values. Second, to evaluate autistic and neurotypical adults' incidental and intentional face recognition abilities, a mixed method 2 (Task: incidental, intentional) x 2 (Group: ASD, neurotypical) ANOVA was conducted with Task as the within-subject factor and *d′* accuracy as the dependent variable. SPSS v26 (IBM Statistics) was used to conduct all analyses. Greenhouse-Geisser corrections were applied when Mauchley's test of sphericity was violated ($p < .05$) and Bonferroni corrections were applied to follow-up analyses and pairwise comparisons.

Next, to evaluate the association between face fixation patterns and recognition accuracy, a series of Pearson correlations were implemented with bootstrapping simulations (5000 iterations; Efron & Tibshirani, 1994) controlling for multiple comparisons and determining the likelihood of obtaining true effects within 95% confidence intervals (Chmiel & Gorkiewicz, 2012; Vasilopoulos et al., 2015; Westfall, 2011). The relationships between autism symptom severity and gaze fixation patterns to internal features were evaluated by correlating area-normalized looking times and fixation counts to each featural ROI and autistic adults' ADOS-2 scores. Incidental and intentional *d′* metrics were also correlated with ADOS-2 scores to determine the impact of autistic symptom presentation on face recognition ability. Finally, to investigate the associations between featural fixation patterns and recognition accuracy, area-normalized fixation measures were correlated with incidental and intentional *d′* scores for autistic and neurotypical adults separately.

3.3 Results

3.3.1 Featural Fixation Patterns During Incidental and Intentional Face Encoding

Autistic and neurotypical fixation patterns to faces during incidental and intentional encoding are shown in **Figure 7**; normality metrics are presented in **Appendix E**. On average, core internal features (left eye, right eye, nasion, nose, and mouth) were all looked at for longer periods of time, and more often, than expected by chance alone (As ≥ 1.74), and this was true for both autistic and neurotypical groups. Alternatively, fixations to non-core features (e.g., forehead, cheeks, chin) occurred more randomly (As $= 0.48 - 0.85$). It is important to note, however, that substantial variability was noted for all features, with some individuals showing strong biases of visual interest for certain features (e.g., As ≥ 5), whereas other individuals did not have the same degree of saliency capture (e.g., As ≤ 2).

The 6 (Feature) x 2 (Task) x 2 (Group) ANOVA unveiled significant main effects of Feature for area-normalized looking time ($F(2.47,106.29) = 39.95$, $MSE = 57.67$, $p < .001$, $\eta_p^2 = .43$) and fixation count ($F(2.24, 96.43) = 41.64$, $MSE = 83.86$, $p < .001$, $\eta_p^2 = .49$). As shown in **Figure 7**, the nasion was looked at longer and more often than any other feature (ps $\leq .01$), followed in turn by the left eye, right eye, and nose, which did not differ from each other (ps $= 1.00$) but were looked at more often, and for longer periods of time, than the mouth and non-core features ($p < .001$). Fixation patterns to internal facial features did not differ across diagnostic Groups (main effect and interactions: ps $\geq .06$), although autistic adults did spend less time looking at the face (and made fewer fixations towards the face) than did neurotypical adults (main effect of Group, Looking Time: $M_{\text{ASD}} = 4.75$, $SE_{\text{ASD}} = 0.23$, $M_{\text{NTC}} = 5.54$, $SE_{\text{NTC}} = 0.25$, $F(1,43) = 5.23$, $MSE = 15.82$, $p = .03$, $\eta_p^2 = .11$; Fixation Count: $M_{\text{ASD}} = 5.91$, $SE_{\text{ASD}} = 0.23$, $M_{\text{NTC}} = 6.64$, $SE_{\text{NTC}} = 0.25$, $F(1,43) = 4.52$, $MSE = 15.80$, $p = .04$, $\eta_p^2 = .10$).

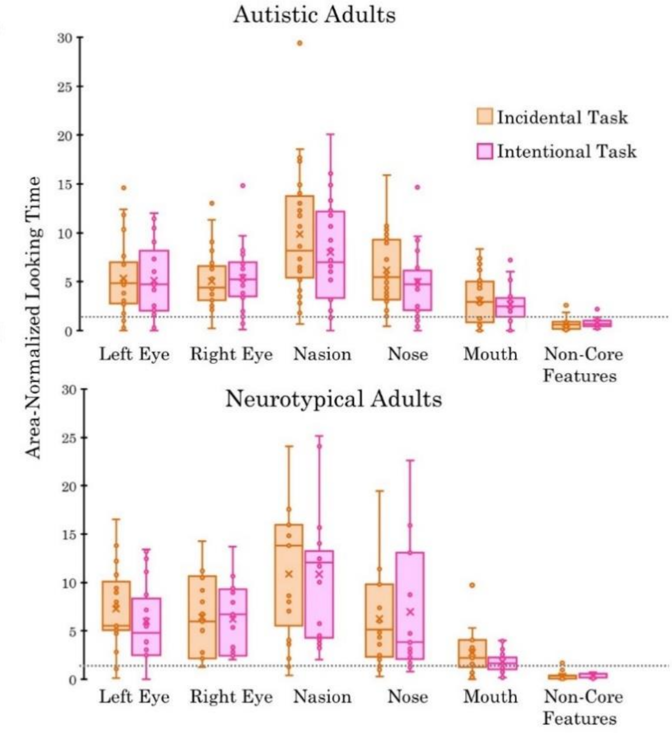

Figure 7. Area-normalized looking time to facial features during incidental (orange) and intentional (pink) encoding for autistic and neurotypical adults. Dashed lines mark the threshold (1.0) for random/intentional eye movements. Within each box plot, the mean is indicated by an x, the solid lines indicate the median, and whiskers extend to the limits of the interquartile range. Normality metrics are also presented in **Table E1.**

Fixation patterns varied across tasks – irrespective of group membership – such that more time was spent looking at (and more fixations were made towards) the face during incidental encoding compared to intentional encoding (main effects of Task, Looking Time: $F(1,43) = 5.98$, $MSE = 3.45$, $p = .02$, $\eta_p^2 = .12$; Fixation Count: $F(1,43) = 5.92$, $MSE = 3.51$, $p = .02$, $\eta_p^2 = .12$). Fixation patterns were not significantly associated with autistic symptomology (ps $\geq .14$).

3.3.2 Incidental and Intentional Face Recognition Accuracy

Recognition accuracy did not differ across task demands (*p* = .25) and was also unaffected by group membership (main effect of Group: *p* = .59; Group x Task interaction: *p* = .89; **Figure 8A**). However, when *d′* scores were assessed solely for autistic adults, Pearson correlations revealed that ADOS-2 scores were negatively associated with intentional face recognition accuracy (*r* = -.56, *p* = .005, $CI_{95\%}$ = [-.84 – -.18]), but not incidental recognition accuracy (*r* = -.13, *p* = .54). As shown in **Figure 9B**, autistic adults with lower ADOS-2 scores were more accurate at intentionally recognizing faces than their autistic counterparts with higher ADOS-2 scores.

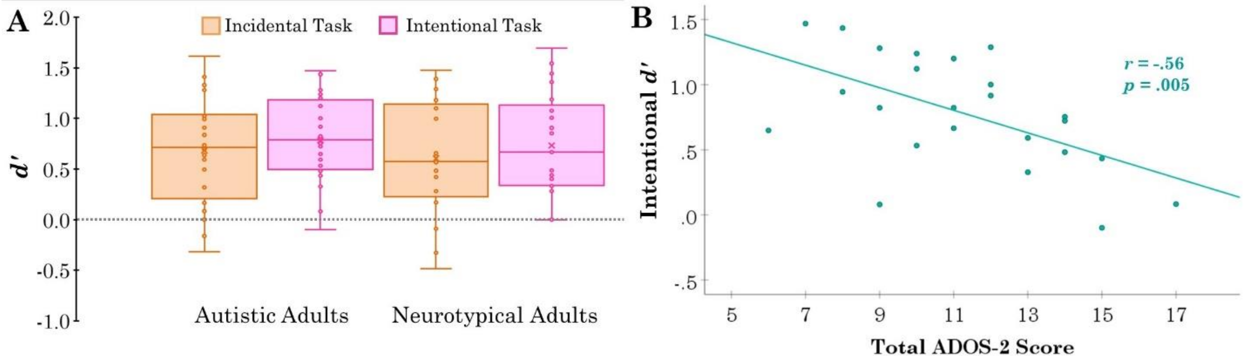

Figure 8. *Panel A:* Incidental (orange) and intentional (pink) face recognition accuracy scores (*d′*) for autistic and neurotypical adults. The dashed line indicates chance level on the recognition tasks. For each box plot, the solid line represents the median and whiskers extend to the limits of the interquartile range. *Panel B:* ADOS-2 scores as a function of intentional recognition accuracy for autistic adults.

3.3.3 The Relationship Between Fixations to Facial Features During Encoding and Face Recognition Accuracy

No significant associations were found between fixation patterns and recognition accuracy for either group (*p*s ≥ .06; **Appendix E**).

4.4 Discussion

Face recognition impairments are not a diagnostic component of ASD; however, many autistic adults experience pervasive difficulties recognizing others throughout their daily lives (Cygan et al., 2018; Faja et al., 2009; Hedley et al., 2011; Kirchner et al., 2011; O'Hearn et al., 2010; Tanaka & Sung, 2016; Weigelt et al., 2012; Williams et al., 2005). On the other hand, some autistic adults do not experience difficulties recognizing faces, demonstrating abilities within (or in some cases even enhanced relative to) the typical range (Hedley et al., 2012; Kanner, 1943; Klin et al., 1999; Nishimura et al., 2008; Schauder et al., 2019). Visual attention to the eyes is theorized to be a primary neurocognitive mechanism driving autistic face recognition behaviours (Moriuchi et al., 2017; Tanaka & Sung, 2016;) and shows a great deal of phenotypic heterogeneity across the autism population. Here, face fixation patterns and face recognition accuracy abilities were evaluated within a diverse group of autistic adults and neurotypical control adults. Group-level and within-group analyses examined the relationship between gaze fixation patterns during face encoding and incidental/intentional face recognition accuracy, as well as potential associations with clinical autistic symptomology.

Overall, autistic adults spent marginally less time attending to the face than neurotypical adults, in line with accounts of reduced social attention in autism (Chita-Tegmark, 2016; Klin et al., 2002; Papagiannopoulou, Chitty, Hermens, Hickie, & Lagopoulos, 2014; Senju & Johnson, 2009; Snow et al., 2011). Although, once fixations were directed within the face, groups did not differ in the average fixation looking times or counts across features. At the group-level, autistic and neurotypical adults fixated on the internal features of the face more than would be expected by chance alone, supporting the viewpoint that these features are particularly salient for optimizing face recognition and generating a high degree of social interest for autistic and neurotypical observers alike. Paralleling that reported in Chapter 2, the nasion was looked at longer, and more often, than any other feature, followed by the left eye, right eye, and nose, with the mouth being looked at the least of all core features. These fixation distributions coincide with the traditional T-shaped pattern reported throughout the neurotypical literature (Henderson et al., 2003, 2005; Hills et al., 2013; Itier, 2015; Janik et al., 1978; Mehoudar et al., 2014; Walker-Smith et al., 1977; Yarbus, 1967) in which the eye region is specifically targeted, with the greatest emphasis on the nasion.

Critically, the present study demonstrates that autistic adults do not always exhibit atypical gaze fixations during face encoding and does not support the *eye avoidance* hypothesis at the group level. Similar to that reported by Hedley and colleagues (2012) – in which autistic adults did not differ from their neurotypical counterparts on fixation allocation during intentional face recognition – the present findings highlight that, under two different task demands, autistic adults often direct their attention towards the eye region and look at the left eye, nasion, and right eye of faces in ways that are similar to neurotypical adults. The relative visual interest of each feature did vary considerably for autistic and neurotypical adults (see Figure 8 & Table E1); for example, while the left eye was particularly salient for many individuals, this feature captured little attention for others. However, no significant correlations were detected within groups in relation to gaze fixation patterns and recognition accuracy within groups, likely due to the limited sample sizes.

Adults with and without an ASD were also not significantly different on face recognition accuracy at the group level, although a prominent association was established between autistic symptom presentation and intentional recognition accuracy (*d′*) scores within the ASD group (**Figure 8B**), providing further insights into the autistic face recognition phenotype (Lewis, Shakeshaft, & Plomin, 2018; Losh et al., 2009; Weigelt et al., 2012). Here we see that even though autistic adults, as a group, achieved similar levels of intentional recognition accuracy as their neurotypical peers, autistic adults with higher ADOS-2 scores performed more poorly than autistic adults with more mild symptomologies. These findings support the variability of face recognition difficulties reported throughout clinical practice and the scientific literature and highlight that core cognitive and behavioural attributes of autism negatively influence autistic adults' ability to recognize faces when attention is intentionally focused on encoding identifying characteristics. Alternatively, when autistic adults focus on another attribute of social cognition (e.g., trustworthiness) when they first encounter faces, their recognition accuracy does not appear to be affected by their clinical phenotype. These findings add to the growing body of literature demonstrating the impact of autistic traits on face recognition abilities (McPartland et al., 2011; Kirchner et al., 2011) and extend our understanding to acknowledge that autistic symptomology appears to be specifically related to intentional measures of face recognition. It is also possible that some autistic adults, particularly those with higher ADOS-2 scores, may be better able to optimize face recognition accuracy when they are left unconstrained or engage in more passive encoding strategies (e.g., focusing on a person's trustworthiness) rather than explicitly trying to remember the person's face for later on. Collectively this study supports a neurodiversity framework within the domain of face recognition (Baron-Cohen, 2017; Mandy, 2018; Masataka, 2017; Silberman, 2017), viewing autistic performance as existing along the same spectrum of abilities as neurotypical adults and highlighting that in some circumstances autistic adults perform similarly to, or better than, their neurotypical counterparts. The array of situations in which face recognition is optimized or hindered in neurotypical and autistic adults provides exciting avenues for future research.

The current research also adds to the growing body of neuroimaging evidence implicating deviations and alterations in the recruitment of neural networks employed by autistic and neurotypical adults during face recognition and social processing (e.g., Nomi & Uddin, 2015). During intentional face recognition (the most commonly implemented empirical paradigm in the scientific literature), neurotypical adults rely on a distributed neural network reflecting a complex interplay of prefrontal and temporal cortical regions associated with executive functions, intentional focus, encoding, and the face network (e.g., middle temporal gyrus, fusiform gyrus), as well as subcortical regions related to consolidation, saliency detection, and social reward (e.g., insula, ventral striatum, amygdala; (Haxby & Hoffman, 2000; Ishai, 2008). Alternatively, in the case of autism, where the connections between neural networks are altered, reliance on cognitive strategies that recruit under-connected regions (e.g., prefrontal cortex) may in fact impede performance, whereas reliance on alternative strategies and neural routes (e.g., passively encoding identity) may be more successful in optimizing their ability to recognize others.

These findings have significant implications not only for clinical applications and therapeutic strategies for autistic individuals presenting with pervasive face recognition deficits, but also for the understanding of autistic face recognition within the scientific community. Specifically, most studies evaluating face recognition abilities in autistic individuals rely on intentional measures that require explicit attention to the face and identifying features, often resulting in high cognitive demands. Therefore, additional research is required to replicate and extend the present findings to clarify whether the face recognition deficits reported throughout the literature are truly reflective of autistic face recognition experiences and abilities, or instead reflect the unsuitability of the empirical measures used to test face recognition behaviours for autistic adults, perhaps requiring adaptation for this diverse population and others struggling with intentional task demands.

In summary, this second experiment reveals that autistic adults appropriately allocate fixations to facial features during face encoding and achieve comparable levels of face recognition accuracy as neurotypical control adults under incidental and intentional task demands, although considerable heterogeneity exists within both populations. Using an individual differences approach and neurodiversity perspective, this research establishes that intentional face recognition abilities are associated with clinical autistic symptomologies, although incidental recognition does not appear to be associated with autistic behaviours.

Chapter 4: The N170 as a Neural Marker of Holistic and Featural Processing in Autistic and Neurotypical Adults

"The general expression of a face is the sum of a multitude of small details, which are viewed in such rapid succession that we seem to perceive them all at a single glance."
-Sir Francis Galton (1883)

4.1 Introduction

The ability to detect facial features within one's environment and integrate these components into a cohesive whole is a complex but necessary process for the efficient perception and recognition of faces. These earliest stages of face processing are crucial for facilitating higher-order social processes (e.g., emotion recognition, gaze perception, identification) and have been proposed to be at the core of social communication difficulties and impairments in ASD (Laycock, Crewther, & Chouinard, 2020; Senju & Johnson, 2009; Tanaka & Sung, 2016). As outlined in Chapters 1 & 3, disruptions in the detection of facial features (especially the eye region) and/or reduced reliance on holistic processing for faces during these earliest stages of perception can lead to poor or disrupted face percepts, resulting in cascading consequences on subsequent aspects of social processing. These theories of holistic integration and eye sensitivity are largely grounded in findings from behavioural studies, with the neural underpinnings of autistic holistic processing and eye sensitivity remaining largely unknown. In particular, the N170 ERP component – the earliest neural marker of face and feature perception (Bentin, Allison, Puce, Perez, & McCarthy, 1996; Eimer, 2011; Itier et al., 2006; Itier & Taylor, 2004; Nemrodov et al., 2014; Rossion & Jacques, 2011) – provides an excellent tool for unravelling the neurodynamics of these rapid and complex mechanisms with excellent temporal resolution; however, the featural and holistic integration of the N170 amongst autistic adults is largely controversial (for reviews see Feuerriegel et al., 2014; Kang et al., 2018). Furthermore, despite the atypical gaze fixation patterns typically reported for adults with an ASD, visual attention has not yet been controlled for in ERP evaluations within autistic adult samples, thereby compromising researchers' ability to adequately determine true group differences in electrophysiological research. To address these issues within the literature, N170 peak amplitudes and latencies were measured in response to upright/inverted faces and cars as well as isolated eye regions and mouths in a subgroup of autistic and neurotypical adults from the neurocognitive assessment (**Appendix A**) using a gaze-contingent event-related potential (ERP) paradigm that has been established within the neurotypical literature (e.g., Nemrodov et al., 2014; Parkington & Itier, 2018b, 2019a) to control for visual attention to the face.

4.1.1 A Neural Marker of Early Face Perception: The N170 ERP Component

Neurotypical adults recruit a dynamic, distributed neural network during holistic face processing (Haxby & Hoffman, 2000; Ishai, 2008), with neural generators in the fusiform gyrus and occipital-temporal cortex responding to faces and feature configurations with a sensitivity not seen for other categories (Arcurio, Gold, & James, 2012; Engell & McCarthy, 2014; Itier & Taylor, 2004; Kanwisher & Yovel, 2006). This neural signature is further evidenced by a face-sensitive scalp-recorded

ERP over occipital and fusiform face areas, occurring within the first 200 ms of seeing a face (for reviews see Eimer, 2011 and Rossion & Jacques, 2011). In short, the N170 ERP component (henceforth referred to as the N170) is the earliest neural marker of face processing, measured by time-locking scalp-recorded electrical measurements of underlying brain activity (EEG) to the presentation of a face (Bentin et al., 1996; Eimer, 2011; George, Evans, Fiori, Davidoff, & Renault, 1996; Luck, 2014; Rossion & Jacques, 2011). Occurring approximately 120-200 ms post face onset, the N170 is argued to reflect the structural and holistic integration stages of early face perception (Bentin et al., 1996; Eimer, 2000a, 2000b, 2000c; Eimer, 2011; Itier, Herdman, George, Cheyne, & Taylor, 2006; Nemrodov et al., 2014; Parkington & Itier, 2018b; Parkington & Itier, 2019a; Rossion et al., 2000; Rossion & Jacques, 2011). Typically larger over right-side sites (Dundas, Plaut, & Behrmann, 2014; Hillger & Koenig, 1991; Rossion et al., 2000; Rossion, Joyce, Cottrell, & Tarr, 2003), the N170 consistently elicits a larger and faster peak response to faces and eye regions than to objects or other visual categories (Bentin et al., 1996; de Lissa, McArthur, Hawelka, Palermo, Mahajan, & Hutzler, 2014; Eimer, 2011; Itier et al., 2006; Itier & Taylor, 2004a; Kloth, Itier, & Schweinberger, 2013; Nemrodov et al., 2014; Rossion et al., 2000; Rossion & Jacques, 2011).

Importantly, the N170 is reliably enhanced and delayed for inverted faces (Itier & Taylor, 2002; Itier, Taylor, & Lobaugh, 2004; Nemrodov & Itier, 2011; Nemrodov et al., 2014; Rossion et al., 1999; Rossion et al., 2000; Rossion et al., 2003) as well as isolated eye regions (Bentin et al., 1996; Kloth et al., 2013; Nemrodov & Itier, 2011;

Parkington & Itier, 2018b; for reviews, see Rossion & Jacques, 2012 & Eimer, 2011), supporting the eye sensitivity and holistic integration theories outlined in Chapter 1. As a matter of fact, neuroscientists are now able to reliably index the face inversion effect (FIE) at the neural level by comparing N170 amplitudes and latencies for upright and inverted faces. The N170 FIE is prominent amongst neurotypical adults and is regarded as a hallmark index of holistic face processing (Eimer, 2011; Nemrodov et al., 2014; Rossion & Jacques, 2011; Yovel, 2016). Likewise, indices of featural sensitivity can also be determined at the neural level using modulations in N170 responses (e.g., differences between the N170 elicited for full faces versus isolated features; see Parkington & Itier, 2018b). Therefore, the magnitude of these difference scores can be reasoned to signal an individual's sensitivity or reliance on specific facial features and holistic processing biases.

4.1.2 The N170 ERP Component in Autistic Adults

Within the clinical domain, the N170 has been proposed as a potential biomarker for identifying face processing difficulties in autism (Jeste & Nelson, 2008; Kang, Keifer, Levy, Foss-Feig, McPartland, & Lerner, 2018; McPartland, 2016), although the reliability and usefulness of this neural marker for diagnostic purposes is still debated (Kang, McPartland, Keifer, Foss-Feig, Levy, & Lerner, 2019; Key & Corbett, 2020; Vettori, Jacques, Boets, & Rossion, 2019). Critically, only a handful of studies have evaluated the N170 in autistic adults, producing conflicting results (see Feurriegel, Churches, Hofmann, & Keage, 2014 and Kang et al., 2018 for reviews). For instance, some studies report delayed N170 latencies for autistic adults relative to their neurotypical peers (McPartland, Dawson, Webb, Panagiotides, & Carver, 2004; O’Connor, Hamm, & Kirk, 2005; O'Connor, Hamm, & Kirk, 2007). This small but significant finding is further supported by a recent meta-analysis evaluating N170 latency and amplitude differences across 18 studies involving children and adults with an ASD as well as neurotypical control peers (latency effect size: 0.36; Kang et al., 2018). Collectively, this has led some researchers to suggest that autistic face processing difficulties may be a reflection of delayed processing from the earliest stages of face perception. Alternatively, other studies have not found significant differences in N170 latencies between autistic and neurotypical adults (Churches, Wheelwright, Baron-Cohen, & Ring, 2010; Churches, Baron-Cohen, & Ring, 2012; Churches, Damiano, Baron-Cohen, & Ring, 2012; Webb et al., 2010; Webb, Merkle, Murias, Richards, Aylward, & Dawson, 2012), insinuating that holistic processing may not be disrupted in all autistic adults. Several studies have also reported reduced overall N170 amplitudes for autistic adults compared to neurotypical peers (Churches et al., 2012; O’Connor et al., 2005; Webb et al., 2012), suggesting social communication impairments may be rooted in diminished face processing, although these attenuated responses are not always face-specific and are inconsistently reported throughout the literature (amplitude effect size: -0.03; Kang et al., 2018).

The modulation of N170 amplitudes and latencies across instances of face inversion and featural sensitivity also remain unclear in autism. To date, only a few studies have directly evaluated the N170 FIE in autistic adults, again yielding conflicting results, with reduced FIEs observed for autistic adults in some cases

(McPartland et al., 2004; Webb et al., 2012) but preserved FIEs demonstrated when performance demands were controlled (Tavares, Mouga, Oliveira, & Castelo-Branco, 2016). In association with the discovery that autistic adults are able to engage in holistic strategies when explicitly cued (Churches et al., 2012; López et al., 2004), these results indicate that task demands and differences in attention may impact autistic face processing at the neural level.

Furthermore, O'Connor et al. (2007) is currently the only study to directly evaluate autistic adults' N170 responses to faces and isolated features. In this case, autism diagnosis did not impact amplitude responses; however, autistic adults elicited longer N170 latencies for faces, eye regions, and mouths relative to neurotypical adults, despite comparable object latencies across groups. These findings led the authors to propose that autistic face processing atypicalities may be the result of delays in early feature processing and integration (O'Connor et al., 2007), although additional replication and extension of these findings is required to confirm the stability and generalizability of these neural patterns. In particular, empirical evaluations directly evaluating holistic and featural processing within the same group of autistic and neurotypical adults are necessary to more fully understand the stability and generalizability of the temporal neurodynamics underlying autistic face processing.

4.1.3 Biases in Electrode Selection and Visual Attention

It is also important to consider that atypical patterns observed on the N170 in ASD may be confounded by factors unrelated to holistic and featural processing. For example, all studies to date have evaluated the N170 component in autistic adults using a grand average approach, measuring amplitudes and latencies on the same electrodes (that produced the largest responses *on average*, irrespective of group membership) for all participants, despite neuroimaging evidence indicating that autistic adults recruit alternative brain regions and neural pathways for face processing (Courchesne, 2002; Nomi & Uddin, 2015; Wolff et al., 2012). Consequently, this approach does not take into account person-to-person variations in neural generators and, therefore, peak N170 responses may not be fully representative of an individual's optimal face processing abilities. Alternatively, ERP techniques that evaluate neural responses on the electrodes that are maximal for each participant (e.g., Aguado, Parkington, Dieguez-Risco, Hinojosa, & Itier, 2019; McCrackin & Itier, 2018; McCrackin & Itier, 2019; Neath & Itier, 2015; Neath & Itier, 2014; Neath-Tavares & Itier, 2016; Parkington & Itier, 2018b, 2019a) may provide a more sensitive approach that is better suited for the heterogeneous autism population.

Moreover, despite the wealth of evidence demonstrating that autistic individuals spend less time attending to faces relative to neurotypical controls (for review and meta-analysis see Chita-Tegmark, 2016) and emerging evidence from the neurotypical literature signalling the importance of controlling where participants are looking during face perception (de Lissa et al., 2014; Itier & Preston, 2018; Neath & Itier, 2015; Neath & Itier, 2014; Neath-Tavares & Itier, 2016; Nemrodov et al., 2014; Parkington & Itier, 2018b; Parkington & Itier, 2019a) there are currently no studies which directly monitor visual fixation during N170 evaluations of autistic face perception in adults. Therefore, it is possible that atypicalities reported on the N170 may be the result of differences in attention allocation to the visual stimulus (i.e., reduced amplitudes in autism may reflect reduced attention to the face) rather than disrupted responses at the neural level *per se*. As such, it remains uncertain whether holistic and featural mechanisms are intact or impaired amongst autistic adults when visual fixation is enforced to faces, isolated features, and objects.

4.1.4 Study Aims and Research Questions

This experiment addressed these concerns by simultaneously evaluating the temporal neurodynamics of holistic and featural processing within the same individuals for whom face recognition abilities were known (from Chapter 3), using gold-standard metrics of face inversion and feature isolation. Specifically, adults with and without ASD viewed images of upright and inverted faces, upright and inverted cars, isolated eye regions, and isolated mouths while brain activity (EEG) and eye movements were recorded. Data were subsequently cleaned and time-locked to image onset and the peak N170 amplitudes and latencies were evaluated across groups. To evaluate the relationship between individual differences in neural responding and autistic symptomology (as measured by the ADOS-2), difference score indices were calculated for N170 amplitudes and latencies representing face and car inversion (inverted – upright), eye region sensitivity (eye region – upright face), and mouth sensitivity (isolated mouth – upright face).

Overall, neurotypical adults were expected to replicate the classic findings within the literature, demonstrating intact holistic processing with a noticeable FIE on the N170 (i.e., smaller and faster N170 responses for upright, relative to inverted, faces) but absent or reversed car inversion effects. For autistic adults, the expected pattern of results was unclear. On the one hand, if holistic processing is preserved when visual fixation is enforced, then we should see a distinct N170 FIE and neural pattern similar to that anticipated for neurotypical adults. On the other hand, if holistic processing is disrupted in autism, then autistic adults should show a smaller or absent N170 FIE. Furthermore, if a holistic face bias is in fact altered in autism, then negative associations should be observed between autistic symptomology and neural indices of the FIE.

Featural sensitivities were also anticipated for both groups. Neurotypical adults were expected to elicit faster and attenuated N170 responses to upright faces relative to inverted faces, isolated eye regions, and isolated mouths. Face-sensitivity was also anticipated for neurotypical adults, with smaller and attenuated N170s predicted for upright and inverted cars relative to face categories; the car inversion effect was predicted to be smaller than the FIE. If perceptual sensitivity to the eyes is disrupted or atypical in autism, then adults with an ASD should yield N170 responses to the eye region that are disproportionately attenuated (hypo-response) or intensified (hyper-response) relative to neurotypical adults, in line with the eye indifference and avoidance theories of autistic face recognition (Moriuchi et al., 2017; Tanaka & Sung, 2016). In this case, autistic symptomology would also likely relate to the magnitude of the eye sensitivity index, such that adults with higher ADOS-2 scores would yield larger sensitivities to the eyes than autistic adults with lower

ADOS-2 scores. Likewise, if the mouth is particularly salient for autistic face perception (as has been alluded to in some cases; Klin et al., 1999; Pelphrey et al., 2002; Spezio et al., 2006), then an increased sensitivity to the mouth may also be observed for autistic adults relative to their neurotypical peers, with an increased reliance on the mouth for individuals with higher ADOS-2 scores. If, however, no differences in N170 responding are observed between neurotypical and autistic adults at the group level, this would suggest that adults with an ASD process face information in a comparable way to neurotypical control adults when visual attention is accounted for.

4.2 Method

4.2.1 Participants

A total of 38 participants completed this experiment during Session 2 of the neurocognitive assessment[20] (see **Figure A1**, **Appendix A**). Following data processing, 1 autistic participant's data was excluded from analysis because they yielded too few trials per condition after artifact rejection for reliable ERP measurements and the neurotypical adult who performed at chance levels on both recognition tasks (Chapter 3) was excluded. Demographic details for the final sample are presented in **Table 2.**

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[20] One autistic woman presented with head sensitivities so severe EEG set-up was not possible, and 2 other autistic women yielded high impedance values (≥ 35 kΩ) that resulted in unreliable EEG readings. Furthermore, one autistic man did not complete this experiment due to fatigue and three neurotypical controls (2 women, 1 man) did not complete this experiment because data was not available for their ASD-match.

Table 2. Demographic information for autistic and neurotypical adults included in the *Holistic and Featural Processing ERP Experiment*. Mean and range values are shown here with standard deviations in parentheses.

	Autistic Adults (n=18)	**Neurotypical Adults (n=18)**	***t*(33)**	***p***
Gender	9 female, 6 men 2 non-binary, 1 transgender	9 women, 8 men 1 non-binary	-	-
Age	28.28 (9.76) 18 – 48 years	26.78 (9.51) 19 – 50 years	0.47	.64
Full Scale IQ	115.06 (15.52) 91 – 157	115.67 (8.63) 101 – 128	-0.15	.89
Verbal IQ	117.11 (14.38) 100 – 160	114.33 (9.05) 94 – 128	0.69	.49
Performance IQ	109.94 (16.54) 83 – 154	112.78 (10.32) 95 – 134	-0.62	.54

4.2.2 Stimuli

Grey-scaled photographs of upright and inverted faces, upright and inverted cars, isolated eye regions, isolated mouths, and flowers were used for this experiment (**Figure 9**). Sixteen upright faces (8 men, 8 women) were selected from the collection used in Parkington & Itier (2018b). These computer-generated faces only included the internal facial features (left eye, right eye, nose, and mouth) and were matched at both the local (featural) and global (image) levels for pixel intensity and root-mean-squared contrast (see Parkington & Itier, 2018b for further details). Faces subtended 8.13° (horizontal) x 12.64° (vertical) visual angle and were centered (along an axis passing through the nasion) on a 12.88° (horizontal) x 17.89° (vertical) pixel-scrambled background. Inverted face stimuli were generated by isolating the faces within each image and flipping them 180° along the horizontal axis. Isolated eye region and mouth stimuli were also taken from Parkington & Itier (2018). These stimuli subtended 6.92° (horizontal) x 2.45° (vertical) visual angle.

Front-view photographs of 18 different cars from the collection used by Kloth et al. (2013), as well as seven flower photographs from Nemrodov et al. (2014), were also used here. Cars and flowers were all cropped into ovals subtending 8.13° (horizontal) x 12.64° (vertical), to approximate the oval outline of the face stimuli, and inverted copies were generated by flipping these images 180° along their horizontal axes. These car and flower images were then each centered on a 12.88° (horizontal) x 17.89° (vertical) pixel-scrambled background.

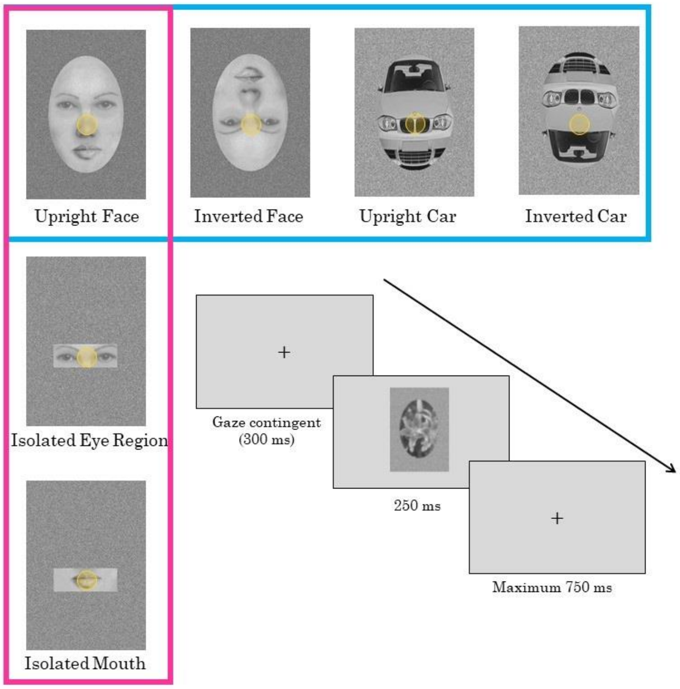

Figure 9. Stimulus exemplars (with central ROIs overlaid) and a sample trial progression demonstrating an oddball trial. Participants were instructed to maintain central fixation and press the spacebar if they detected a flower. Central fixation was confirmed offline using 1.92° regions of interest (ROIs; overlaid yellow circles) centered on each image. Holistic integration (blue box) was evaluated by comparing N170 responses elicited by upright/inverted faces and cars. Featural sensitivity (pink box) was evaluated by comparing N170 responses elicited by upright faces, isolated eye regions, and isolated mouths.

Mirror-flipped copies of all experimental stimuli (upright/inverted faces, upright/inverted cars, eye regions, mouths) were also generated (to eliminate stimulus-asymmetry effects). All images were then run through custom-made MATLAB 2014b scripts adapted from the SHINE package (Willenbockel et al., 2010) to match all images on global pixel intensity (0.58) and root-mean squared contrast (0.47) by adjusting only the background pixels (i.e., face, car, feature, and flower images all remained unaltered).

4.2.3 Procedure

4.2.3.1 Experimental Design

Task order was counterbalanced across participants, such that half of participants completed this ERP experiment first and the *Face Fixation ERP Experiment* (Chapter 5) second while the remaining half of participants completed the ERP tasks in the opposite order.

Here, participants completed an oddball detection task[21] (25% probability) while eye movements and EEG activity were monitored. Participants pressed the spacebar on a standard keyboard if the picture was a flower; no response was required for all other experimental categories. Seated with their head position stabilized in a chinrest, participants were asked to fixate on a central cross which would trigger the presentation of an image, and to maintain central fixation on the subsequent image

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[21] An oddball-detection task was used to ensure sustained attention to the image categories. Given the high demands already placed on participants to limit eye movements in this paradigm, we wanted to ensure all other factors remained as simple as possible. A higher oddball rate was used here (25%) relative to past studies using the same gaze-contingent oddball paradigm (10%; Parkington & Itier, 2018, 2019) to maximize attention capture for autistic participants who may have difficulties sustaining attention to low-frequency targets.

that flashed. All participants completed a short (15 trial) practice phase before starting the experiment proper.

Overall, this experiment included five blocks of 125 trials (20 trials/condition + 5 oddball trials/condition). Each trial began with a gaze-contingent fixation cross[22], during which participants had to maintain fixation within an ROI subtending 1.92° centered around the fixation cross for 300 ms. Once the gaze-contingent trigger was activated, an image (upright/inverted face, upright/inverted car, isolated eye region, isolated mouth, or upright/inverted flower) flashed for 250 ms, followed by another fixation cross. The next trial began after 750 ms or once a spacebar response was registered, whichever occurred first (**Figure 9**).

If the fixation trigger was not activated within five seconds (i.e., if the participant failed to fixate on the cross for 300 ms) the trial was aborted and a drift correction was recorded. Mid-block recalibrations were conducted following two consecutive drift corrections or when the eye recording was clearly off-centre.

4.2.3.2 Eye-Tracking and EEG Recordings

Eye-tracking parameters were the same as outlined in Chapter 2. An ActiCHamp system (Brain Vision, https://brainvision.com) continuously recorded EEG measurements (500 Hz) from custom-made 64-electrode ActiCaps conforming to the 10/20 extended system. PO9 and PO10 electrodes (placed over the posterior occipito-temporal region of each hemisphere), as well as a pair of electrodes placed

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[22] A non-triggered version was also available as an accommodation for participants who had difficulties consistently activating the gaze-contingent trigger. This version proceeded in the same manner, except that a 300-500 ms jittered fixation cross replaced the fixation trigger screen. Seven participants with an ASD and one neurotypical participant completed this non-triggered version.

over the mastoids (TP9 and TP10), were used in lieu of AF3, F1, AF4, and F2 recording sites. Cz was designated as the active reference during all recordings and a ground electrode was placed over the posterior region between POz and PO4. Electrode offsets were kept below 35 kΩ.

4.2.4 Data Processing

To ensure participants were looking at the photographs during stimulus presentation, interest area reports were generated for each participant using DataViewer 2.6 (SR Research, http://sr-research.com). Custom-made MATLAB scripts were then used to compare these reports with the EEG recordings. Any trials in which participants did not maintain fixation with the pre-determined 1.92° central ROI (**Figure 9**) or in which one or more eye movements were made outside of this ROI, were automatically removed. Manual trial selection was implemented for three autistic participants' recordings (all completed on the non-triggered version of this experiment) because of a shift in the eye movement recordings due to glasses glare. In this case, trials deemed to be outside of the pre-determined central ROI were marked. The experimenter (KBP) then determined if a systematic shift was present (e.g., fixations consistently shifted upwards and to the right) on these trials. Any fixations contained within 1.92° of this shifted region were accepted as central fixations and these trials were kept for analysis. Alternatively, any trials in which one or more fixations were made outside of this shifted region were rejected. A total of 7.94% of trials was removed across all participants due to eye movements.

The EEGLab toolbox (Delorme & Makeig, 2004) running under MATLAB 2014b was used to generate an average reference and digitally band-pass filter (0.01 Hz – 30 Hz) EEG recordings. Data were then time-locked to face onset, -100 ms (pre-stimulus onset; baseline) to +350 ms (post-stimulus onset) epoch windows were set, and incorrect trials were removed (0.15% of all trials). Trials with artifacts above or below ±70μV were automatically detected using the EEGLab toolbox; 7.86% of trials were removed across all participants due to EEG artifacts.

4.2.5 Electrode Selection

Participants in both groups produced the standard topographic distributions for all stimulus categories, with maximal N170 responses recorded in the posterior occipto-temporal region. In order to be most sensitive to individual differences in N170 peak responding, each participant's average waveforms were individually inspected using ERPLab (http://erpinfo.org/erplab; see Parkington & Itier, 2018b, 2019a for a similar method). The left- and right-side electrodes yielding the maximal N170 response for all conditions were selected for each participant (**Table 3**) and peak amplitudes and latencies were then extracted from these electrodes between 120 ms and 230 ms post-stimulus onset.

Table 3. Distribution of peak N170 electrodes (over left and right posterior occipital-temporal electrode sites) selected for analysis.

Autistic Adults (n = 18)			
Left-Side Electrodes		**Right-Side Electrodes**	
Electrode	**Number of Participants**	**Electrode**	**Number of Participants**
P7	1	P8	5
P9	8	P10	5
PO7	4	PO8	4
PO9	5	PO10	4

Neurotypical Adults (n = 18)			
Left-Side Electrodes		**Right-Side Electrodes**	
Electrode	**Number of Participants**	**Electrode**	**Number of Participants**
P7	4	P8	1
P9	8	P10	6
PO7	2	PO8	6
PO9	4	PO10	5

4.2.6 Statistical Analysis

Holistic processing and featural sensitivity indices were analyzed separately using mixed method analyses of variance (ANOVAs) in SPSS Statistics v26 (IBM Statistics). In all cases, Group was entered as the between-subject factor and all other independent variables (Category, Orientation, and/or Electrode Side) were entered as within-subject factors.

4.3 Results

4.3.1 Neural Markers of Holistic Processing

To investigate the integrity of holistic and featural processing amongst autistic and neurotypical adults, 2 (Category: Face, Car) x 2 (Orientation: Upright, Inverted) x 2 (Electrode Side: Left-Side, Right-Side) x 2 (Group: ASD, Neurotypical) mixed model ANOVAs were conducted on peak N170 amplitudes and latencies.

4.3.1.1 N170 Peak Amplitude

No significant differences were observed between autistic and neurotypical adults (no main effect or interactions with Group; $ps \geq .12$). Overall, N170 responses were larger over right-side sites (main effect of Electrode Side: $F(1,34) = 8.96$, $MSE = 23.26$, $p = .005$, $\eta_p^2 = .21$) and faces elicited enhanced N170 peak amplitudes compared to cars (main effect of Category: $F(1,34) = 64.59$, $MSE = 10.32$, $p < .001$, $\eta_p^2 = .66$). Orientation did not yield a significant effect on its own ($p = .99$); however, it did interact with Electrode Side and Category (**Figures 10 & 11**).

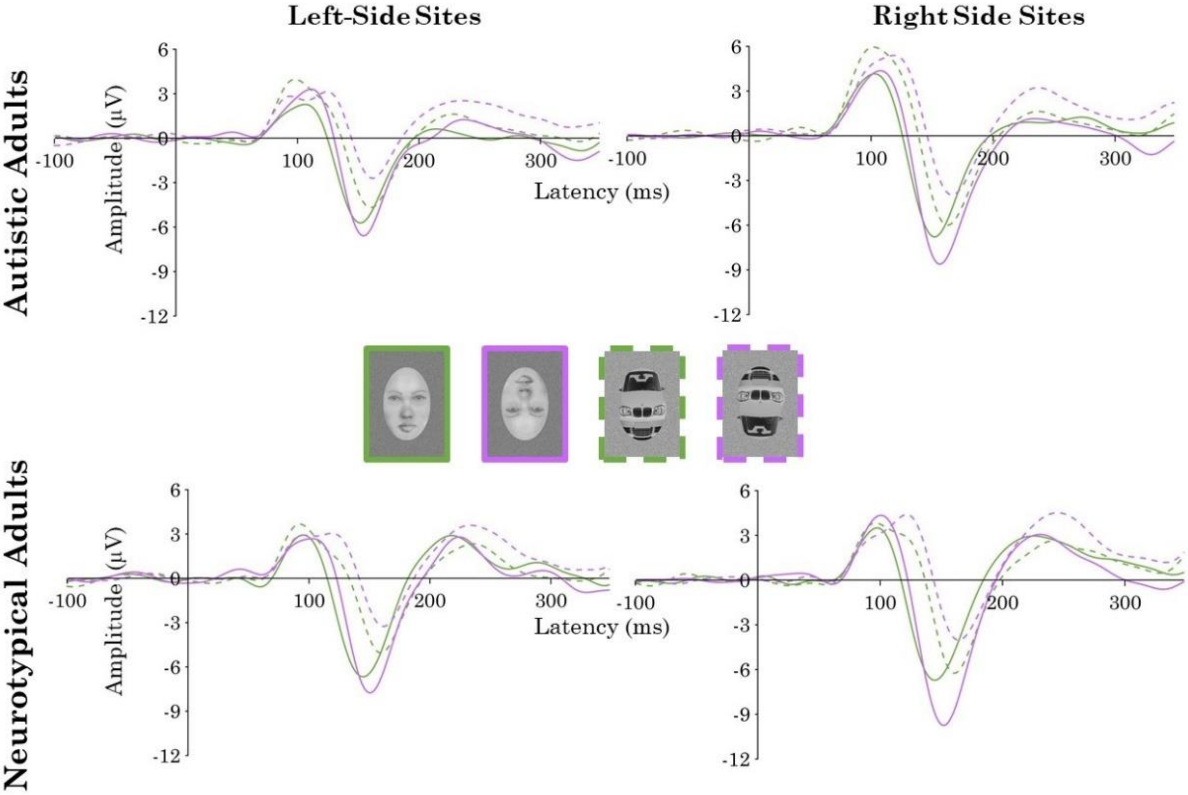

Figure 10. Group-level ERP waveforms (displaying the N170 component) elicited by upright faces (solid green lines), inverted faces (solid purple lines), upright cars (dashed green lines), and inverted cars (dashed purple lines) amongst autistic and neurotypical adults. Here, waveforms were generated by averaging the left- and right-side electrodes at which the N170 was maximal for each participant.

A general inversion effect (inverted > upright) was observed over the right hemisphere, whereas, a reversed inversion effect (upright > inverted) dominated over left-side sites (Orientation x Electrode Side interaction: $F(1,34) = 9.84$, $MSE = 1.88$, $p = .004$, $\eta_p^2 = .22$). Face stimuli replicated the classic face inversion effect (FIE), with larger peak amplitudes for inverted faces relative to upright faces, whereas cars demonstrated an reversed inversion effect in which upright cars elicited consistently larger amplitudes than inverted cars (Orientation x Category: $F(1,34) = 52.56$, $MSE = 4.81$, $p < .001$, $\eta_p^2 = .61$; **Figure 11**).

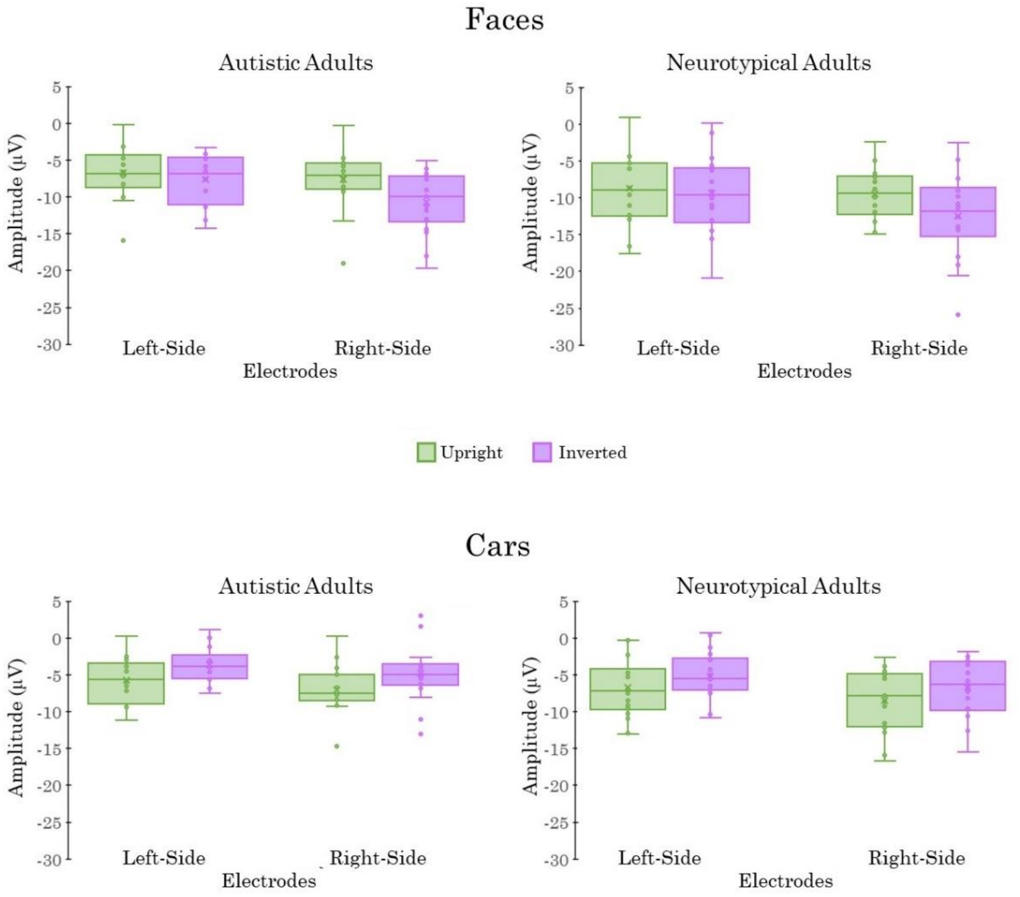

Figure 11. N170 peak amplitudes for upright (green) inverted (purple) faces and cars. Note the persistently enhanced amplitudes for upright relative to inverted cars over both left and right sites, whereas the face inversion effect (inverted face > upright face) only reached significance over right-side sites.

Furthermore, whilst the car inversion effect was evident across both hemispheres (*p*s $< .001$), the FIE was only significant for right-side sites ($p < .001$, left-side sites: $p = .05$, Bonferroni paired *t*-tests significant at $p < .013$; Orientation x Electrode Side x Category interaction : $F(1,34) = 11.61$, $MSE = 2.29$, $p = .002$, $\eta_p^2 = .26$; **Figures 10 & 11**).

4.3.1.2 N170 Peak Latency

The N170 peak response was elicited significantly earlier for faces than cars (main effect of Category: $F(1,34) = 107.16$, $MSE = 74.07$, $p < .001$, $\eta_p^2 = .76$) and was also earlier for upright than inverted images (main effect of Orientation: $F(1,34) = 47.30$, $MSE = 17.20$, $p < .001$, $\eta_p^2 = .58$; **Figure 11**). No Group ($p = .89$) or Electrode Side ($p = .51$) effects were found for N170 latencies, nor did any interactions reach significance.

4.3.2 Neural Markers of Featural Processing & Sensitivity

To evaluate featural processing and sensitivity amongst autistic and neurotypical adults, 3 (Category: Upright Face, Eye Region, Mouth) x 2 (Electrode Side: Left-Side, Right-Side) x 2 (Group: ASD, Neurotypical) mixed model ANOVAs were implemented using peak N170 amplitudes and latencies.

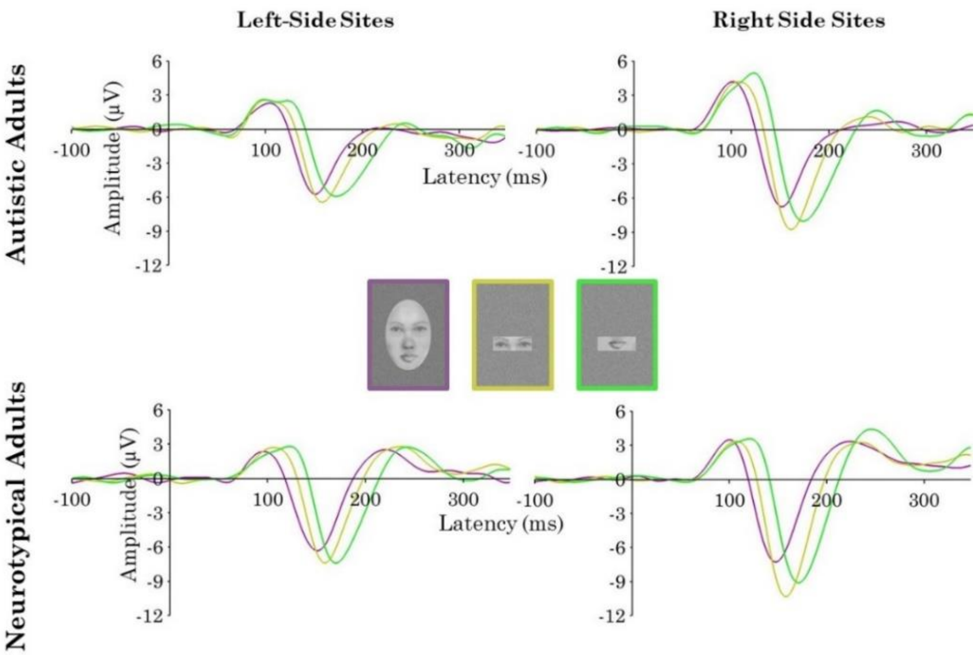

Figure 12. Group-level ERP waveforms (displaying the N170 component) elicited by upright faces (purple), isolated eye regions (yellow), and isolated mouths (lime green) amongst autistic and neurotypical adults. Here, waveforms were generated by averaging the left- and right-side electrodes at which the N170 was maximal for each participant.

4.3.2.1 N170 Peak Amplitude

N170 peak amplitudes were similar for adults with and without autism (main effect of Group and interactions: ps $\geq .20$) but were significantly attenuated for faces relative to amplitudes elicited by isolated eye regions and mouths (ps $< .001$), which did not differ from each other ($p = .60$; main effect of Category: $F(2,68) = 23.02$, $MSE = 4.82$, $p < .001$, $\eta_p^2 = .40$; **Figures 12 & 13**). Amplitudes were generally larger over right-side than over left-side sites ($F(1,34) = 9.18$, $MSE = 25.70$, $p = .005$, $\eta_p^2 = .21$); however, this right lateralization was only significant for isolated eye regions ($p < .001$) and mouths ($p = .005$; Category x Electrode Side interaction: $F(2,68) = 16.26$, $MSE = 1.42$, $p < .001$, $\eta_p^2 = .32$). No hemispheric differences were observed for peak amplitudes to faces (p = .18; Bonferroni-corrected paired t-tests significant at $p \leq$ .017).

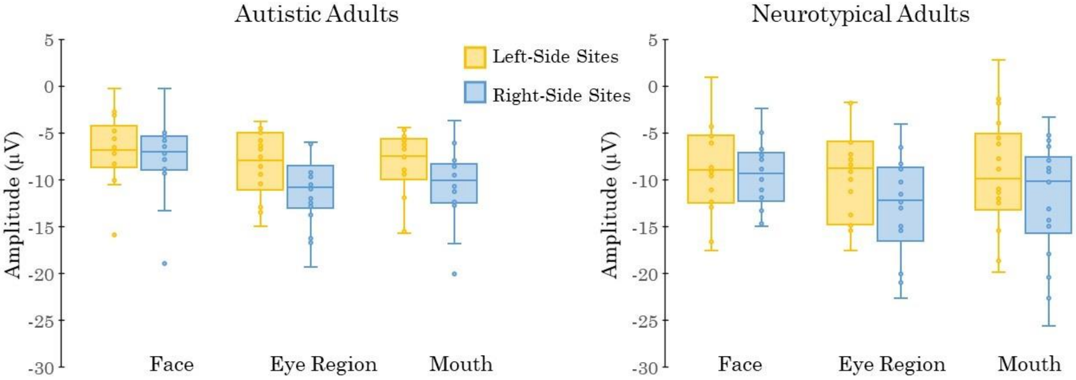

Figure 13. N170 peak amplitudes over left (yellow) and right (blue) sites for upright faces, isolated eye regions, and isolated mouths. Note the larger peak amplitudes for isolated eye regions and mouths (which also show a right lateralization), relative to upright faces.

4.3.2.2 N170 Peak Latency

Faces elicited the fastest N170 responses overall, followed by isolated eye regions, with isolated mouths evoking the slowest responses (F(1.47, 50.06) = 96.00, MSE = 134.97, p < .001, η_p^2 = .74; all paired comparisons: ps < .001). No Group or Electrode Side effects were found, nor did any interactions reach significance (ps ≥ .38).

4.3.3 Autistic Symptomology and Neural Markers of Holistic and Featural Processing

Exploratory correlations were conducted to determine if autistic symptomology relates to neural markers of holistic processing and featural sensitivity. Amplitude and latency measures of the face inversion effect (inverted faces – upright faces), face sensitivity effect (upright faces – upright cars), and car inverted inversion effect (inverted cars – upright cars) were computed over right-side sites[23] to index markers of holistic face processing. Similarly, eye region (eye regions – upright faces) and mouth (mouths – upright faces) sensitivity indices were calculated over right-side sites, as markers of featural processing. Pearson correlations with bootstrapped confidence intervals (5000 iterations) were then conducted to evaluate each of these difference measures as a function of Total ADOS-2 scores in autistic adults[24].

Here, a borderline-significant association was found between total ADOS scores and the magnitude of the car inversion effect amplitude ($r = -.46$, $p = .05$, $CI_{95\%}$: [-.76 – .23]; **Figure 14**). No other correlations were significant.

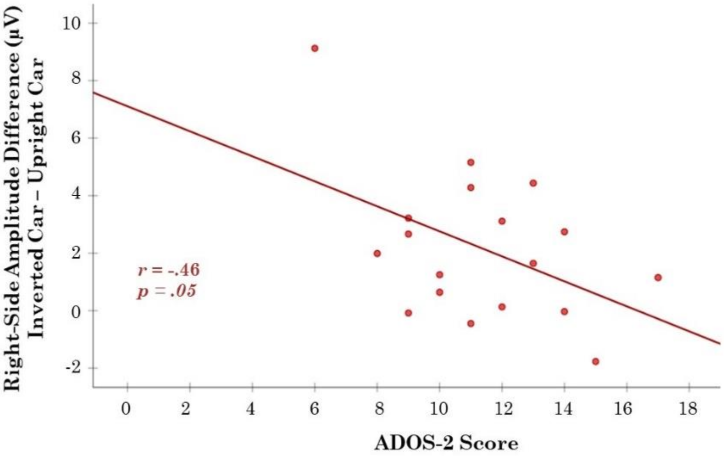

Figure 14. Scatterplot of the relationship between autistic symptomology (ADOS-2 scores) and the car inversion neural index over right-side sites. Positive scores indicate larger amplitudes for inverted cars; negative scores indicate larger amplitudes for upright cars.

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[23] Correlation analyses were focused on right-side sites to evaluate brain-behaviour relationships across sites producing the clearest signal.

[24] The ADOS-2 was not administered to neurotypical adults and thus it is not possible to evaluate these relationships in the control sample.

4.4 Discussion

When fixation was enforced, autistic and neurotypical adults elicited comparable N170 peak amplitudes and latencies at the group-level. In fact, both groups demonstrated measurable face and car inversion effects, consistent with patterns reported throughout the neurotypical literature (Bentin et al., 1996; Eimer, 2011; Itier, Taylor, & Lobaugh, 2004; Itier & Taylor, 2004b; Kloth et al., 2013; Rossion et al., 2000; Rossion et al., 2003; Rossion & Jacques, 2011), signifying intact and preserved holistic processing in autism. Specifically, upright faces elicited distinctly larger and faster N170 peaks relative to objects (highlighting the N170's sensitivity to faces) as well as attenuated amplitudes and faster latencies compared to inverted faces (signifying the N170's sensitivity to orientation and featural configuration), patterns that were upheld for autistic and neurotypical adults alike. These findings provide evidence in support of preserved sensitivities to face orientation and holistic biases in face perception amongst autistic adults, consistent with recent reports (Churches et al., 2010; Churches et al., 2012; López et al., 2004; Tavares et al., 2016; Webb et al., 2010). Notably, autistic adults elicited N170 peak responses on par with neurotypical amplitudes and latencies for all visual categories, thereby demonstrating that early visual perception does not appear to be delayed or less sensitive in autism. Instead, autistic adults with face recognition abilities within neurotypical limits demonstrate preserved holistic mechanisms during early face perception when visual fixation is enforced. Thus, the present findings do not support disruptions in autistic holistic integration at the neural level, indicating that autistic weaknesses in social communication are likely not rooted in a breakdown of holistic processing during the earliest stages of face perception, but rather are likely the result of disruptions in later stages of the social processing network.

It is interesting to note that cars produced the opposite pattern as faces, with larger and faster N170 responses to upright cars compared to their inverted counterparts, a pattern that was upheld for both groups. Throughout the literature, objects most commonly produce a negligible inversion effect (Itier et al., 2004; Itier & Taylor, 2004; Rossion et al., 2000; Rossion et al., 2003; Rossion & Jacques, 2011), although a reversed pattern has been observed for investigations implementing cars (Kloth et al., 2013), similar to that done here. The precise nature of the variability in inversion effects across object categories and studies is largely unknown, although one possibility arises from the face-like nature of car stimuli. For instance, some participants spontaneously reported that the upright and inverted cars looked like faces in some cases, especially inverted cars with distinct front headlights positioned in similar locations as the eye region of faces. As shown in **Figure 10**, the inverted car category does support these qualitative reports, thereby suggesting that inverted cars may have been impacted by influences of pareidolia and perceived more as face-like objects, yielding smaller and faster N170 responses relative to upright cars which were processed in a more object-consistent fashion. This premise is consistent with typical N170 responses for faces and face-like objects amongst neurotypical and autistic adults (Akdeniz, 2020; Churches et al., 2012; Proverbio & Galli, 2016), demonstrating yet again that autistic adults are capable of processing faces and objects in similar ways as neurotypical controls when required by task demands.

Beyond the group-level effects, a marginal association between car inversion amplitude and autistic symptomology emerged at the individual level, such that ADOS-2 scores were inversely associated with car inversion effect magnitude; no other correlations were statistically significant. These findings do not coincide with initial predictions (which anticipated face-specific inversion effects that would reduce in magnitude with increasing autistic symptom severity) and require further replication in larger samples to clarify the validity of these associations. Although orientation sensitivity appears to be preserved on the N170 peak at the group level, additional research is needed at the individual level to directly evaluate the heterogeneity and implementation of these mechanisms in relation to behavioural tendencies.

Featural sensitivity was also found to be preserved amongst autistic adults, evidenced by comparable N170 peak responses to faces, isolated eye regions, and mouths as neurotypical adults. N170 amplitudes were smallest and fastest for upright, intact faces whereas isolated eye regions and mouths elicited larger and delayed responses. Importantly, the classic eye region sensitivity (i.e., enhanced and delayed N170 peaks for eye regions versus faces) was observed for both autistic and neurotypical adults, adding to the growing body of literature unveiling the human sensitivity to the eyes (de Lissa et al., 2014; Eimer, 1998; Emery, 2000; Itier et al., 2006; Itier et al., 2007; Itier, 2015; Parkington & Itier, 2018b; Parkington & Itier, 2019a), and providing strong evidence in favour of a typical sensitivity to the eyes in autism at the level of the N170. Although no differences were observed between peak amplitudes elicited by isolated eye regions and mouths for either group, eye regions consistently elicited faster peak responses than mouths. The current research partially parallels O'Connor et al.'s (2007) findings, demonstrating preserved featural sensitivity during early autistic face perception, with feature type playing a particularly prominent role in neural timing. These results are also in line with neurotypical reports of face and feature processing in which eye movements were not recorded (Bentin et al., 1996; Nemrodov & Itier, 2011) but are in contrast to a more recent report implementing a similar gaze-contingent paradigm in young adults (Parkington & Itier, 2018b). Although the eye region and mouth were never directly compared in this latter study, isolated mouths elicited comparable N170 amplitudes to a single eye but were markedly attenuated relative to isolated eye regions. Therefore, it is unexpected that the eye region would be similar in terms of amplitude to the mouth for both groups in the present study and requires additional follow-up to determine the root of these differences across studies.

Critically, an atypical eye sensitivity was not observed at the group level for autistic adults, nor were ADOS-2 scores related to eye or mouth sensitivity indices. Based on group-level evaluations of the N170 ERP component, the eye avoidance and indifference theories are not supported within a group of autistic adults with face recognition abilities within the neurotypical range, indicating that focusing on the eye region of a face does not elicit a hypo- or hyper-sensitive neural response on the

N170 peak in autism nor is an indifference observed across features. Thus, potential arousal or sensitivity mechanisms related to avoidance and/or reduced attention to the eyes in autism are more likely to be found at later stages of social cognitive processing, in line with quantitative theories of autistic face processing (Cygan et al., 2018; Senju & Johnson, 2009; Weigelt et al., 2012). Instead, the present results reveal that autistic adults are capable of perceiving faces and features in a similar way to their neurotypical counterparts when visual attention is controlled.

Chapter 5: Examining Autistic and Neurotypical Adults' Neural Sensitivity to Features Within a Face

> *"Looking into someone's eyes changes the entire conversation."*
> -Anonymous

5.1 Introduction

Reduced and/or atypical attention to the eyes is a prominent characteristic of autism (APA, 2013; Chita-Tegmark, 2016; Ewing et al., 2018; Frazier et al., 2017; Jones & Klin, 2013; Wang et al., 2019), although the temporal neurodynamics guiding these behaviours remain largely unstudied. Here, this final experiment presents the first systematic evaluation of autistic and neurotypical responses to features within a face using co-registered eye-tracking and EEG techniques. A subset of adults who participated in the neurocognitive face processing assessment (**Appendix A**) completed a gaze-contingent ERP task measuring N170 peak amplitudes and latencies to faces in which fixation was enforced to the left eye, right eye, nasion, nose, or mouth. This enforced fixation procedure has been established within the neurotypical population (Itier & Preston, 2018; Neath & Itier, 2015; Neath-Tavares & Itier, 2016; Nemrodov et al., 2014; Parkington et al., 2017; Parkington & Itier, 2018b; Parkington & Itier, 2019a) and not only permits evaluation of the neural response to each feature equally (whereas free-viewing parameters do not spontaneously sample all features to the same degree, especially within an autistic population) but also simulates a situation in which face information must be captured within 1-2 fixations (a strategy that has been deemed essential to optimizing neurotypical face recognition performance; Hsaio & Cottrell, 2008; Peterson & Eckstein, 2012, 2013; van Belle et al., 2010).

5.1.1 Holistic Face Perception: A Malleable Construct

Neurotypical fixation and saccade patterns to faces are highly consistent and reproduceable within individuals (Arizpe et al., 2017; Henderson et al., 2003; Longmore et al., 2015; Shepherd et al., 1981; Walker-Smith et al., 1977; Yarbus, 1967). This integration of features in a reliable, methodical fashion supports a reliance on holistic mechanisms during early face perception and highlights the importance of assimilating all features into a single, whole percept for effective processing. It does not, however, assume that all facial feature information is relied upon to the same degree.

Recent ERP advancements have unveiled that neurotypical holistic integration is, in fact, a flexible mechanism that is affected by the features visible in central vision (de Lissa et al., 2014; Itier & Preston, 2018; Nemrodov et al., 2014; Parkington & Itier, 2018b, 2019). In fact, N170 peak amplitudes show a systematic attenuation when more features are visible in parafovea and are particularly impacted by the presence of an eye (Parkington & Itier, 2019a). Even though it is well accepted that neurotypical gaze fixations are dynamically distributed across various facial features, with observers commonly returning to certain features (e.g., left eye) over the course of time (Arizpe et al., 2017; Henderson et al., 2003, 2005; Mehoudar et al., 2014; Sekiguchi, 2011; Yarbus, 1967), visual attention has only recently been accounted for in investigations evaluating the N170. In a landmark study, McPartland and colleagues (2010) revolutionized our understanding of early face perception by demonstrating that attentional cueing to the eye region and mouth of a face enhanced N170 responding relative to faces that were not cued. These findings were later replicated and extended using state-of-the-art gaze-contingent ERP techniques (de Lissa et al., 2014; Itier & Preston, 2018; Neath & Itier, 2015; Neath-Tavares & Itier, 2016; Nemrodov et al., 2014; Parkington, Ermis, & Itier, 2017, Parkington & Itier, 2018b, 2019); demonstrating the malleability of holistic face perception – a mechanism previously assumed to be rigid – contingent upon where an observer focuses within a face.

5.1.2 The Role of the Eyes in Holistic Face Perception

The eyes are considered integral for optimizing holistic processing at the neural level (Eimer, 1998; Itier & Preston, 2018; Neath & Itier, 2015; Neath-Tavares & Itier, 2016; Nemrodov et al., 2014; Parkington & Itier, 2018b, 2019; Rousselet, Ince, van Rijsbergen, & Schyns, 2014). In line with the eye region sensitivity reported throughout the literature (see Chapter 1 for review), neurotypical adults consistently demonstrate enhanced N170 amplitudes for faces in which fixation is enforced to the left or right eye, relative to fixation on other core (nasion, nose, or mouth) or non-core (forehead) features (de Lissa et al., 2014; Itier & Preston, 2018; Neath & Itier, 2015; Neath-Tavares & Itier, 2016; Nemrodov et al., 2014; Parkington & Itier, 2018b, 2019). This neural signature is often more pronounced in the hemisphere ipsilateral to the eye in focus (i.e., left eye fixations elicit larger responses over left-side sites whereas right eye fixations elicit larger responses over right-side sites; see Figure 3 in Parkington & Itier, 2019a) and is not driven by differences in low-level properties across features, such as pixel intensity or contrast (Parkington & Itier, 2018b).

Alternatively, the temporal responding of the N170 ERP component appears to be optimized more so for nasion or nose fixations, despite measurably attenuated peak amplitudes relative to fixation directly on the eyes (de Lissa et al., 2014; Itier & Preston, 2018; Nemrodov et al., 2014; Parkington & Itier, 2018b). These N170 modulations persist across task demands (de Lissa et al., 2014; Itier & Preston, 2018; Neath & Itier, 2015; Neath-Tavares & Itier, 2016; Nemrodov et al., 2014; Parkington & Itier, 2018b; Parkington & Itier, 2019a), emotional expressions (Neath & Itier, 2015; Neath-Tavares & Itier, 2016), and manipulations in face size (Parkington et al., 2017), highlighting the saliency and stability of the neurotypical response to faces. Collectively, these findings provide compelling evidence in favour of a sensitivity to the eyes within a full face (which may more accurately be referred to as an *eye region sensitivity*; Parkington & Itier, 2018b) at the neural level.

5.1.3 The Unknown Impact of Visual Fixation on the N170 in Autism

Despite the fact that many adults with an ASD spend less time attending to faces and, in particular, the eyes (Chita-Tegmark, 2016), there are currently no empirical studies controlling for visual attention while measuring N170 face responses in autistic adults. Thus, it remains unclear whether the handful of studies reporting attenuated and/or delayed N170 responses to faces in ASD (for reviews see Feuerriegel et al., 2014 and Kang et al., 2018) reflect true differences in face processing at the neural level or if the observed patterns instead reflect systematic differences in visual attention to the face during ERP recordings.

According to the eye avoidance theory, autistic adults may experience a hypersensitivity to the eyes, leading to an active avoidance of the eye region (Tanaka & Sung, 2016), whereas the eye indifference hypothesis speculates that reduced attention to the eyes may be a function of reduced sensitivity and a relative indifference to the eyes (Moriuchi et al., 2017). Alternatively, hyposensitivity may also be observed, such that autistic adults may be less sensitive to the eyes than other features, leading to reduced attention to the eyes because of an attenuated sensitivity to the eyes. As such, autistic individuals may rely on other features (e.g., mouth) for extracting face cues (e.g., identity, emotional expression; Ewing et al., 2018; Ketelaars, In't Velt, Mol, Swaab, Bodrij, & van Rijn, 2017; Spezio et al., 2006), resulting in a possible increased sensitivity to these other features in autism.

5.1.4 Study Goals & Research Questions

To address this significant gap in the literature and elucidate the role of fixation to internal features during early autistic face perception, N170 measurements were recorded while fixation was enforced to the left eye, right eye, nasion, nose, and mouth of faces using co-registered eye-tracking in our group of adults with and without ASD. Overall, neurotypical adults were expected to replicate previous findings, in which left and right eye fixations elicit significantly larger N170 amplitudes relative to nasion, nose, and mouth fixations, although N170 latencies were anticipated to be fastest for nasion and nose fixations, of intermediate speed for faces with eye fixations, and slowest for faces with mouth fixation. Conversely, the anticipated patterns for autistic adults were less clear. On the one hand, if the N170 eye sensitivity is intact in autism, then autistic adults should elicit comparable N170 peak responses as neurotypical adults, with the eyes still producing the largest responses overall. Likewise, if the mouth is in fact a feature of interest and relevance for autistic individuals, then we should see a heightened (and possibly faster) N170 response for mouth fixations amongst participants with an ASD but not for neurotypical controls. On the other hand, if hypo- or hyper- N170 responses are elicited for adults with an ASD relative to the control group, this would be indicative of atypical feature sensitivity in autism.

5.2 Method

5.2.1 Participants

Thirty-seven participants from the neurocognitive assessment completed this experiment, with most (16 autistic, 18 neurotypical) also contributing data to the *Holistic and Featural Processing ERP Experiment*[25] (Chapter 4). After data processing, 3 participants' (2 autistic and 1 neurotypical) data were excluded because too many trials had to be removed due to eye movements and EEG artifacts. The neurotypical woman who performed at chance levels on the face recognition tasks (Chapter 3) was also excluded here, resulting in a final sample of 17 autistic adults and 17 age-, gender-, ethnicity-, and IQ-matched neurotypical adults[26].

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[25] Two (2) autistic men who provided data to Chapter 5 did not complete the current task due to fatigue, and one (1) autistic man who did not complete the *Holistic and Featural Processing ERP Experiment* provided valid data for the present analysis.

[26] The reader is referred to Table 2 (Chapter 5) for demographic information.

5.2.2 Stimuli

Upright faces (10 men, 10 women) centred on the left eye, right eye, nasion, nose, and mouth were selected from the collection of stimuli used in Parkington & Itier (2018). These computer-generated faces only included the internal facial features of the face (left eye, right eye, nose, and mouth) and were matched at both the local (featural) and global (image) levels for pixel intensity and root-mean-squared contrast (see Parkington & Itier, 2018b for further details).

Faces subtended 8.13° (horizontal) x 12.64° (vertical) visual angle and were presented on a 12.88° (horizontal) x 17.89° (vertical) pixel-scrambled background. Oddball stimuli comprised of six (upright) flower stimuli from the aforementioned *Holistic and Featural Processing ERP Experiment* which were centered on the pixel-scrambled background at the five locations roughly corresponding to the faces' left eye, right eye, nasion, nose, and mouth positions. Mirror-flipped copies of all stimuli were generated (to eliminate stimulus-asymmetry effects) and the images were run through custom-made MATLAB 2014b scripts adapted from the SHINE package (Willenbockel et al., 2010) to match all images on global pixel intensity (0.58) and root-mean squared contrast (0.47) by adjusting only the background pixels (i.e., face and flower images all remained unaltered).

5.2.3 Procedural Design and EEG and Eye-Tracking Recordings

This experiment proceeded in a similar manner as that described above in Chapter 5, except that only four blocks (of 120 images: 20 trials/condition + 20 oddball trials) were needed to display the five experimental conditions (see **Figure 15**). The

EEG electrode montage and all recording measurements were collected as described in Chapter 4.

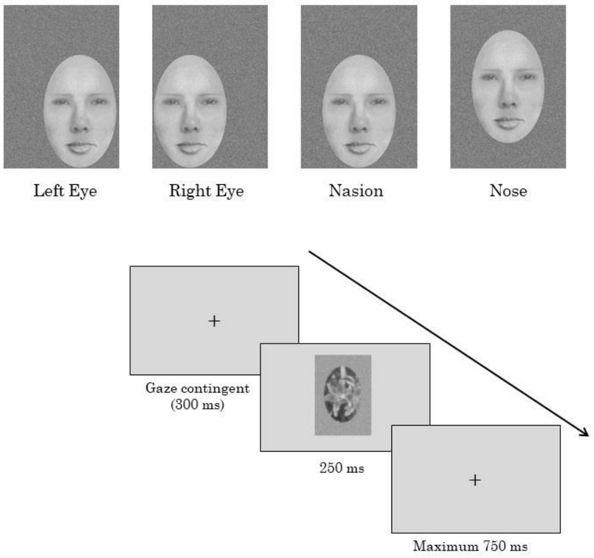

Figure 15. Stimulus exemplars and a sample trial progression demonstrating an oddball trial for this experiment. Participants were instructed to maintain central fixation and press the spacebar if they detected a flower. Face and flower position were manipulated within each image so that the feature of interest (e.g., left eye) would be centered (i.e., where the participant should be focusing). Central fixation was confirmed offline using 1.92° regions of interest (ROIs) centered on each image/feature. ERP waveforms were measured in relation to face onset.

5.2.4 Data Processing & Electrode Selection

All data processing techniques were the same as those outlined above for the *Holistic and Featural Processing Experiment*. Peak N170 amplitude and latency measurements were extracted from the electrodes outlined in **Table 4** between 110 ms and 200 ms post-stimulus onset.

Table 4. Distribution of peak N170 electrodes over left and right posterior occipito-temporal electrode sites selected for analysis.

Autistic Adults (n=17)			
Left-Side Electrodes		**Right-Side Electrodes**	
Electrode	**Number of Participants**	**Electrode**	**Number of Participants**
P7	2	P8	1
P9	5	P10	4
PO7	3	PO8	8
PO9	7	PO10	4
PO3	0		

Neurotypical Adults (n=17)			
Left-Side Electrodes		**Right-Side Electrodes**	
Electrode	**Number of Participants**	**Electrode**	**Number of Participants**
P7	3	P8	2
P9	7	P10	6
PO7	3	PO8	5
PO9	3	PO10	4
PO3	1		

5.2.5 Statistical Analysis

N170 peak amplitude and latency responses to faces with fixation enforced on different core facial features were analyzed separately using 5 (Featural Fixation: Left Eye, Right Eye, Nasion, Nose, Mouth) x 2 (Electrode Side: Left-Side, Right-Side) x 2 (Group: ASD, Neurotypical) mixed method ANOVAs in SPSS Statistics v26 (IBM Statistics). In all cases, Group was entered as the between-subject factor, with Featural Fixation and Electrode Side being entered as within-subject factors.

5.3 Results

5.3.1 N170 Peak Amplitude

The 5 (Featural Fixation) x 2 (Electrode Side) x 2 (Group) mixed method ANOVA revealed a significant main effect of Fixation ($F(2.53, 80.33) = 23.03$, $MSE =$

3.87, $p < .001$, $\eta_p^2 = .42$) that was not affected by Group (main effect of Group: $p = .43$, Group-interactions: $ps \geq .06$).

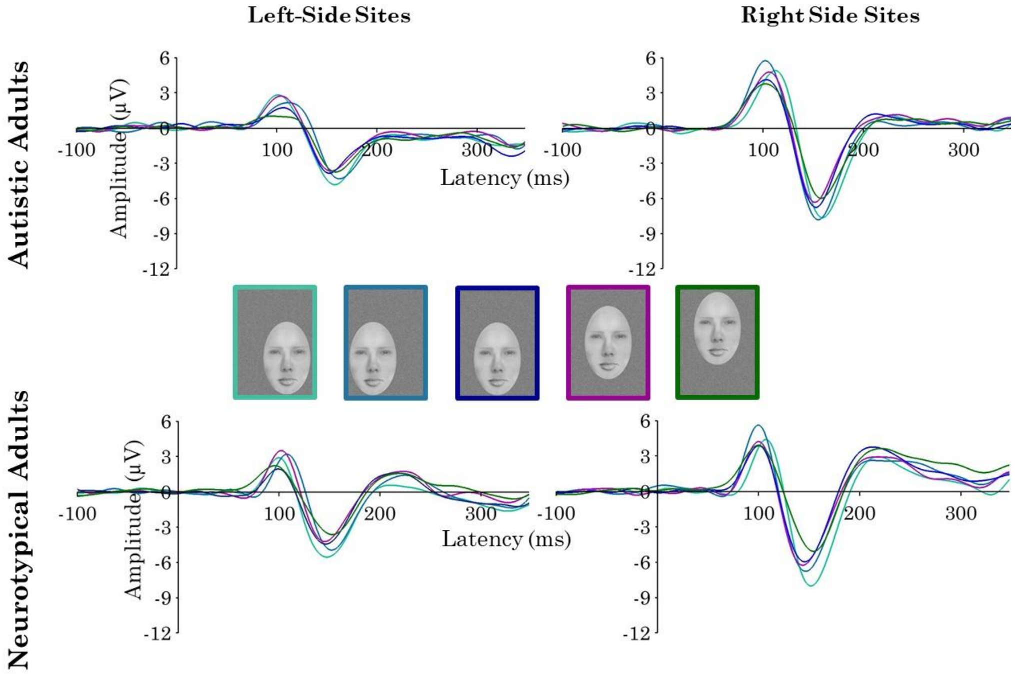

Figure 16. Group-level ERP waveforms displaying the N170 component, elicited by faces with enforced fixation to the left eye (teal), right eye (blue), nasion (dark blue), nose (purple), and mouth (cyan) amongst autistic and neurotypical adults. Here, waveforms were generated by averaging the electrodes at which the N170 was maximal for each participant over left- and right-side sites.

Here, neurotypical and autistic adults elicited significantly larger N170 peak amplitudes to faces with fixation enforced to the left and right eyes than to any other features, which did not differ from each other (**Figures 16 & 17**). N170 amplitudes were also larger over right-side sites (main effect of Electrode Side: $F(1,32) = 7.90$, $MSE = 38.18$, $p = .008$, $\eta_p^2 = .20$) and were further qualified by a significant Featural Fixation x Electrode Side interaction ($F(3.15, 100.87) = 2.83$, $MSE = 1.90$, $p = .04$, $\eta_p^2 = .08$). Follow-up pairwise *t*-tests revealed that left and right eye fixations elicited enhanced peak amplitudes at right-side sites ($ps \leq .006$), whereas no hemispheric differences were found for other features (pairwise comparisons: ps $\geq .02$; Bonferroni-corrected significance at $p < .01$).

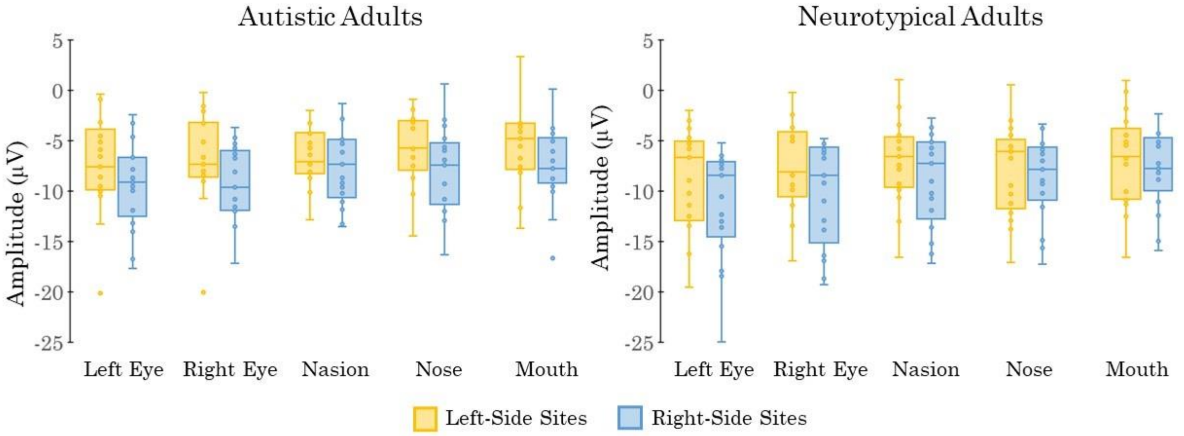

Figure 18. N170 peak amplitudes elicited by faces with enforced fixation to the left eye, right eye, nasion, nose and mouth for autistic and neurotypical adults.

5.3.2 N170 Peak Latency

Overall, the 5 (Featural Fixation) x 2 (Electrode Side) x 2 (Group) ANOVA unveiled N170 peak latency responses were significant modulated by Featural Fixation ($F(1.99,61.75) = 18.53$, $MSE = 63.91$, $p < .001$, $\eta_p^2 = .38$) but were not affected by diagnostic group (ps $\geq .18$). N170 latencies elicited by faces with nasion and nose fixations yielded the fastest peaks overall (ps $\leq .001$), with left eye, right eye, and mouth fixations yielding noticeably slower N170 peaks. This effect was further qualified by a Featural Fixation x Electrode Side interaction ($F(3.06, 94.81) = 11.88$, $MSE = 21.54$, $p < .001$, $\eta_p^2 = .28$). Follow-up analyses (Bonferroni-corrected significance at $p < .01$) revealed that N170 latencies were faster over right-side sites for right eye fixations ($p < .001$) and marginally so for left eye fixations ($p = .05$). No other hemispheric differences were observed across fixations to other core features (*p*s ≥ .51)

6.4 Discussion

Contrary to the eye avoidance (Tanaka & Sung, 2016) and eye indifference hypotheses (Moriuchi et al., 2017) of early autistic face perception, the present results provide evidence in favour of a preserved sensitivity to the eyes in autism, at the level of the N170 ERP component. Overall, eye fixations yielded the most prominent peak amplitudes, consistent with the N170 eye sensitivity (left/right eyes > nasion/nose > mouth) reported throughout the neurotypical literature (de Lissa et al., 2014; Itier & Preston, 2018; Neath & Itier, 2015; Neath-Tavares & Itier, 2016; Nemrodov et al., 2014; Parkington & Itier, 2018b). Critically, this pattern was observed for autistic and neurotypical adults alike and did not vary as a function of diagnosis. Thus, autistic adults did not elicit atypical neural responses to the eyes relative to their neurotypical counterparts and thus group-level hypo- or hyper-sensitivity to the eyes were not supported during the earliest stages of autistic face perception and holistic integration, opposing initial predictions that atypicalities would be present on the N170 ERP component. Alternatively, in line with the findings from Chapter 4, the present results provide compelling evidence in support of intact holistic integration mechanisms in autism and instead propose that disruptions in the processing and reliance on information gathered from another's eyes may occur at later stages of the visuo-cognitive pathway rather than on the N170 peak.

On the other hand, modulation of N170 latency responses were more in line with mechanisms serving to maximize holistic processing (nasion/nose < eyes/mouth), rather than featural sensitivity. At first glance these findings may seem counter-intuitive: how can attention to areas of the face with less socially relevant information (nasion/nose) lead to faster, and arguably more efficient, face processing? However, it is important to remember that this study implemented a gaze-contingent paradigm in which eye movements were restricted. Therefore, the present findings should be considered within a context where visual exploration is discouraged, and efficient processing relies on fixation to a single feature. In this case, it makes more sense that nasion and nose fixations yield the fastest N170 latencies. By focusing attention on the relative centre of the face, the visual system is able to collect an optimal snapshot of information: fixating on a part of the face that does not contain a lot of visual input on the fovea, yet provides all critical features (eyes, nose, mouth) in parafovea to optimize holistic processing and, potentially, lateral inhibition mechanisms. This strategy was observed for both groups, demonstrating the importance of focusing on the nasion/nose to optimize holistic integration for autistic and neurotypical adults alike. The present results thereby show that autistic adults are not impaired in the visual perception and holistic integration of faces when fixation is enforced.

The current research has significant implications for the understanding and development of autistic and neurotypical face processing mechanisms and theories at both the behavioural and neural levels. However, it is essential to acknowledge and consider that the present analyses only reflect trials in which fixations were constrained to a pre-defined ROI (~2°: the relative size of the eye's fovea). Thus, it is clear that autistic adults can focus on the eyes when necessary (and when doing so elicit a comparable neural response to neurotypical control adults) but the current findings do not speak to variations in N170 patterns across all trials nor during more naturalistic free-viewing paradigms, critical areas for future investigation.

Chapter 6: General Discussion

> *"Above all, the recognition of faces depends not only on the ability to parse the visual aspects of the face – its particular features and their over-all configuration – and compare them with others but also on the ability to summon the memories, experiences, and feelings associated with that face."*
>
> -Oliver Sacks (2010), *The New Yorker*

Attending to another's eyes during social overtures is an essential building block for facilitating social interactions and decisions, including face recognition (Emery, 2000; Itier & Batty, 2009; Itier, 2015; Kleinke, 1986). At the group level, neurotypical adults typically demonstrate strong face recognition skills, whereas face recognition accuracy is often impaired in adults with an ASD (Faja et al., 2009; McPartland et al., 2011; Scherf et al., 2008; Tanaka & Sung, 2016; Trepagnier et al., 2002; Weigelt et al., 2012; Williams et al., 2005). Many autistic adults also experience pervasive difficulties attending to others' eyes (American Psychiatric Association, 2013; Dalton et al., 2005; Frazier et al., 2017; Klin et al., 2002; Pelphrey et al., 2002; Yi et al., 2014), leading researchers to propose that autistic face recognition difficulties may be attributed to disruptions in the earliest stages of face perception (e.g., sensitivity to the eyes, holistic face integration; Moriuchi et al., 2017; Senju & Johnson, 2009; Tanaka & Sung, 2016). It is essential to consider, however, that a full spectrum of face recognition abilities exists within both the neurotypical and autism populations, with abilities extending from pervasive difficulties recognizing others (i.e., developmental prosopagnosia; Cygan et al., 2018; Duchaine & Nakayama, 2006; Kirchner et al., 2011; O'Hearn et al., 2010) to never forgetting a face (i.e., super-recognizers; Kanner, 1941; Russell et al., 2009; Tardif et al., 2019).

To date, research investigating the direct relationships between gaze fixation patterns during face encoding and subsequent recognition accuracy is lacking at the individual (within-group) level for adults with and without an ASD. To address this clinically relevant gap in the literature and better understand autistic and neurotypical face recognition abilities through a neurodiversity framework, the work presented in this dissertation incorporated correlations and comparative metrics (FIE, eye/mouth sensitivity) with traditional group-level analyses. This line of research is especially important for autistic adults for whom atypical gaze patterns and/or frequent errors recognizing others have socially relevant consequences.

Chiefly, Chapter 2 established the first direct associations between feature saliency (with a specific focus on the eyes) and face recognition abilities amongst a large sample of neurotypical adults, improving the field's understanding of the degree to which individual differences in gaze patterns to facial features influences incidental and intentional recognition accuracy. Results revealed that neurotypical adults strategically directed fixations towards the internal features of the face, with the nasion being looked at for longer periods of time, and more often, than any other features during face encoding, followed closely by the left and right eyes as well as the upper bridge of the nose, although substantial variation was observed across participants. Critically, whilst fixation patterns did not differ across task demands at the group level, correlation analyses revealed that increased fixation to the left eye and nasion were related to improved incidental recognition accuracy relative to adults who spent less time attending to these regions of the face. Increased fixation to the nose, on the other hand, was negatively associated with incidental accuracy such that adults with an increased reliance on this feature made more errors. In contrast, intentional face recognition was largely unrelated to where adults fixated within the face, although individuals who spent more time attending to non-core features of the face performed more poorly than their peers who directed their fixation towards internal features[27]. Collectively, these findings indicate that adults have likely developed an individualized gaze fixation strategy that works best for them during face encoding based on their developmental experience (for discussion see Arizpe et al., 2017; Peterson et al., 2016; Tsank & Eckstein, 2017) – an essential factor to be considered in prospective face recognition research. Furthermore, this research highlights that the features neurotypical observers focus on during the first two seconds of a social encounter play a critical role in facilitating successful face recognition, a phenomenon that appears to be true more so for incidental circumstances (more akin to the cognitive mechanisms we employ during typical every day encounters) than for intentional recognition (the hallmark of empirical investigation).

Building on this work, an in-depth neurocognitive assessment was then implemented, extending the investigation to a clinical sample of adults with an ASD and neurotypical control adults (**Appendix A**). Considering the neurological basis of autism (Belmonte, 2004; Courchesne, 2002; Jones & Klin, 2013; Just & Pelphrey, 2013; Minshew & Keller, 2010), it is imperative to acknowledge that the behavioural

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[27] See **Appendix D** for a discussion of the significant mediating effect of perspective taking traits on this relationship between non-core features and recognition accuracy.

manifestations and social deficits apparent in the disorder are rooted in neural development, connectivity, and activation. Thus, the present investigation evaluated face processing abilities at both the behavioural (Chapter 3) and neural (Chapters 4 & 5) levels to acquire well-rounded profiles of face recognition abilities in relation to the eye indifference/avoidance and holistic integration theories (Moriuchi et al., 2017; Tanaka & Sung, 2016) during the earliest stages of face perception.

Chapter 3 unveiled that, on average, adults with an ASD did not differ from neurotypical controls on measures of incidental or intentional recognition accuracy. Autistic adults spent slightly less time fixating on the face during encoding relative to neurotypical adults, although once fixations were directed towards the face, feature saliency patterns did not differ between neurotypical and autistic adults. Paralleling findings from Chapter 2, the nasion was looked at for longer periods of time, and more often, during face encoding, irrespective of group membership or task. Fixations were also directed towards the left eye, right eye, and nose to a significant degree for both groups, followed thereafter by the mouth. Exploratory correlation analyses did not reveal any statistically significant associations between fixation patterns and autism symptom severity.

Contrary to initial predictions, adults with an ASD did not spend less time than neurotypical adults attending to the eyes during face encoding and did not show evidence of a reliance on the mouth or other facial features. Area-normalized looking times and fixation counts further demonstrated that the relative saliency and importance of internal core facial features was preserved in ASD. Consequently, the present findings are not in line with the eye avoidance or indifference theories of face processing (Moriuchi et al., 2017; Tanaka & Sung, 2016) but instead provide evidence in support of preserved gaze fixation patterns for adults with an ASD during the encoding of face photographs. This research adds to the neurodiversity and social cognition literature by demonstrating that autistic gaze fixation patterns fall along the same continuum of performance as age-, gender-, ethnicity-, and IQ-matched neurotypical adults.

Face recognition accuracy (*d′*) was also not impacted by task demands or group membership. However, within the ASD group, intentional face recognition accuracy was strongly associated with symptom severity (ADOS-2 scores), paralleling a previous report (McPartland et al., 2011). These results demonstrate for the first time that autistic adults with more severe symptom presentations may be disproportionately affected by task demands during face encoding. In particular, autistic adults with higher ADOS-2 scores yielded lower accuracies during intentional face recognition than adults with lower ADOS-2 scores, although incidental recognition accuracy was not related to autism symptom presentation.

It is interesting to consider that while intentional recognition accuracy varied across ADOS-2 profiles, autistic adults did not differ from their neurotypical counterparts on either incidental or intentional recognition *d′* measures, a surprising finding given many of the participants qualitatively reported face recognition difficulties in their daily lives (Parkington & Itier, 2019b). Instead, adults with an ASD demonstrated face recognition accuracy scores within comparable ranges to their neurotypical matches on both incidental and intentional recognition, demonstrating that autistic behaviours represent cases along the full continuum of social abilities, in line with the neurodiversity perspective of autism (Baron-Cohen, 2017; Mandy, 2018; Masataka, 2017; Silberman, 2017). It is critical to consider, however, that many participants (in both groups) performed relatively poorly[28] ($d' < 0.5$) on at least one face recognition task. Therefore, although autistic adults performed comparably to neurotypical controls, face recognition difficulties are present and measurable at the individual level for neurotypical and autistic adults alike.

The current research is also one of the first investigations to present gaze fixation patterns and face recognition accuracy for women and non-binary individuals with an ASD. To date, autism research at large has been biased towards the male autistic phenotype due to the increased prevalence of boys and men with ASD relative to autistic girls and women. However, recent advancements in autism awareness has led to an increase in autism diagnosis in adolescence and adulthood for women and non-binary individuals as well as an increased awareness of the necessity of including diverse gender samples in autism research. Although gender differences were not of primary interest to this dissertation, the current neurocognitive assessment happened to include more autistic women and gender non-conforming individuals than previous face recognition research, which may partially explain the lack of differences between neurotypical and ASD groups. Girls and women with ASD often

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[28] A d' value of 0.5 corresponds to a 60% hit rate and 40% false rate; accuracy levels that are well below the standard 70-75% accuracy cut-off implemented in many neurotypical face recognition studies.

display fewer irregularities in eye contact and present with different cognitive and behavioural profiles than autistic men (Hendrickx, 2015; Lai et al., 2017; Lai et al., 2018; Schuck et al., 2019), signifying the importance of considering potential gender differences in future investigations of autistic social cognition.

Finally, the eye indifference/avoidance and holistic integration theories of early face perception were simultaneously evaluated at the neural level using a gaze-contingent ERP paradigm that compared peak N170 amplitudes and latencies elicited to upright and inverted faces and objects as well as isolated features (Chapter 4) and elicited in response to faces with fixation enforced on core facial features (Chapter 5). Collectively these studies present the first ERP experiments to monitor eye movements during N170 evaluations in autistic and neurotypical adults for whom face recognition abilities were known. Here, autistic adults demonstrated intact and preserved neural markers of early face perception, indicating holistic integration and sensitivity to the eyes is not disrupted in autistic adults who show face recognition accuracies on par with neurotypical adults.

Considering opposing evidence indicating attenuated N170 amplitudes and/or delayed latencies for autistic adults relative to neurotypical peers (Churches et al., 2010; Churches et al., 2012; Churches et al., 2012; Kang et al., 2018; McPartland et al., 2004; O’Connor et al., 2005; O'Connor et al., 2007; Webb et al., 2010; Webb et al., 2012), the present findings suggest that discrepancies between investigations likely reflect differences between autistic and neurotypical adults’ visual attention to the stimuli, rather than deficits in N170 responding and face perception *per se*. Autistic individuals (including adults within the present sample, see Chapter 3) often spend less time attending to another person's face than do neurotypical adults and report pervasive difficulties initiating and maintaining eye contact with others (APA, 2013). However, no studies to date have controlled for fixation within the face while recording ERP measurements for autistic adults. Here, holistic and featural mechanisms were preserved in autistic adults with typical face recognition abilities where fixation was enforced to each visual category. Therefore, the attenuated amplitudes or delayed latencies reported in some studies may in fact reflect degraded N170 responses elicited by inattention to the visual categories – especially faces and social information – an important confounding attribute which should be considered and measured in future investigations.

The current research also highlights the importance of accounting for and evaluating heterogeneity in neural expression during investigations of face processing. For instance, the present analyses focused on peak responses from the electrodes that were maximal for each participant (as opposed to the classic grand-average approach implemented in all previous N170 investigations in autistic adults) so as to be optimally sensitive to individual variations in N170 responding. Using this methodology, ERP measures can more accurately represent each person's neural response to visual categories (i.e., complete visual processing). Alternatively, grand-average approaches may inadvertently capture incomplete or unreliable measures of ERP amplitudes and latencies from electrodes that do not accurately represent peak performance for all participants. As such, this individualized approach permits a more accurate depiction of N170 peak responding across participants and diagnostic groups, eliminating potential confounds in measuring attenuated amplitudes for some participants (especially those with autism) who may not consistently show optimal responding on the same electrodes as neurotypical adults. The implementation of an individual-peak methodology, particularly when dealing with clinical populations who may differ in their overall neural signatures and/or recruitment pathways, is an important alternative for neuroscientists to consider. By implementing an individualized approach that aims to decrease systemic biases in measuring neural responses, such as that done here, only then will we be able to more concretely understand the temporal neurodynamics of autistic face processing.

This collection of work is not, however, without its limitations. Primarily, the old/new recognition paradigm implemented in Chapters 2 and 3 prioritized accuracy during the test phase to provide individuals of all recognition abilities fair opportunity, especially given the deprived nature (grey-scaled and cropped) of the faces. Thus, it is possible that this design, in addition to the use of static photograph stimuli, could limit our abilities to decipher behavioural associations. It is worth noting, however, that no participants performed at ceiling on either task, indicating that the task demands were sufficiently difficult to challenge participants' memory. As such, it is possible that the face recognition difficulties facing autistic adults are more so related to how long it takes them to recognize a face (i.e., response time) rather than their ability to arrive at an accurate discrimination, a factor being considered now. Secondly, this paradigm does not allow researchers to determine the confidence or degree to which each face was remembered (i.e., familiarity versus recollection), limiting the ability to expand on the quantitative aspects of face recognition. Future studies should elaborate on these theories by employing paradigms that can help discern the stability and function of distinct memory processes (e.g., remember-know-don't know and/or confidence ratings) within incidental and intentional settings. Furthermore, the neuroimaging studies included in Chapters 4 and 5 only focused on the peak of the N170 ERP component. Whilst this robust neural marker provides a reliable way for neuroscientists to index early face processing and provides valuable insights for scientific and clinical considerations, it only represents a small subset of the neural activation data available. Differences were not observed between autistic and neurotypical adults with the classic analyses reported here, although the current research does not rule out the possibility that neural divergences may be observed beyond the N170 peak. It is possible that group differences and/or autistic disruptions in holistic and/or eye sensitivity processing may become evident when a more whole-brain approach to examining neural patterns across all electrodes and time points is implemented. For example, recent advancements in mass univariate analysis – which focuses on evaluating changes in responses across time points and electrodes (Fields & Kuperberg, 2019; Luck & Gaspelin, 2017; McCrackin & Itier, 2019; Pernet, Chauveau, Gaspar, & Rousselet, 2011) – provide promising avenues for researchers and practitioners to evaluate the temporal neurodynamics of social and cognitive processing from alternative perspectives.

Despite the above shortcomings, the data presented throughout this dissertation provide critical new insights for understanding within-group individual differences in face recognition amongst adults with and without ASD. Demonstrating a lack of between-group differences in relation to gaze patterns to internal facial features and incidental/intentional face recognition accuracy in neurotypical and autistic adults, these results provide evidence against the eye indifference hypothesis (Moriuchi et al., 2017). The nasion captured the attention of adults with an ASD more so than any core feature and the eyes and the bridge of the nose were also more salient than the mouth and non-core features; thus, autistic adults are not indifferent to the attentional saliency of the eyes. The eye avoidance hypothesis (Tanaka & Sung, 2016) was also not supported based on the data presented here: adults with an ASD did not differ from their neurotypical peers in terms of gaze fixations to the eye region and there was no evidence of hyper-sensitivity to the eyes on the N170 ERP component. These findings do not, however, rule out the possibility of hyper-arousal mechanisms occurring in response to the eyes at later cognitive stages beyond the N170 time window (e.g., during the late positive potential time reflecting arousal appraisal around 300-700ms post-stimulus) leading to gaze aversion patterns and potential difficulties with face recognition. Instead, the present research findings dovetail with the growing body of eye-tracking evidence indicating preserved gaze fixation patterns and recognition accuracy amongst adults with an ASD (Hedley et al., 2012) and suggest that quantitative theories of face recognition implicating disruptions in the storage, consolidation, and/or retrieval of face identities (including differentiation between familiarity and recollection; Cygan et al., 2018; Weigelt et al., 2012; Weigelt, Koldewyn, & Kanwisher, 2013) are more likely to be root causes of autistic face recognition difficulties than the qualitative aspects explored here.

Collectively, these data implicate a small but important role of the eyes (especially the left eye and nasion) in neurotypical incidental face recognition accuracy at the individual level. The present research also reveals adults with an ASD perform comparably to neurotypical control adults on measures of face recognition when provided sufficient time to respond and elicit preserved N170 markers of holistic integration and eye sensitivity when fixation is enforced. In one of the first demonstrations of consistent associations between autistic behaviors and intentional face recognition accuracy at the clinical (ADOS-2) and non-clinical (AQ) levels, this research signifies the importance of autistic symptomology in driving recognition abilities. As a whole, this dissertation highlights the importance of examining individual (within-group) differences in autistic and neurotypical populations and adopting a neurodiversity framework when investigating social processing in autism. Representing some of the first steps towards a better understanding of the neurocognitive mechanisms underlying incidental and intentional face recognition in adults with and without an ASD, this work suggests that attention to the eyes during face encoding is essential for facilitating the recognition of others.

References

Adolphs, R., Spezio, M. L., Parlier, M., & Piven, J. (2008). Distinct face-processing strategies in parents of autistic children. *Current Biology, 18*(14), 1090-1093. doi:10.1016/j.cub.2008.06.073

Aguado, L., Parkington, K. B., Dieguez-Risco, T., Hinojosa, J. A., & Itier, R. J. (2019). Joint modulation of facial expression processing by contextual congruency and task demands. *Brain Sciences, 9*(5), 116. doi:10.3390/brainsci9050116

Akdeniz, G. (2020). Brain activity underlying face and face pareidolia processing: An ERP study. *Neurological Sciences, 41*(6), 1557-1565. doi:10.1007/s10072-019-04232-4

Akechi, H., Senju, A., Uibo, H., Kikuchi, Y., Hasegawa, T., & Hietanen, J. K. (2013). Attention to eye contact in the west and east: Autonomic responses and evaluative ratings. *PloS One, 8*(3), e59312. doi:10.1371/journal.pone.0059312

Allely, S. C. (2019). The female phenotype of autism spectrum disorder: The 'camouflage' hypothesis. doi:10.5281/zenodo.3236679

American Psychiatric Association. (2013a). *Diagnostic and statistical manual of mental disorders* (5th Ed. ed.). Arlington, VA, USA:

American Psychiatric Association. (2013b). *Diagnostic and statistical manual of mental disorders* (5th ed.). Washington, DC, USA:

Andrews, T. J., Davies-Thompson, J., Kingstone, A., & Young, A. W. (2010). Internal and external features of the face are represented holistically in face-selective regions of visual cortex. *Journal of Neuroscience, 30*(9), 3544-3552. doi:10.1523/JNEUROSCI.4863-09.2010

Aoki, Y., Cortese, S., & Tansella, M. (2015). Neural bases of atypical emotional face processing in autism: A meta-analysis of fMRI studies. *The World Journal of Biological Psychiatry, 16*(5), 291-300. doi:10.3109/15622975.2014.957719

Arcurio, L. R., Gold, J. M., & James, T. W. (2012). The response of face-selective cortex with single face parts and part combinations. *Neuropsychologia, 50*(10), 2454-2459. doi:10.1016/j.neuropsychologia.2012.06.016

Arizpe, J., Walsh, V., Yovel, G., & Baker, C. I. (2017). The categories, frequencies, and stability of idiosyncratic eye-movement patterns to faces. *Vision Research, 141*, 191-203. doi:10.1016/j.visres.2016.10.013

Austin, E. J. (2005). Personality correlates of the broader autism phenotype as assessed by the autism spectrum quotient (AQ). *Personality and Individual Differences, 38*(2), 451-460. doi:10.1016/j.paid.2004.04.022

Bainbridge, W. A., Isola, P., & Oliva, A. (2013). The intrinsic memorability of face photographs. *Journal of Experimental Psychology. General, 142*(4), 1323-1334. doi:10.1037/a0033872

Baron-Cohen, S. (2017). Editorial perspective: Neurodiversity – a revolutionary concept for autism and psychiatry. *Journal of Child Psychology and Psychiatry, 58*(6), 744-747. doi:10.1111/jcpp.12703

Baron-Cohen, S., Wheelwright, S., Skinner, R., Martin, J., & Clubley, E. (2001). The autism-spectrum quotient (AQ): Evidence from asperger syndrome/high-functioning autism, males and females, scientists and mathematicians. *Journal of Autism and Developmental Disorders, 31*(1), 5. doi:10.1023/A:1005653411471

Barton, J. J. S., Radcliffe, N., Cherkasova, M. V., Edelman, J., & Intriligator, J. M. (2006). Information processing during face recognition: The effects of familiarity, inversion, and morphing on scanning fixations. *Perception, 35*(8), 1089-1105. doi:10.1068/p5547

Belmonte, M. K. (2004). Autism and abnormal development of brain connectivity. *The Journal of Neuroscience, 24*(42), 9228-9231. doi:10.1523/jneurosci.3340-04.2004

Bentin, S., Allison, T., Puce, A., Perez, E., & McCarthy, G. (1996). Electrophysiological studies of face perception in humans. *Journal of Cognitive Neuroscience, 8*(6), 551-565.

Bishop-Fitzpatrick, L., Mazefsky, C.A., Eack, S.M., & Minshew, N.J. (2017). Correlates of social functioning in autism spectrum disorder: The role of social cognition. *Research in Autism Spectrum Disorders, 35*(3), 25-34. doi: 10.1016/j.rasd.2016.11.013

Bobak, A. K., Bennetts, R. J., Parris, B. A., Jansari, A., & Bate, S. (2016). An in-depth cognitive examination of individuals with superior face recognition skills. *Cortex, 82*, 48-62. doi:10.1016/j.cortex.2016.05.003

Boucher, J., & Anns, S. (2018). Memory, learning and language in autism spectrum disorder. *Autism & Developmental Language Impairments, 3*, 239694151774207. doi:10.1177/2396941517742078

Boutet, I., Lemieux C.L., Goulet, M.A., & Collin, C.A. (2017). Faces elicit different scanning patterns depending on task demands. *Attention, Perception, & Psychophysiology, 79,* 1050-1063. doi: 10.3758/s13414-017-1284-y

Bruce, V., & Young, A. (1986). Understanding face recognition. *British Journal of Psychology, 77*, 305-327.

Buck, T. R., Viskochil, J., Farley, M., Coon, H., McMahon, W. M., Morgan, J., & Bilder, D. A. (2014). Psychiatric comorbidity and medication use in adults with autism spectrum disorder. *Journal of Autism and Developmental Disorders, 44*(12), 3063-3071. doi:10.1007/s10803-014-2170-2

Cage, E., Cage, E., Di Monaco, J., Di Monaco, J., Newell, V., & Newell, V. (2018). Experiences of autism acceptance and mental health in autistic adults. *Journal of Autism and Developmental Disorders, 48*(2), 473-484. doi:10.1007/s10803-017-3342-7

Campbell, A., & Tanaka, J. W. (2018). Inversion impairs expert budgerigar identity recognition: A face-like effect for a nonface object of expertise. *Perception, 47*(6), 647-659. doi:10.1177/0301006618771806

Caron, M. (2004). Do high functioning persons with autism present superior spatial abilities? *Neuropsychologia, 42*(4), 467-481. doi:10.1016/j.neuropsychologia.2003.08.015

Cheek, J. M., & Buss, A. H. (1981). Shyness and sociability. *Journal of Personality and Social Psychology, 41*(2), 330-339.

Chita-Tegmark, M. (2016). Social attention in ASD: A review and meta-analysis of eye-tracking studies. *Research in Developmental Disabilities, 48*, 79-93. doi:10.1016/j.ridd.2015.10.011

Chmiel, I., & Gorkiewicz, M. (2012). The bootstrap and multiple comparisons procedures as remedy on doubts about correctness of ANOVA results. *Applied Medical Informatics, 30*(1), 9-15.

Chuk, T., Crookes, K., Hayward, W. G., Chan, A. B., & Hsiao, J. H. (2017). Hidden markov model analysis reveals the advantage of analytic eye movement patterns in face recognition across cultures. *Cognition, 169*, 102-117. doi:10.1016/j.cognition.2017.08.003

Churches, O., Baron-Cohen, S., & Ring, H. (2012). The psychophysiology of narrower face processing in autism spectrum conditions. *NeuroReport, 23*(6), 395-399. doi:10.1097/WNR.0b013e3283525bc8

Churches, O., Damiano, C., Baron-Cohen, S., & Ring, H. (2012). Getting to know you: The acquisition of new face representations in autism spectrum conditions. *NeuroReport, 23*(11), 668-672. doi:10.1097/WNR.0b013e3283556658

Churches, O., Wheelwright, S., Baron-Cohen, S., & Ring, H. (2010). The N170 is not modulated by attention in autism spectrum conditions. *NeuroReport, 21*(6), 399-403. doi:10.1097/WNR.0b013e328334311b

Connor, K. M., Davidson, J. R. T., Churchill, L. E., Sherwood, A., Weisler, R. H., & Foa, E. (2000). Psychometric properties of the social phobia inventory (SPIN): New self-rating scale. *The British Journal of Psychiatry, 176*(4), 379-386. doi:10.1192/bjp.176.4.379

Courchesne, E. (2002). Abnormal early brain development in autism. *Molecular Psychiatry, 7 Suppl 2*(s2), S21-S23. doi:10.1038/sj.mp.4001169

Crook III, T. H., & Larrabee, G. J. (1992). Changes in facial recognition memory across the adult life span. *Journal of Gerontology, 47*(3), P138-P141. Retrieved from https://search.proquest.com/docview/72911929

Cygan, H. B., Okuniewska, H., Jednoróg, K., Marchewka, A., Wypych, M., & Nowicka, A. (2018). Face processing in a case of high functioning autism with developmental prosopagnosia. *Acta Neurobiologiae Experimentalis, 78*(2), 114-131. doi:10.21307/ane-2018-011

Dalton, K. M., Nacewicz, B. M., Johnstone, T., Schaefer, H. S., Gernsbacher, M. A., Goldsmith, H. H., . . . Davidson, R. J. (2005). Gaze fixation and the neural circuitry of face processing in autism. *Nature Neuroscience, 8*(4), 519-526. doi:10.1038/nn1421

Davis, J., McKone, E., Zirnsak, M., Moore, T., O'Kearney, R., Apthorp, D., & Palermo, R. (2017). Social and attention-to-detail subclusters of autistic traits differentially predict looking at eyes and face identity recognition ability. *British Journal of Psychology, 108*(1), 191-219. doi:10.1111/bjop.12188

Davis, T. E., Hess, J. A., Moree, B. N., Fodstad, J. C., Dempsey, T., Jenkins, W. S., & Matson, J. L. (2011). Anxiety symptoms across the lifespan in people diagnosed with autistic disorder. *Research in Autism Spectrum Disorders, 5*(1), 112-118. doi:10.1016/j.rasd.2010.02.006

Dawson, G. & Fernald, M. (1987). Perspective-taking ability and its relationship to the social behavior of autistic children. *Journal of Autism and Developmental Disorders, 17*(4), 487-498.

de Lissa, P., McArthur, G., Hawelka, S., Palermo, R., Mahajan, Y., & Hutzler, F. (2014). Fixation location on upright and inverted faces modulates the N170. *Neuropsychologia, 57*, 1-11. doi:10.1016/j.neuropsychologia.2014.02.006

DeGutis, J., Wilmer, J., Mercado, R. J., & Cohan, S. (2013). Using regression to measure holistic face processing reveals a strong link with face recognition ability. *Cognition, 126*(1), 87-100. doi:10.1016/j.cognition.2012.09.004

Delorme, A., & Makeig, S. (2004). EEGLAB: An open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods, 134*(1), 9-21. doi:10.1016/j.jneumeth.2003.10.009

Dennett, H. W., McKone, E., Tavashmi, R., Hall, A., Pidcock, M., Edwards, M., & Duchaine, B. (2011). The cambridge car memory test: A task matched in format to the cambridge face memory test, with norms, reliability, sex differences, dissociations from face memory, and expertise effects. *Behavior Research Methods, 44*(2), 587-605. doi:10.3758/s13428-011-0160-2

Duchaine, B., & Nakayama, K. (2006). The cambridge face memory test: Results for neurologically intact individuals and an investigation of its validity using inverted face stimuli and prosopagnosic participants. *Neuropsychologia, 44*(4), 576-585. doi:10.1016/j.neuropsychologia.2005.07.001

Dundas, E. M., Plaut, D. C., & Behrmann, M. (2014). An ERP investigation of the co-development of hemispheric lateralization of face and word recognition. *Neuropsychologia, 61*, 315-323. doi:10.1016/j.neuropsychologia.2014.05.006

Efron, B. & Tibshirani, R.J. (1994). *An introduction to the bootstrap.* New York, USA: Monographs on Statistics and Applied Probability (57).

Eimer, M. (1998). Does the face-specific N170 component reflect the activity of a specialized eye processor? *NeuroReport, 9*(13), 2945-2948. doi:10.1097/00001756-199809140-00005

Eimer, M. (2000a). Effects of face inversion on the structural encoding and recognition of faces: Evidence from event-related brain potentials. *Cognitive Brain Research, 10*(1), 145-158. doi:10.1016/S0926-6410(00)00038-0

Eimer, M. (2000b). Event-related brain potentials distinguish processing stages involved in face perception and recognition. *Clinical Neurophysiology, 111*(4), 694-705. doi:10.1016/S1388-2457(99)00285-0

Eimer, M. (2000c). The face-specific N170 component reflects late stages in the structural encoding of faces. *NeuroReport, 11*(10), 2319-2324. doi:10.1097/00001756-200007140-00050

Eimer, M. (2011). The face-sensitive N170 component of the event-related brain potential. In A. J. Calder, G. Rhodes, M. H. Johnson & J. V. Haxby (Eds.), *Oxford handbook of face perception* (pp. 329-344). Oxford, UK: Oxford University Press. doi:10.1093/oxfordhb/9780199559053.013.0017

Emery, N. J. (2000). The eyes have it: The neuroethology, function and evolution of social gaze. *Neuroscience and Biobehavioral Reviews, 24*(6), 581-604. doi:10.1016/S0149-7634(00)00025-7

Engell, A. D., & McCarthy, G. (2014). Face, eye, and body selective responses in fusiform gyrus and adjacent cortex: An intracranial EEG study. *Frontiers in Human Neuroscience, 8*, 642. doi:10.3389/fnhum.2014.00642

Ewing, L., Pellicano, E., King, H., Lennuyeux-Comnene, L., Farran, E. K., Karmiloff-Smith, A., & Smith, M. L. (2018). Atypical information-use in children with autism spectrum disorder during judgments of child and adult face identity. *Developmental Neuropsychology, 43*(4), 370-384. doi:10.1080/87565641.2018.1449846

Faja, S., Webb, S., Merkle, K., Aylward, E., & Dawson, G. (2009). Brief report: Face configuration accuracy and processing speed among adults with high-functioning autism spectrum disorders. *Journal of Autism and Developmental Disorders, 39*(3), 532-538. doi:10.1007/s10803-008-0635-x

Falkmer, M., Larsson, M., Bjallmark, A., & Falkmer, T. (2010). The importance of the eye area in face identification abilities and visual search strategies in persons with asperger syndrome. *Research in Autism Spectrum Disorders, 4*, 724-730.

Fedor, J., Lynn, A., Foran, W., DiCicco-Bloom, J., Luna, B., & O'Hearn, K. (2017). Patterns of fixation during face recognition: Differences in autism across age. *Autism : The International Journal of Research and Practice, 22*(7), 866-880. doi:10.1177/1362361317714989

Ferraro, F. R., Hansen, R., & Deling, L. (2018). Executive function index (EFI) performance in nonclinical individuals with high levels of autistic traits. *Applied Neuropsychology: Adult, 25*(2), 149-154. doi:10.1080/23279095.2016.1263199

Feuerriegel, D., Churches, O., Hofmann, J., & Keage, H. A. D. (2014). The N170 and face perception in psychiatric and neurological disorders: A systematic review. *Clinical Neurophysiology, 126*(6), 1141-1158. doi:10.1016/j.clinph.2014.09.015

Fields, E. C., & Kuperberg, G. R. (2019). Having your cake and eating it too: Flexibility and power with mass univariate statistics for ERP data. *Psychophysiology, 57*(2), e13468-n/a. doi:10.1111/psyp.13468

Fletcher-Watson, S., Leekam, S. R., Benson, V., Frank, M. C., & Findlay, J. M. (2009). Eye-movements reveal attention to social information in autism spectrum disorder. *Neuropsychologia, 47*(1), 248-257. doi: 10.1016/j.neuropsychologia.2008.07.016

Frazier, T. W., Strauss, M., Klingemier, E. W., Zetzer, E. E., Hardan, A. Y., Eng, C., & Youngstrom, E. A. (2017). A meta-analysis of gaze differences to social and nonsocial information between individuals with and without autism. *Journal of the American Academy of Child and Adolescent Psychiatry, 56*(7), 546-555. doi: 10.1016/j.jaac.2017.05.005

Frith, U., & Happe, F. (1994). Autism: Beyond "theory of mind". *Cognition, 50*((1-3)), 115-132.

George, N., Evans, J., Fiori, N., Davidoff, J., & Renault, B. (1996). Brain events related to normal and moderately scrambled faces. *Cognitive Brain Research, 4,* 65-76.

Goldinger, S. D., He, Y., & Papesh, M. H. (2009). Deficits in cross-race face learning: Insights from eye movements and pupillometry. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 35*(5), 1105-1122. doi:10.1037/a0016548

Grandin, T. & Panek, R. (2008). *The autistic brain: Helping different kinds of minds succeed.* Houghton, Mifflin Harcourt.

Green, R., Travers, A., Howe, Y., & McDougle, C. (2019). Women and autism spectrum disorder: Diagnosis and implications for treatment of adolescents and adults. *Current Psychiatry Reports, 21*(4), 1-8. doi:10.1007/s11920-019-1006-3

Haig. (1985). How faces differ: A new comparative technique. *Perception, 14,* 601-615.

Halliday, D. W. R., MacDonald, S. W. S., Scherf, K. S., Sherf, S. K., & Tanaka, J. W. (2014). A reciprocal model of face recognition and autistic traits: Evidence from an individual differences perspective. *PloS One, 9*(5), e94013. doi:10.1371/journal.pone.0094013

Happé, F., & Frith, U. (2006). The weak coherence account: Detail-focused cognitive style in autism spectrum disorders. *Journal of Autism and Developmental Disorders, 36*(1), 5-25. doi:10.1007/s10803-005-0039-0

Hautus, M.J. (1995). Corrections for extreme proportions and their biasing effects on estimated values of *d'*. *Behavioral Research Methods, Instruments, & Computers, 27*(1), 46-51.

Haxby, J. V., & Hoffman, E. A. (2000). Distinct representations of eye gaze and identity in the distributed human neural system for face perception. *Nature Neuroscience, 3*(1), 80-84. doi:10.1038/71152

Haxby, J. V., Ungerleider, L. G., Clark, V. P., Schouten, J. L., Hoffman, E. A., & Martin, A. (1999). The effect of face inversion on activity in human neural systems for face and object perception. *Neuron (Cambridge, Mass.), 22*(1), 189-199. doi:10.1016/s0896-6273(00)80690-x

Hedley, D., Brewer, N., & Young, R. (2011). Face recognition performance of individuals with Asperger syndrome on the Cambridge face memory test. *Autism Research, 4*(6), 449-455. doi:10.1002/aur.214

Hedley, D., Young, R., & Brewer, N. (2012). Using eye movements as an index of implicit face recognition in autism spectrum disorder. *Autism Research, 5*(5), 363-379. doi:10.1002/aur.1246

Henderson, J., Williams, C., Castelhano, M., & Falk, R. (2003). Eye movements and picture processing during recognition. *Perception & Psychophysics, 65*(5), 725-734. doi:10.3758/BF03194809

Henderson, J., Williams, C., & Falk, R. (2005). Eye movements are functional during face learning. *Memory & Cognition, 33*(1), 98-106. doi:10.3758/BF03195300

Hendrickx, S. (2015). *Women and girls with autism spectrum disorder: Understanding life and experiences from early childhood to old age.* London, UK: Jessica Kingsley Publishers.

Hermens, F., Golubickis, M., & Macrae, C.N. (2018). Eye movements while judging faces for trustworthiness and dominance. *PeerJ 6:*e5702. doi: 10.7717/peerj.5702

Hessels, R. S., Kemner, C., van den Boomen, C., & Hooge, I. T. C. (2016). The area-of-interest problem in eyetracking research: A noise-robust solution for face and sparse stimuli. *Behavior Research Methods, 48*(4), 1694-1712. doi:10.3758/s13428-015-0676-y

Hill, E. L., & Frith, U. (2003). Understanding autism: Insights from mind and brain. *Philosophical Transactions. Biological Sciences, 358*(1430), 281-289. doi:10.1098/rstb.2002.1209

Hillger, L. A., & Koenig, O. (1991). Separable mechanisms in face processing: Evidence from hemispheric specialization. *Journal of Cognitive Neuroscience, 3*(1), 42-58.

Hills, P. J., Cooper, R. E., & Pake, J. M. (2013). First fixations in face processing: The more diagnostic they are the smaller the face-inversion effect. *Acta Psychologica, 142*(2), 211-219. doi:10.1016/j.actpsy.2012.11.013

Hills, P. J., & Pake, J. M. (2013). Eye-tracking the own-race bias in face recognition: Revealing the perceptual and socio-cognitive mechanisms. *Cognition, 129*(3), 586-597. doi:10.1016/j.cognition.2013.08.012

Hills, P. J., Ross, D. A., & Lewis, M. B. (2011). Attention misplaced: The role of diagnostic features in the face-inversion effect. *Journal of Experimental Psychology. Human Perception and Performance, 37*(5), 1396-1406. doi:10.1037/a0024247

Hobson, R. P., Ouston, J., & Lee, A. (1988). What's in a face? the case of autism. *The British Journal of Psychology, 79*(4), 441-453. doi:10.1111/j.2044-8295.1988.tb02745.x

Hoekstra, R. A., Bartels, M., Cath, D. C., & Boomsma, D. I. (2008). Factor structure, reliability and criterion validity of the autism-spectrum quotient (AQ): A study in dutch population and patient groups. *Journal of Autism and Developmental Disorders, 38*(8), 1555-1566. doi:10.1007/s10803-008-0538-x

Hsaio, J. H., & Cottrell, G. (2008). Two fixations suffice in face recognition. *Psychological Science, 19*(10), 998-1006. doi:10.1111/j.1467-9280.2008.02191.x

Hudson, C., Hall, L., & Harkness, K. (2019). Prevalence of depressive disorders in individuals with autism spectrum disorder: A meta-analysis. *Journal of Abnormal Child Psychology, 47*(1), 165-175. doi:10.1007/s10802-018-0402-1

Hull, L., Petrides, K. V., & Mandy, W. (2020). The female autism phenotype and camouflaging: A narrative review. *Review Journal of Autism and Developmental Disorders.* doi: 10.1007/s40489-020-00197-9

Hull, L., Lai, M., Baron-Cohen, S., Allison, C., Smith, P., Petrides, K. V., & Mandy, W. (2020). Gender differences in self-reported camouflaging in autistic and non-autistic adults. *Autism, 24*(2), 352-363. doi:10.1177/1362361319864804

Hurst, R. M., Mitchell, J. T., Kimbrel, N. A., Kwapil, T. K., & Nelson-Gray, R. O. (2007). Examination of the reliability and factor structure of the autism spectrum quotient (AQ) in a non-clinical sample. *Personality and Individual Differences, 43*(7), 1938-1949. doi: 10.1016/j.paid.2007.06.012

Ishai, A. (2008). Let's face it: It's a cortical network. *NeuroImage, 40*(2), 415-419. doi: 10.1016/j.neuroimage.2007.10.040

Itier, R. J. (2015). Attention to eyes in face perception. In J. M. Fawcett, E. F. Risko & A. Kingstone (Eds.), *The handbook of attention* (pp. 369-387). Cambridge, MA, USA: MIT Press.

Itier, R. J., & Batty, M. (2009). Neural bases of eye and gaze processing: The core of social cognition. *Neuroscience and Biobehavioral Reviews, 33*(6), 843-863.

Itier, R. J., Herdman, A. T., George, N., Cheyne, D., & Taylor, M. J. (2006). Inversion and contrast-reversal effects on face processing assessed by MEG. *Brain Research, 1115*(1), 108-120. doi: 10.1016/j.brainres.2006.07.072

Itier, R. J., & Taylor, M. J. (2002). Inversion and contrast polarity reversal affect both encoding and recognition processes of unfamiliar faces: A repetition study using ERPs. *NeuroImage, 15*, 353-372. doi: 10.1006/nimg.2001.0982

Itier, R. J., & Taylor, M. J. (2004a). N170 or N1? spatiotemporal differences between object and face processing using ERPs.*14*, 132-142. doi:10.1093/cercor/bhg111

Itier, R., & Taylor, M. (2004b). Source analysis of the N170 to faces and objects. *NeuroReport, 15*(8), 1261-1265. doi: 10.1097/01.wnr.0000127827.73576.d8

Itier, R. J., Taylor, M. J., & Lobaugh, N. J. (2004). Spatiotemporal analysis of event-related potentials to upright, inverted, and contrast-reversed faces: Effects on encoding and recognition. *Psychophysiology, 41*(4), 643-653. doi: 10.1111/j.1469-8986.2004.00183.x

Janik, S. W., Wellens, A. R., Goldberg, M. L., & Dellosso, L. F. (1978). Eyes as the center of focus in the visual examination of human faces. *Perceptual and Motor Skills, 47*, 857-858.

Jenkins, R., Dowsett, A. J., & Burton, A. M. (2018). How many faces do people know? *Proceedings of the Royal Society. B, Biological Sciences, 285*(1888), 20181319. doi: 10.1098/rspb.2018.1319

Jeste, S. S., & Nelson, C. A. (2008). Event related potentials in the understanding of autism spectrum disorders: An analytical review. *Journal of Autism and Developmental Disorders, 39*(3), 495-510. doi: 10.1007/s10803-008-0652-9

Jones, W., & Klin, A. (2013). Attention to eyes is present but in decline in 2–6-month-old infants later diagnosed with autism. *Nature (London), 504*(7480), 427-431. doi: 10.1038/nature12715

Joseph, R. M., & Tanaka, J. (2003). Holistic and part-based face recognition in children with autism. *Journal of Child Psychology and Psychiatry, 44*(4), 529-542. doi: 10.1111/1469-7610.00142

Just, M.A. & Pelphrey, K.A. (2013). *Development and Brain Systems in Autism*. New York, USA: Psychology Press.

Kang, E., Keifer, C. M., Levy, E. J., Foss-Feig, J. H., McPartland, J. C., & Lerner, M. D. (2018). Atypicality of the N170 event-related potential in autism spectrum disorder: A meta-analysis. *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging, 3*(8), 657-666. doi: 10.1016/j.bpsc.2017.11.003

Kang, E., McPartland, J. C., Keifer, C. M., Foss-Feig, J. H., Levy, E. J., & Lerner, M. D. (2019). Reply to: Can the N170 be used as an electrophysiological biomarker indexing face processing difficulties in autism spectrum disorder? *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging, 4*(3), 324-325. doi:10.1016/j.bpsc.2018.09.004

Kanner, L. (1943). Autistic disturbances of emotional affect. *Nervous Child, 2*, 217-250.

Kanwisher, N., & Yovel, G. (2006). The fusiform face area: A cortical region specialized for the perception of faces. *Philosophical Transactions. Biological Sciences, 361*(1476), 2109-2128. doi: 10.1098/rstb.2006.1934

Ketelaars, M. P., In't Velt, A., Mol, A., Swaab, H., Bodrij, F., & van Rijn, S. (2017). Social attention and autism symptoms in high functioning women with autism spectrum disorders. *Research in Developmental Disabilities, 64*, 78-86. doi: 10.1016/j.ridd.2017.03.005

Key, A. P., & Corbett, B. A. (2020). The unfulfilled promise of the N170 as a social biomarker. *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging, 5*(3), 342-353. doi: 10.1016/j.bpsc.2019.08.011

Kirchner, J., Hatri, A., Heekeren, H., & Dziobek, I. (2011). Autistic symptomatology, face processing abilities, and eye fixation patterns. *Journal of Autism and Developmental Disorders, 41*(2), 158-167. doi: 10.1007/s10803-010-1032-9

Kleinke, C. L. (1986). Gaze and eye contact. *Psychological Bulletin, 100*(1), 78-100. doi: 10.1037/0033-2909.100.1.78

Klin, A., Jones, W., Schultz, R., Volkmar, F., & Cohen, D. (2002). Visual fixation patterns during viewing of naturalistic social situations as predictors of social competence in individuals with autism. *Archives of General Psychiatry, 59*(9), 809-816. doi: 10.1001/archpsyc.59.9.809

Klin, A., Sparrow, S., de Bildt, A., Cicchetti, D., Cohen, D., & Volkmar, F. (1999). A normed study of face recognition in autism and related disorders. *Journal of Autism and Developmental Disorders, 29*(6), 499-508. doi: 10.1023/A:1022299920240

Kline, R.B. (1998). *Methodology in the social sciences: Principles and practice of structural equation modeling.* Guildford Press.

Kloth, N., Itier, R. J., & Schweinberger, S. R. (2013). Combined effects of inversion and feature removal on N170 responses elicited by faces and car fronts. *Brain and Cognition, 81*(3), 321-328. doi: 10.1016/j.bandc.2013.01.002

Konar, Y., Bennett, P. J., & Sekuler, A. B. (2010). Holistic processing is not correlated with face-identification accuracy. *Psychological Science, 21*(1), 38-43. doi: 10.1177/0956797609356508

Kuusikko-Gauffin, S., Eira, J., Alice, C., Rachel, P., Katja, J., Marja-Leena, M., . . . Irma, M. (2011). Face memory and object recognition in children with high-functioning autism or asperger syndrome and in their parents. *Research in Autism Spectrum Disorders, 5*(1), 622-628. doi:10.1016/j.rasd.2010.07.007

Lahaie, A., Mottron, L., Arguin, M., Berthiaume, C., Jemel, B., & Saumier, D. (2006). Face perception in high-functioning autistic adults. *Neuropsychology, 20*(1), 30-41. doi:10.1037/0894-4105.20.1.30

Langdell, T. (1978). Recognition of faces: An approach to the study of autism. *Journal of Child Psychology and Psychiatry, 19*(3), 255-268. doi:10.1111/j.1469-7610.1978.tb00468.x

Laycock, R., Crewther, S. G., & Chouinard, P. A. (2020). Blink and you will miss it: A core role for fast and dynamic visual processing in social impairments in autism spectrum disorder. *Current Developmental Disorders Reports,* , 1-11. doi:10.1007/s40474-020-00220-y

Leder, H., & Bruce, V. (2000). When inverted faces are recognized: The role of configural information in face recognition. *The Quarterly Journal of Experimental Psychology. A, Human Experimental Psychology, 53*(2), 513-536. doi:10.1080/027249800390583

Lewis, G., Shakeshaft, N., & Plomin, R. (2018). Face identity recognition and the social difficulties component of the autism-like phenotype: Evidence for phenotypic and genetic links. *Journal of Autism and Developmental Disorders, 48*(8), 2758-2765. doi:10.1007/s10803-018-3539-4

Longmore, C. A., Liu, C. H., & Young, A. W. (2015). The importance of internal facial features in learning new faces. *The Quarterly Journal of Experimental Psychology, 68*(2), 249-260. doi:10.1080/17470218.2014.939666

López, B., Donnelly, N., Hadwin, J., & Leekam, S. (2004). Face processing in high-functioning adolescents with autism: Evidence for weak central coherence. *Visual Cognition, 11*(6), 673-688. doi:10.1080/13506280344000437

Lord, C., Luyster, R. J., Gotham, K., & Guthrie, W. (2012). *Autism diagnostic observation schedule, second edition (ADOS-2)*. Torrance, CA, USA: Western Psychological Services.

Losh, M., Adolphs, R., Poe, M. D., Couture, S., Penn, D., Baranek, G. T., & Piven, J. (2009). Neuropsychological profile of autism and the broad autism phenotype. *Archives of General Psychiatry, 66*(5), 518-526. doi:10.1001/archgenpsychiatry.2009.34

Lowe, M.X., Gallivan, J.P., Ferber, S., & Cant, J.S. (2016). Feature diagnosticity and task context shape activity in human scene-selective cortex. *NeuroImage, 125*(1), 681-692. doi: 10.1016/j.neuroimage.2015.10.089

Luck, S.J. (2014). *An introduction to the event-related potential technique.* (2nd Edition). Cambridge, MA, USA: MIT Press.

Luck, S. J., & Gaspelin, N. (2017). How to get statistically significant effects in any ERP experiment (and why you shouldn't). *Psychophysiology, 54*(1), 146-157. doi:10.1111/psyp.12639

Ma, D., Correll, J., & Wittenbrink, B. (2015). The chicago face database: A free stimulus set of faces and norming data. *Behavior Research Methods, 47*(4), 1122-1135. doi:10.3758/s13428-014-0532-5

Malcolm, G. L., Lanyon, L. J., Fugard, A. J. B., & Barton, J. J. S. (2008). Scan patterns during the processing of facial expression versus identity: An exploration of task-driven and stimulus-driven effects. *Journal of Vision (Charlottesville, Va.), 8*(8), 2. doi:10.1167/8.8.2

Mandy, W. (2018). The research domain criteria: A new dawn for neurodiversity research? *Autism, 22*(6), 642-644. doi:10.1177/1362361318782586

Manor, B. R., & Gordon, E. (2003). Defining the temporal threshold for ocular fixation in free-viewing visuocognitive tasks. *Journal of Neuroscience Methods, 128*(1), 85-93. doi:10.1016/S0165-0270(03)00151-1

Masataka, N. (2017). Implications of the idea of neurodiversity for understanding the origins of developmental disorders. *Physics of Life Reviews, 20*, 85-108. doi:10.1016/j.plrev.2016.11.002

Maurer, D., Grand, R. L., & Mondloch, C. J. (2002). *The many faces of configural processing*. England: Elsevier Ltd. doi:10.1016/S1364-6613(02)01903-4

McCrackin, S. D., & Itier, R. J. (2018). Is it about me? time-course of self-relevance and valence effects on the perception of neutral faces with direct and averted gaze. *Biological Psychology, 135*, 47-64. doi:10.1016/j.biopsycho.2018.03.003

McCrackin, S. D., & Itier, R. J. (2019). Perceived gaze direction differentially affects discrimination of facial emotion, attention, and gender - an ERP study. *Frontiers in Neuroscience, 13*, 517. doi:10.3389/fnins.2019.00517

McKelvie, S. J. (1976). The role of eyes and mouth in the memory of a face. *The American Journal of Psychology, 89*(2), 311-323. doi:10.2307/1421414

McKone, E., & Yovel, G. (2009). Why does picture-plane inversion sometimes dissociate perception of features and spacing in faces, and sometimes not? toward a new theory of holistic processing. *Psychonomic Bulletin & Review, 16*(5), 778-797. doi:10.3758/PBR.16.5.778

McPartland, J. C. (2016). Considerations in biomarker development for neurodevelopmental disorders. *Current Opinion in Neurology, 29*(2), 118-122. doi:10.1097/wco.0000000000000300

McPartland, J., Cheung, C. H. M., Perszyk, D., & Mayes, L. C. (2010). Face-related ERPs are modulated by point of gaze. *Neuropsychologia, 48*(12), 3657-3660. doi:10.1016/j.neuropsychologia.2010.07.020

McPartland, J., Dawson, G., Webb, S. J., Panagiotides, H., & Carver, L. J. (2004). Event-related brain potentials reveal anomalies in temporal processing of faces in autism spectrum disorder. *Journal of Child Psychology and Psychiatry, 45*(7), 1235-1245. doi:10.1111/j.1469-7610.2004.00318.x

McPartland, J., Webb, S., Keehn, B., & Dawson, G. (2011). Patterns of visual attention to faces and objects in autism spectrum disorder. *Journal of Autism and Developmental Disorders, 41*(2), 148-157. doi:10.1007/s10803-010-1033-8

Mehoudar, E., Arizpe, J., Baker, C. I., & Yovel, G. (2014). Faces in the eye of the beholder: Unique and stable eye scanning patterns of individual observers. *Journal of Vision, 14*(7), 6. doi:10.1167/14.7.6

Miles, W. (1930). Ocular dominance in human adults. *Journal of General Psychology, 4*(1), 412-430.

Minshew, N. J., & Keller, T. A. (2010). The nature of brain dysfunction in autism: Functional brain imaging studies. *Current Opinion in Neurology, 23*(2), 124-130. doi:10.1097/wco.0b013e32833782d4

Morgan, M., & Hills, P. J. (2019). Correlations between holistic processing, autism quotient, extraversion, and experience and the own-gender bias in face recognition. *PloS One, 14*(7), e0209530. doi:10.1371/journal.pone.0209530

Moriuchi, J.M., Klin, A., & Jones, W. (2017). Mechanisms of diminished attention to eyes in autism. *American Journal of Psychiatry, 174*(1), 26-35. Doi: 10.1176/appi.ajp.2016.15091222

Nahar, A., Thippeswamy, H., Shanker Reddy, M. S., Kishore, M. T., & Chaturvedi, S. K. (2019). Psychiatric comorbidity in persons with high-functioning autism spectrum disorders: Findings from a tertiary care neuropsychiatric hospital. *Asian Journal of Psychiatry, 41*, 50-53. doi:10.1016/j.ajp.2018.09.008

Neath, K. N., & Itier, R. J. (2014). Facial expression discrimination varies with presentation time but not with fixation on features: A backward masking study using eye-tracking. *Cognition & Emotion, 28*(1), 115-131. doi:10.1080/02699931.2013.812557

Neath, K., & Itier, R. J. (2015). Fixation to features and neural processing of facial expressions in a gender discrimination task. *Brain and Cognition, 9*, 97-111.

Neath-Tavares, K. N., & Itier, R. J. (2016). Neural processing of fearful and happy facial expressions during emotion-relevant and emotion-irrelevant tasks: A fixation-to-feature approach. *Biological Psychology, 119*, 122-140. doi:10.1016/j.biopsycho.2016.07.013

Nemrodov, D., Anderson, T., Preston, F. F., & Itier, R. J. (2014). Early sensitivity for eyes within faces: A new neuronal account of holistic and featural processing. *NeuroImage, 97*, 81-94. doi:10.1016/j.neuroimage.2014.04.042

Nemrodov, D., & Itier, R. J. (2011). The role of eyes in early face processing: A rapid adaptation study of the inversion effect. *British Journal of Psychology, 102*(4), 783-798. doi:10.1111/j.2044-8295.2011.02033.x

Nishimura, M., Rutherford, M. D., & Maurer, D. (2008). Converging evidence of configural processing of faces in high-functioning adults with autism spectrum disorders. *Visual Cognition, 16*(7), 859-891. doi:10.1080/13506280701538514

Nomi, J. S., & Uddin, L. Q. (2015). Face processing in autism spectrum disorders: From brain regions to brain networks. *Neuropsychologia, 71*, 201-216. doi:10.1016/j.neuropsychologia.2015.03.029

O’Connor, K., Hamm, J. P., & Kirk, I. J. (2005). The neurophysiological correlates of face processing in adults and children with asperger’s syndrome. *Brain and Cognition, 59*(1), 82-95. doi:10.1016/j.bandc.2005.05.004

O'Connor, K., Hamm, J. P., & Kirk, I. J. (2007). Neurophysiological responses to face, facial regions and objects in adults with asperger's syndrome: An ERP investigation. *International Journal of Psychophysiology, 63*(3), 283-293. doi:10.1016/j.ijpsycho.2006.12.001

O’Hearn, K., Larsen, B., Fedor, J., Luna, B., & Lynn, A. (2020). Representational similarity analysis reveals atypical age-related changes in brain regions supporting face and car recognition in autism. *NeuroImage, 209*, 116322. doi:10.1016/j.neuroimage.2019.116322

O’Hearn, K., Schroer, E., Minshew, N., & Luna, B. (2010). Lack of developmental improvement on a face memory task during adolescence in autism. *Neuropsychologia, 48*(13), 3955-3960. doi:10.1016/j.neuropsychologia.2010.08.024

Osterling, J. A., Dawson, G., & Munson, J. A. (2002). Early recognition of 1-year-old infants with autism spectrum disorder versus mental retardation. *Development and Psychopathology, 14*(2), 239-251. doi:10.1017/S0954579402002031

O'Toole, A. J. (2011). Psychological and neural perspectives on human face recognition. In S. Z. Li, & A. K. Jain (Eds.), *Handbook of face recognition* (pp. 349-369). New York, USA: Springer Science+Business Media, Inc.

Ozonoff, S., & Strayer, D. (2001). Further evidence of intact working memory in autism. *Journal of Autism and Developmental Disorders, 31*(3), 257-263. doi:10.1023/A:1010794902139

Palermo, R., Willis, M.L., Rivolta, D., McKone, E., Wilson, C.E., & Calder, A.J. (2011). Impaired holistic coding of facial expression and facial identity in congenital prosopagnosia. *Neuropsychologia, 49.* 1226-1235. doi: 10.1016/j.neuropsychologia.2011.02.021

Papagiannopoulou, E. A., Chitty, K. M., Hermens, D. F., Hickie, I. B., & Lagopoulos, J. (2014). A systematic review and meta-analysis of eye-tracking studies in children with autism spectrum disorders. *Social Neuroscience, 9*(6), 610-632. doi:10.1080/17470919.2014.934966

Parkington, K. B., Clements, R. J., Landry, O., & Chouinard, P. A. (2015). Visual-motor association learning in undergraduate students as a function of the AQ. *Experimental Brain Research, 233*(10), 2883-2895. doi:10.1007/s00221-015-4358-x

Parkington, K.B., Ermis, R.E., & Itier, R.J. (2017). Preserved eye sensitivity of the N170 ERP component across face size. *Journal of Vision, 17*(10), 1029. doi: 10.1167/17.10.1029

Parkington, K.B. & Itier, R.J. (2018a). The impact of viewing time to internal facial features on face recognition performance following implicit and explicit encoding. *Journal of Vision, 18*(10), 167. doi: 10.1167/18.10.167

Parkington, K. B., & Itier, R. J. (2018b). One versus two eyes makes a difference! early face perception is modulated by featural fixation and feature context. *Cortex, 109*, 35-49. doi:10.1016/j.cortex.2018.08.025

Parkington, K. B., & Itier, R. J. (2019a). From eye to face: The impact of face outline, feature number, and feature saliency on the early neural response to faces.*1722*, 146343. doi:10.1016/j.brainres.2019.146343

Parkington, K. B., & Itier, R. J. (2019b). A thematic analysis of first-hand reports of face recognition and eye contact in adults with and without autism spectrum disorder. *Poster presentation at the International Meeting for Autism Research*.

Pelphrey, K., Sasson, N., Reznick, J., Paul, G., Goldman, B., & Piven, J. (2002). Visual scanning of faces in autism. *Journal of Autism and Developmental Disorders, 32*(4), 249-261. doi:10.1023/A:1016374617369

Pernet, C. R., Chauveau, N., Gaspar, C., & Rousselet, G. A. (2011). LIMO EEG: A toolbox for hierarchical linear MOdeling of ElectroEncephaloGraphic data. *Computational Intelligence and Neuroscience, 2011*, 831409-11. doi:10.1155/2011/831409

Peterson, M. F., & Eckstein, M. P. (2012). Looking just below the eyes is optimal across face recognition tasks. *Proceedings of the National Academy of Sciences of the United States of America, 109*(48), 19525-19526.

Peterson, M. F., & Eckstein, M. P. (2013). Individual differences in eye movements during face identification reflect observer-specific optimal points of fixation. *Psychological Science, 24*(7), 1216-1225. doi:10.1177/0956797612471684

Peterson, E. & Miller, S.F. (2012). The eyes test as a measure of individual differences: How much of the variance reflects verbal IQ? *Frontiers in Psychology,* doi: 10.3389/fpsyg.2012.00220

Peterson, M. F., Lin, J., Zaun, I., & Kanwisher, N. (2016). Individual differences in face-looking behavior generalize from the lab to the world. *Journal of Vision (Charlottesville, Va.), 16*(7), 12. doi:10.1167/16.7.12

Proverbio, A. M., & Galli, J. (2016). Women are better at seeing faces where there are none: An ERP study of face pareidolia. *Social Cognitive and Affective Neuroscience, 11*(9), 1501-1512. doi:10.1093/scan/nsw064

Radloff, L. S. (1977). The CES-D scale. *Applied Psychological Measurement, 1*(3), 385-401. doi:10.1177/014662167700100306

Rai, D., Heuvelman, H., Dalman, C., Culpin, I., Lundberg, M., Carpenter, P., & Magnusson, C. (2018). Association between autism spectrum disorders with or without intellectual disability and depression in young adulthood. *JAMA Network Open, 1*(4), e181465. doi:10.1001/jamanetworkopen.2018.1465

Ratto, A., Kenworthy, L., Yerys, B., Bascom, J., Wieckowski, A., White, S., . . . Anthony, L. (2018). What about the girls? sex-based differences in autistic traits and adaptive skills. *Journal of Autism and Developmental Disorders, 48*(5), 1698-1711. doi:10.1007/s10803-017-3413-9

Ree, M. J., French, D., MacLeod, C., & Locke, V. (2008). Distinguishing cognitive and somatic dimensions of state and trait anxiety: Development and validation of the state-trait inventory for cognitive and somatic anxiety (STICSA). *Behavioural and Cognitive Psychotherapy, 36*(3), 313-332. doi:10.1017/S1352465808004232

Reed, P., Lowe, C., & Everett, R. (2011). Perceptual learning and perceptual search are altered in male university students with higher autism quotient scores. *Personality and Individual Differences, 51*(6), 732-736. doi:10.1016/j.paid.2011.06.016

Rhodes, G., Jeffery, L., Taylor, L., & Ewing, L. (2013). Autistic traits are linked to reduced adaptive coding of face identity and selectively poorer face recognition in men but not women. *Neuropsychologia, 51*(13), 2702-2708. doi:10.1016/j.neuropsychologia.2013.08.016

Richler, J. J., Cheung, O. S., & Gauthier, I. (2011). Holistic processing predicts face recognition. *Psychological Science, 22*(4), 464-471. doi:10.1177/0956797611401753

Richler, J. J., & Gauthier, I. (2014). A meta-analysis and review of holistic face processing. *Psychological Bulletin, 140*(5), 1281-1302. doi:10.1037/a0037004

Robinson, J.E. (2008). *Look me in the eyes: My life with Asperger's*. London, UK: Ebery.

Rollins, L., Bertero, E., & Hunter, L. (2019). Facial features and recognition memory: Eye-movement study on the encoding and retrieval of unfamiliar child faces in children and adults. *Infant and Child Development, 28*(5), n/a. doi:10.1002/icd.2148

Romano, J. P., Shaikh, A. M., & Wolf, M. (2008). Control of the false discovery rate under dependence using the bootstrap and subsampling. *Test, 17*(3), 417-442.

Rose, F., Rose, F., Lincoln, A., Lincoln, A., Lai, Z., Lai, Z., . . . Bellugi, U. (2007). Orientation and affective expression effects on face recognition in williams syndrome and autism. *Journal of Autism and Developmental Disorders, 37*(3), 513-522. doi:10.1007/s10803-006-0200-4

Rossion, B., Delvenne, J. -., Debatisse, D., Goffaux, V., Bruyer, R., Crommelinck, M., & Guérit, J. -. (1999). Spatio-temporal localization of the face inversion effect: An event-related potentials study. *Biological Psychology, 50*(3), 173-189. doi:10.1016/S0301-0511(99)00013-7

Rossion, B., Gauthier, I., Tarr, M., Despland, P., Bruyer, R., Linotte, S., & Crommelinck, M. (2000). The N170 occipito-temporal component is delayed and enhanced to inverted faces but not to inverted objects: An electrophysiological account of face-specific processes in the human brain. *NeuroReport, 11*(1), 69-72. doi:10.1097/00001756-200001170-00014

Rossion, B. (2009). Distinguishing the cause and consequence of face inversion: The perceptual field hypothesis. *Acta Psychologica, 132*(3), 300-312. doi:10.1016/j.actpsy.2009.08.002

Rossion, B., Dricot, L., Devolder, A., Bodard, J., Commelinck, M., de Gelder, B., & Zoontjes, R. (2000b). Hemispheric asymmetries for whole-based and part-based face processing in the human fusiform gyrus. *Journal of Cognitive Neuroscience, 12*(5), 793-802.

Rossion, B., & Gauthier, I. (2002). How does the brain process upright and inverted faces? *Behavioral and Cognitive Neuroscience Reviews, 1*(1), 63-75. doi:10.1177/1534582302001001004

Rossion, B., & Jacques, C. (2011). The N170: Understanding the time course of face perception in the human brain. In E. S. Kappenman, & S. J. Luck (Eds.), *The oxford handbook of event-related potential components* (pp. 115-141) Oxford Uiversity Press.

Rossion, B., Joyce, C. A., Cottrell, G. W., & Tarr, M. J. (2003). Early lateralization and orientation tuning for face, word, and object processing in the visual cortex. *NeuroImage, 20*(3), 1609-1624. doi:10.1016/j.neuroimage.2003.07.010

Rousselet, G. A., Ince, R. A. A., van Rijsbergen, N. J., & Schyns, P. G. (2014). Eye coding mechanisms in early human face event-related potentials. *Journal of Vision, 14*(13), 7. doi:10.1167/14.13.7

Royer, J., Blais, C., Charbonneau, I., Déry, K., Tardif, J., Duchaine, B., . . . Fiset, D. (2018). Greater reliance on the eye region predicts better face recognition ability. *Cognition, 181*, 12-20. doi:10.1016/j.cognition.2018.08.004

Russell, R., Duchaine, B., & Nakayama, K. (2009). Super-recognizers: People with extraordinary face recognition ability. *Psychonomic Bulletin & Review, 16*(2), 252-257. doi:10.3758/PBR.16.2.252

Ruzich, E., Allison, C., Smith, P., Watson, P., Auyeung, B., Ring, H., & Baron-Cohen, S. (2015). Measuring autistic traits in the general population: A systematic review of the autism-spectrum quotient (AQ) in a nonclinical population sample of 6,900 typical adult males and females. *Molecular Autism, 6*(1), 2. doi:10.1186/2040-2392-6-2

Sadr, J., Jarudi, I., & Sinha, P. (2003). The role of eyebrows in face recognition. *Perception, 32*(3), 285-293. doi:10.1068/p5027

Schauder, K. B., Park, W. J., Tsank, Y., Eckstein, M. P., Tadin, D., & Bennetto, L. (2019). Initial eye gaze to faces and its functional consequence on face identification abilities in autism spectrum disorder. *Journal of Neurodevelopmental Disorders, 11*(1), 1-42. doi:10.1186/s11689-019-9303-z

Scherf, K. S., Elbich, D., Minshew, N., & Behrmann, M. (2015). Individual differences in symptom severity and behavior predict neural activation during face processing in adolescents with autism. *NeuroImage. Clinical, 7*(C), 53-67. doi:10.1016/j.nicl.2014.11.003

Scherf, K. S., Behrmann, M., Minshew, N., & Luna, B. (2008). Atypical development of face and greeble recognition in autism. *Journal of Child Psychology and Psychiatry, 49*(8), 838-847. doi:10.1111/j.1469-7610.2008.01903.x

Schuck, R., Flores, R., & Fung, L. (2019). Brief report: Sex/gender differences in symptomology and camouflaging in adults with autism spectrum disorder. *Journal of Autism and Developmental Disorders, 49*(6), 2597-2604. doi:10.1007/s10803-019-03998-y

Schyns, P. G., Bonnar, L., & Gosselin, F. (2002). Show me the features! understanding recognition from the use of visual information. *Psychological Science, 13*(5), 402-409. doi:10.1111/1467-9280.00472

Sekiguchi, T. (2011). Individual differences in face memory and eye fixation patterns during face learning. *Acta Psychologica, 137*(1), 1-9. doi:10.1016/j.actpsy.2011.01.014

Sekuler, A. B., Gaspar, C. M., Gold, J. M., & Bennett, P. J. (2004). Inversion leads to quantitative, not qualitative, changes in face processing. *Current Biology, 14*(5), 391-396. doi:10.1016/j.cub.2004.02.028

Senju, A., & Johnson, M. A. (2009). Atypical eye contact in autism: Models, mechanisms, and development. *Neuroscience Biobehavioral Reviews, 33*(8), 1204-1214.

Shalom, D.B. (2003). Memory in autism: Review and synthesis. *Cortex, 39*(4-5). 1129-1138. doi : 10.1016/s0070-9452(08)70881-5

Shepherd, J., Davies, G., & Ellis, H. (1981). Studies of cue saliency. In G. Davies, H. Ellis & J. Shepherd (Eds.), *Perceiving and remembering faces* (pp. 105-131). London, UK: Academic Press.

Silberman, S. (2017). Beyond "Deficit-based" thinking in autism research: Comment on "Implications of the idea of neurodiversity for understanding the origins of developmental disorders" by nobuo masataka. *Physics of Life Reviews, 20*, 119-121. doi:10.1016/j.plrev.2017.01.022

Snow, J., Ingeholm, J. E., Levy, I. F., Caravella, R. A., Case, L. K., Wallace, G. L., & Martin, A. (2011). Impaired visual scanning and memory for faces in high-functioning autism spectrum disorders: It's not just the eyes. *Journal of the International Neuropsychological Society, 17*(6), 1021-1029. doi:10.1017/S1355617711000981

Sormaz, M., Andrews, T. J., & Young, A. W. (2013). Contrast negation and the importance of the eye region for holistic representations of facial identity. *Journal of Experimental Psychology. Human Perception and Performance, 39*(6), 1667-1677. doi:10.1037/a0032449

Spezio, M. L., Adolphs, R., Hurley, R. S. E., & Piven, J. (2006). Abnormal use of facial information in high-functioning autism. *Journal of Autism and Developmental Disorders, 37*(5), 929-939. doi:10.1007/s10803-006-0232-9

Sterling, L., Dawson, G., Webb, S., Murias, M., Munson, J., Panagiotides, H., & Aylward, E. (2008). The role of face familiarity in eye tracking of faces by individuals with autism spectrum disorders. *Journal of Autism and Developmental Disorders, 38*(9), 1666-1675. doi:10.1007/s10803-008-0550-1

Stevenson, J. L., & Hart, K. R. (2017). Psychometric properties of the autism-spectrum quotient for assessing low and high levels of autistic traits in college students. *Journal of Autism and Developmental Disorders, 47*(6), 1838-1853. doi:10.1007/s10803-017-3109-1

Sucksmith, E., Allison, C., Baron-Cohen, S., Chakrabarti, B., & Hoekstra, R. A. (2012). Empathy and emotion recognition in people with autism, first-degree relatives, and controls. *Neuropsychologia, 51*(1), 98-105. doi:10.1016/j.neuropsychologia.2012.11.013

Sucksmith, E., Roth, I., & Hoekstra, R. (2011). Autistic traits below the clinical threshold: Re-examining the broader autism phenotype in the 21st century. *Neuropsychology Review, 21*(4), 360-389. doi:10.1007/s11065-011-9183-9

Tanaka, J. W., & Curran, T. (2001). A neural basis for expert object recognition. *Psychological Science, 12*(1), 43-47. doi:10.1111/1467-9280.00308

Tanaka, J. W., & Farah, M. J. (1993). Parts and wholes in face recognition. *The Quarterly Journal of Experimental Psychology Section A, 46*(2), 225-245. doi:10.1080/14640749308401045

Tanaka, J. W., & Simonyi, D. (2016). The "parts and wholes" of face recognition: A review of the literature. *The Quarterly Journal of Experimental Psychology: QJEP Classics Revisited, 69*(10), 1876-1889. doi:10.1080/17470218.2016.1146780

Tanaka, J. W., & Sung, A. (2016). The “Eye avoidance” hypothesis of autism face processing. *Journal of Autism and Developmental Disorders, 46*(5), 1538-1552. doi:10.1007/s10803-013-1976-7

Tanaka, J., & Sengco, J. (1997). Features and their configuration in face recognition. *Memory & Cognition, 25*(5), 583-592. doi:10.3758/BF03211301

Tardif, J., Morin Duchesne, X., Cohan, S., Royer, J., Blais, C., Fiset, D., . . . Gosselin, F. (2019). Use of face information varies systematically from developmental prosopagnosics to super-recognizers. *Psychological Science, 30*(2), 300-308. doi:10.1177/0956797618811338

Tavares, P. P., Mouga, S. S., Oliveira, G. G., & Castelo-Branco, M. (2016). Preserved face inversion effects in adults with autism spectrum disorder: An event-related potentials study. *Clinical Neuroscience, 27*(8), 587-592. doi:10.1097/WNR.0000000000000576

Taylor, M., Edmonds, G., McCarthy, G., & Allison, T. (2001). Eyes first! eye processing develops before face processing in children. *Neuroreport, 12*(8), 1671-1676. doi:10.1097/00001756-200106130-00031

Trepagnier, C., Sebrechts, M. M., & Peterson, R. (2002). Atypical face gaze in autism. *Cyberpsychology & Behavior, 5*(3), 213-217. doi:10.1089/109493102760147204

Tsank, Y., & Eckstein, M. P. (2017). Domain specificity of oculomotor learning after changes in sensory processing. *The Journal of Neuroscience, 37*(47), 11469-11484. doi:10.1523/JNEUROSCI.1208-17.2017

Turano, M. T., Marzi, T., & Viggiano, M. P. (2016). Individual differences in face processing captured by ERPs. *International Journal of Psychophysiology, 101*, 1-8. doi:10.1016/j.ijpsycho.2015.12.009

Valentine, T. (1988). Upside-down faces: A review of the effect of inversion upon face recognition. *The British Journal of Psychology, 79*(4), 471-491. doi:10.1111/j.2044-8295.1988.tb02747.x

Valla, J. M., Maendel, J. W., Ganzel, B. L., Barsky, A. R., & Belmonte, M. K. (2013). Autistic trait interactions underlie sex-dependent facial recognition abilities in the normal population. *Frontiers in Psychology, 4*, 286. doi:10.3389/fpsyg.2013.00286

van Belle, G., Ramon, M., Lefèvre, R., & Rossion, B. (2010). Fixation patterns during recognition of personally familiar and unfamiliar faces. *Frontiers in Psychology, 1*(20), 1-8. doi : 10.3389/fpsyg.2010.00020

Vasilopoulos, T., Morey, T. E., Dhatariya, K., & Rice, M. J. (2015). *Limitations of significance testing in clinical research: A review of multiple comparisons* *corrections and effect size calculations with correlated measures* doi:10.1213/ANE.0000000000001107

Vettori, S., Jacques, C., Boets, B., & Rossion, B. (2019). Can the N170 be used as an electrophysiological biomarker indexing face processing difficulties in autism spectrum disorder? doi:10.1016/j.bpsc.2018.07.015

Vinette, C., Gosselin, F., & Schyns, P. G. (2004). Spatio-temporal dynamics of face recognition in a flash: It's in the eyes. *Cognitive Science, 28*(2), 289-301. doi:10.1016/j.cogsci.2004.01.002

Vogelsang, M., Palmeri, T., & Busey, T. (2017). Holistic processing of fingerprints by expert forensic examiners. *Cognitive Research: Principles and Implications, 2*(1), 1-12. doi:10.1186/s41235-017-0051-x

Walker-Smith, G. J., Gale, A. G., & Findlay, J. M. (1977). Eye movement strategies involved in face perception. *Perception, 6*, 313-326.

Wallace, S., Sebastian, C., Pellicano, E., Parr, J., & Bailey, A. (2010). Face processing abilities in relatives of individuals with ASD. *Autism Research, 3*(6), 345-349. doi:10.1002/aur.161

Wang, Q., Hoi, S. P., Wang, Y., Song, C., Li, T., Lam, C. M., . . . Yi, L. (2019). Out of mind, out of sight? investigating abnormal face scanning in autism spectrum disorder using gaze-contingent paradigm. *Developmental Science, 23*(1), e12856-n/a. doi:10.1111/desc.12856

Wang, R., Li, J., Fang, H., Tian, M., & Liu, J. (2012a). Individual differences in holistic processing predict face recognition ability. *Psychological Science, 23*(2), 169-177. doi:10.1177/0956797611420575

Wang, R., Li, J., Fang, H., Tian, M., & Liu, J. (2012b). Individual differences in holistic processing predict face recognition ability. *Psychological Science, 23*(2), 169-177. doi:10.1177/0956797611420575

Webb, S. J., Jones, E. J. H., Merkle, K., Murias, M., Greenson, J., Richards, T., . . . Dawson, G. (2010). Response to familiar faces, newly familiar faces, and novel faces as assessed by ERPs is intact in adults with autism spectrum disorders. *International Journal of Psychophysiology, 77*(2), 106-117. doi:10.1016/j.ijpsycho.2010.04.011

Webb, S. J., Merkle, K., Murias, M., Richards, T., Aylward, E., & Dawson, G. (2012). ERP responses differentiate inverted but not upright face processing in adults with ASD. *Social Cognitive and Affective Neuroscience, 7*(5), 578-587. doi:10.1093/scan/nsp002

Wechsler, D. (2011). *Weschler Abbreviated Scale of Intelligence – Second Edition (WASI-II).* San Antonio, TX, USA: NCS Pearson.

Weigelt, S., Koldewyn, K., & Kanwisher, N. (2012). Face identity recognition in autism spectrum disorders: A review of behavioral studies. *Neuroscience and Biobehavioral Reviews, 36*(3), 1060-1084. doi:10.1016/j.neubiorev.2011.12.008

Weigelt, S., Koldewyn, K., & Kanwisher, N. (2013). Face recognition deficits in autism spectrum disorders are both domain specific and process specific. *PloS One, 8*(9), e74541. doi:10.1371/journal.pone.0074541

Westfall, P. H. (2011). On using the bootstrap for multiple comparisons. *Journal of Biopharmaceutical Statistics: Special Issue on Computer-Intensive Methods with Emphasis on Bootstrap and Medical Research Applications, 21*(6), 1187-1205. doi:10.1080/10543406.2011.607751

Willenbockel, V., Sadr, J., Fiset, D., Horne, G. O., Gosselin, F., & Tanaka, J. W. (2010). Controlling low-level image properties: The SHINE toolbox. *Behavior Research Methods, 42*(3), 671-684. doi:10.3758/brm.42.3.671

Williams, D. L., Goldstein, G., & Minshew, N. J. (2005). Impaired memory for faces and social scenes in autism: Clinical implications of memory dysfunction. *Archives of Clinical Neuropsychology, 20*(1), 1-15. doi:10.1016/j.acn.2002.08.001

Wilmer, J. B., Germine, L., Chabris, C. F., Chatterjee, G., Williams, M., Loken, E., . . . Kanwisher, N. G. (2010). Human face recognition ability is specific and highly heritable. *Proceedings of the National Academy of Sciences of the United States of America, 107*(11), 5238-5241. doi:10.1073/pnas.0913053107

Wolff, J. J., Gu, H., Gerig, G., Elison, J. T., Styner, M., Gouttard, S., . . . Piven, J. (2012). Differences in white matter fiber tract development present from 6 to 24 months in infants with autism.*169*, 589-600.

Woodbury-Smith, M. R., Robinson, J., Wheelwright, S., & Baron-Cohen, S. (2005). Screening adults for asperger syndrome using the AQ: A preliminary study of its diagnostic validity in clinical practice. *Journal of Autism and Developmental Disorders, 35*(3), 331-335. doi:10.1007/s10803-005-3300-7

Xu, B., & Tanaka, J. W. (2013). Does face inversion qualitatively change face processing: An eye movement study using a face change detection task. *Journal of Vision, 13*(2), 22. doi:10.1167/13.2.22

Yarbus, A. L. (1967). *Eye movements and vision* Springer Science + Business Media, LLC.

Yi, L., Fan, Y., Quinn, P. C., Feng, C., Huang, D., Li, J., . . . Lee, K. (2013). Abnormality in face scanning by children with autism spectrum disorder is limited to the eye region: Evidence from multi-method analyses of eye tracking data. *Journal of Vision (Charlottesville, Va.), 13*(10), 5. doi:10.1167/13.10.5

Yi, L., Feng, C., Quinn, P. C., Ding, H., Li, J., Liu, Y., & Lee, K. (2014). Do individuals with and without autism spectrum disorder scan faces differently? A new Multi-Method look at an existing controversy. *Autism Research, 7*(1), 72-83. doi:10.1002/aur.1340

Yin, R. K. (1969). Looking at upside down faces. *Journal of Experimental Psychology, 81*(1), 141-145.

Yovel, G. (2016). Neural and cognitive face-selective markers: An integrative review. *Neuropsychologia, 83*, 5-13.

Yovel, G., Wilmer, J. B., & Duchaine, B. (2014). What can individual differences reveal about face processing? *Frontiers in Human Neuroscience, 8*, 562. doi:10.3389/fnhum.2014.00562

Yucel, G. H., Belger, A., Bizzell, J., Parlier, M., Adolphs, R., & Piven, J. (2015). Abnormal neural activation to faces in the parents of children with autism. *Cerebral Cortex (New York, N.Y. 1991), 25*(12), 4653-4666. doi:10.1093/cercor/bhu147

Zener, D. (2019). Journey to diagnosis for women with autism. *Advances in Autism, 5*(1), 2-13. doi:10.1108/AIA-10-2018-0041

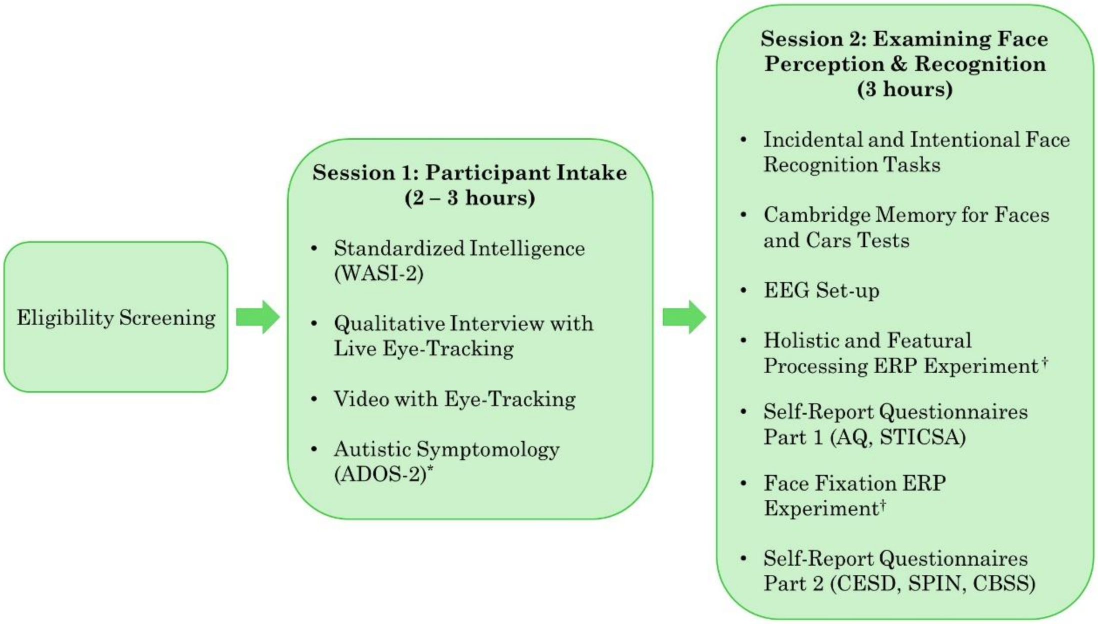
Zheng, X., Mondloch, C. J., Nishimura, M., Vida, M. D., & Segalowitz, S. J. (2011). Telling one face from another: Electrocortical correlates of facial characteristics among individual female faces. *Neuropsychologia, 49*(12), 3254-3264. doi:10.1016/j.neuropsychologia.2011.07.030

Zwaigenbaum, L., Bryson, S., Rogers, T., Roberts, W., Brian, J., & Szatmari, P. (2005). Behavioral manifestations of autism in the first year of life. *International Journal of Developmental Neuroscience, 23*(2-3), 143-152. doi:10.1016/j.ijdevneu.2004.05.001

Appendices

Appendix A: Neurocognitive Assessment in Adults with and without ASD

A multi-dimensional neurocognitive assessment was conducted between December 2017 and December 2019 with autistic and neurotypical adults using a combination of qualitative and quantitative techniques in static, dynamic, and live contexts (**Figure A1**). This experimental protocol was reviewed, and received clearance through, a University of Waterloo Human Research Ethics Committee. This dissertation focuses on the *Incidental and Intentional Face Recognition Tasks* (Chapter 4), the *Holistic and Featural Processing ERP Experiment* (Chapter 5), and the *Face Fixation ERP Experiment* (Chapter 6) [29].



* Only participants with a previously confirmed or suspected ASD diagnosis completed this set of activities.
† Order of tasks counterbalanced across participants.

Figure 7. Procedural flowchart for the neurocognitive assessment conducted in adults with and without ASD.

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[29] For additional information regarding the tasks not included in this dissertation, the reader is referred to our conference abstract (Qualitative Interview: Parkington & Itier, 2019a) and/or to personally contact KBP.

Participant Recruitment and Screening

Due to the complexity of the experimental protocol used over the course of the neurocognitive assessment (i.e., multiple 3+ hour sessions, face-to-face qualitative interview, eye tracking protocols, gaze-contingent EEG), clinical recruitment focused on adults with a confirmed or suspected Level 1 or Level 2 autism spectrum disorder diagnosis (i.e., no co-existing intellectual disorder; APA, 2013)[30]. Neurotypical adults with no first-degree relatives with an ASD were targeted to serve as age-, gender-, ethnicity-, and IQ-matched controls once the demographic profiles of autistic participants were known.

Participants were recruited from the Kitchener-Waterloo, Greater Toronto Area, Niagara Falls, and London regions in Southeastern Ontario, Canada. Recruitment posters were distributed throughout these communities in common-place areas accessible to university students and faculty (e.g., accessibility services, campus poster boards) as well as the general public (e.g., libraries, coffee shops, community bulletin boards). Website and newsletter announcements were also distributed by five major local and national autism networks, seven campus-based services, as well as family members and practitioners working within the autism community. KBP engaged in a public talk with autistic adults (A-Team Waterloo Region, November 2018) and provided one-on-one meetings or tours of the lab space,

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[30] Due to the high co-occurrence of mental health conditions in autistic adults (Buck et al., 2014b; Nahar et al., 2019; Zener, 2019) psychiatric profiles were not used as an exclusion criterion for the ASD group. See below for an overview of the mental health composition and medication use of autistic adults in the present assessment.

to answer any preliminary questions and reduce anxieties pertaining to the experimental protocol, as needed.

Upon expressed interest, potential participants completed an eligibility screening questionnaire with KBP (see **Appendix B**). Most screenings were completed over the telephone, with a handful completed in person or via email to accommodate participants' needs. Three autistic adults (1 female, 2 male) were not eligible for the present investigation due to a co-existing intellectual disability (1) or neurological disorder[31] (2). Furthermore, two participants (1 autistic male, 1 neurotypical female) did not return for the second experimental session and thus are not included in any of the present reports.

Participant Demographics

A total of 24 autistic adults[32] aged 18 to 52 years and 22 age-, gender-, ethnicity-, and IQ-matched neurotypical controls[33] completed the current neurocognitive assessment in exchange for cash payment ($10/hour) and, when applicable, course credit. **Table A1** presents the demographic profiles of all participants; **Table A2** summarizes co-occurring psychiatric disorders and medication use in the adults with an ASD. Characterizations of experiment-specific demographics are described in the respective *Method* sections.

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[31] Fetal alcohol spectrum disorder (female) and cerebral palsy (male).

[32] Twenty participants reported having a previously confirmed ASD diagnosis (by a psychologist or physician) at least one month before the eligibility screening and four participants presented with a suspected/self-identifying ASD diagnosis. All autistic symptom profiles met or exceeded the ADOS-2 diagnostic threshold; therefore, the present reports henceforth do not distinguish between autistic adults with confirmed or suspected diagnoses.

[33] Data for one additional neurotypical participant was collected but subsequently excluded from analyses due to non-compliance with task demands.

Table A1. Demographic profiles for all adults who completed the two-session neurocognitive assessment. Group matching was confirmed with independent sample *t*-tests; no differences were observed at the group-level.

	Autistic Adults (n = 24)	**Neurotypical Adults (n = 22)**	***p***
Gender	12 female, 9 male, 2 non-binary, 1 transgender	11 female, 9 male, 2 non-binary	-
Age	29.54 (9.70) 18 – 52 years	27.55 (10.06) 19 – 50 years	.50
Ethnicity	22 White, 2 Asian	20 White, 2 Asian	-
Full Scale IQ	115.88 (15.57) 91 – 160	114.85 (8.80) 101 – 128	.80
Verbal IQ	117.04 (13.92) 100 – 160	114.25 (8.82) 95 – 134	.44
Performance IQ	111.46 (17.10) 83 – 154	111.45 (10.68) 94 – 128	1.00

Contrary to the current state of autistic face recognition research, the present sample includes a substantial (50%) proportion of autistic women and is one of the first to recognize non-binary and transgender identities amongst autistic adults (accounting for 13% of the present sample). As such, the findings derived from this neurocognitive assessment not only have significant implications for the general autism community at large but will also provide invaluable insights into the female autism phenotype (Allely, 2019; Hull, Petrides, & Mandy, 2020; Ketelaars et al., 2017; Ratto et al., 2018), an under-represented and vital part of the autistic community.

Co-occurring Psychiatric Conditions and Medication Use in Autistic Adults

Consistent with psychiatric profiles of adults with an ASD throughout clinical practice and the literature (Buck et al., 2014; Cage, Di Monaco, & Newell, 2018; Davis et al., 2011; Hudson, Hall, & Harkness, 2019; Nahar, Thippeswamy, Shanker Reddy, Kishore, & Chaturvedi, 2019; Rai et al., 2018; Zener, 2019), most participants in this sample reported at least one co-occurring psychiatric condition (19) and were taking at least one medication[34] (13) to aid with autistic and/or other mental health symptoms.

Table A2. Co-occurring psychiatric disorders (*Top Panel*) and medication use (*Bottom Panel*) for the autistic adults who participated in the two-session neurocognitive assessment (Chapter 3).

Co-Occurring Psychiatric Disorder(s)	**Frequency of Occurrence**
No Co-Occurring Psychiatric Diagnosis	5
Anxiety Disorder	(15)
Generalized Anxiety Disorder	8
Social Anxiety Disorder	2
Obsessive-Compulsive Disorder (OCD)	2
Post-Traumatic Stress Disorder (PTSD)	1
Panic Disorder	2
Mood Disorder	(12)*
Major Depressive Disorder	10
Dysthymia	1
Bipolar Affective Disorder	1
Neurodevelopmental Disorder	(8)
Learning Disability	3
Attention-Deficit Hyperactivity Disorder (ADHD)	5
Borderline Personality Disorder	2
Anorexia Nervosa	1

Medication Use	**Frequency of Occurrence**
No Medications	9
Anti-depressant (e.g., Cipralex, Wellbutrin)	10**
Anti-psychotic (e.g., Abilify, Risperidone)	2
Mood Stabilizer (Lithium)	1
Anti-Convulsant (e.g., Gabapentine, Carbamazepine)	3
ADHD Medication (e.g., Concerta, Strattera)	4
Medical Cannabis	2

* All autistic adults with a co-existing mood disorder also reported having an anxiety disorder (9) or ADHD (3) diagnosis.

** Two adults were also taking a second anti-depressant (Trazadone) for sleeping difficulties.

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[34] Cannabis was considered a medication for psychiatric purposes if the individual specified that it was prescribed by a physician or psychiatrist for anxiety, depression, sleep, or autistic symptoms. The two participants who regularly consumed medical cannabis were not under the influence for at least 5 hours prior to each experimental session. Recreational cannabis use was not recorded.

Of these individuals, seven autistic adults only reported one co-occurring psychiatric disorder (OCD, social anxiety, general anxiety, attention-deficit hyperactivity disorder; ADHD, or learning disability), whereas nine autistic adults reported two co-existing conditions, and three individuals reported three or more psychiatric disorders. Co-occurring neurodevelopmental disorders, Generalized Anxiety Disorder, and Major Depressive Disorder were amongst the most prevalent conditions reported. All autistic adults reporting a co-existing mood disorder also reported at least one other comorbid anxiety (9) or ADHD (3) diagnosis.

Five autistic participants reporting at least one co-existing psychiatric disorder were not taking any medications at the time of testing. Alternatively, nine autistic adults reported regular consumption of one medication (6 anti-depressants, 2 medical cannabis, 1 norepinephrine reuptake inhibitor) and six reported daily consumption of two or more[35] medications.

Session 1: Participant Intake

Informed written consent was obtained from all participants at the beginning of Session 1, after which participants completed a short demographics questionnaire. The researcher (KBP) then overviewed the methodological techniques to be implemented across the experimental sessions and familiarized participants with the equipment (e.g., eye-tracker, EEG system) and general set-up. The Miles test (Miles, 1930) was used to determine each participant's dominant eye for the eye-tracker and

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[35] One woman reported five daily medications for various psychiatric symptoms in addition to an "as needed" prescription for Ativan.

participants were fitted with an appropriately sized EEG ActiCap (Brain Vision) for Session 2.

The Weschler Abbreviated Scale of Intelligence – Second Edition (WASI-2; Weschler, 2011) was administered to adults with and without an ASD to quantify standardized intelligence for group matching and to screen for intellectual disability (IQ ≥ 70) in autistic participants. All four subtests assessing verbal (vocabulary and similarities) and spatial (block design and Raven's progressive matrices) abilities were administered based on standardized guidelines and standardized scores were calculated for Performance IQ, Verbal IQ, and Total IQ (Weschler, 2011). Average to above-average standardized scores were confirmed for all participants (see Table A1), and independent *t*-tests revealed that groups were appropriately matched on metrics of intellectual functioning.

Thereafter, the beliefs and experiences of adults with and without ASD in regards to face recognition, eye contact, and social interaction were also investigated alongside eye movements during face-to-face vs. video situations in the *Qualitative Interview and Video with Eye-Tracking Experiment*[36]. Adults with a suspected or previously diagnosed ASD completed the ADOS-2 at the end of Session 1 (see Chapter 3 for details); neurotypical adults did not complete this behavioural assessment. Overall, Session 1 took approximately two (neurotypical adults) to three (autistic adults) hours to complete, with time accommodations provided as necessary.

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[36] Due to an equipment malfunction with the live eye-tracking equipment, one autistic man completed the Incidental and Intentional Face Recognition Tasks in lieu of the Qualitative Interview and Video Eye-Tracking during Session 1.

Session 2: Evaluations of Face Perception and Recognition

Following the provision of informed written consent for Session 2 activities, participants completed the *Intentional and Intentional Face Recognition Tasks* using the same protocol as outlined in Chapter 2. Standardized assessments of face (Cambridge Face Memory Test, CFMT; Duchaine & Nakayama, 2006) and car (Cambridge Car Memory Test, CCMT; Dennett et al., 2011) recognition were also collected but are not elaborated on here.

Approximately halfway through the second session[37], participants were fitted with an appropriately fitting ActiCap with 64 embedded electrodes. Participants them completed the *Holistic and Featural Processing ERP Experiment* and *Face Fixation ERP Experiment,* in a counterbalanced order. Self-report measures quantifying general anxiety (STICSA; Ree, French, MacLeod, & Locke, 2008), social anxiety (SPIN; Connor et al., 2000), depression (CESD; Radloff, 1977), autistic traits (AQ; Baron-Cohen et al., 2001), as well as shyness and sociability (Cheek & Buss, 1981). Overall, Session 2 took approximately three hours to complete.

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[37] Due to technical difficulties during Session 2, one autistic man returned for a third experimental session to complete the EEG set-up and experiments. One autistic woman presented with severe touch sensitivities and was not able to tolerate the sensations of the syringe and gel on her scalp. Therefore, EEG set-up was discontinued for this participant.

Appendix B: Eligibility Screening Questionnaire

GENERAL ELIGIBILITY QUESTIONS:

1. Have you ever been diagnosed with an Autism Spectrum Disorder? YES / NO
   If yes: When did you receive that diagnosis? _______

   If before 2013: What diagnosis were you given?
   ASD / AUTISTIC DISORDER / ASPERGER'S DISORDER / PERVASIVE DEVELOPMENTAL DISORDER NOT OTHERWISE SPECIFIED

   If yes: Who have you that diagnosis (e.g,. doctor, psychologist)?

   ____

   If yes: Have you ever participated in any intervention programs or social skill workshops?

   If yes: What types of programs and/or workshops have you participated in? (e.g., applied behavioural analysis, intensive behavioural intervention, speech-language therapy, social-emotional workshops, etc.)

2. How old are you? ______ (eligibility criteria: 18+ years)

3. How long have you lived in Canada and/or the USA? _______ (eligibility criteria: 10+ years)

4. What is your primary ethnicity/race (e.g., Caucasian/White, Middle Eastern, Asian, etc.)? ______________________________

5. In which city/town are you currently living? (eligibility criteria: within recruitment region)
   If not from K-W but within recruitment area: Are you able to travel to the University of Waterloo? YES / NO (eligibility criteria: yes)

6. Do you require wheelchair-accessible facilities? YES / NO

7. Do you have normal or corrected-to-normal (glasses or contact lenses) vision? YES / NO (eligibility criteria: yes)

8. Have you ever experienced a coma, accident or head injury (e.g., concussion)? YES / NO (eligibility criteria: no)

9. Have you ever undergone surgery or had a medical condition that you feel has negatively affected your mental functioning? YES / NO (eligibility criteria: no)

10. Do you have any neurological disorders or brain lesions? YES / NO (eligibility criteria: no)

11. [*for ASD:* Aside from your diagnosis of Autism Spectrum Disorder,] have you ever been diagnosed with any [other] psychological or psychiatric disorders? (e.g, learning disorder/dyslexia, major depressive disorder, general anxiety disorder, social anxiety disorder, obsessive compulsive disorder, ADHD, bipolar disorder, schizophrenia, personality disorder, etc.)? YES / NO (control eligibility criteria: no)

12. Have you ever been diagnosed with an intellectual disability (or mental retardation)? YES / NO (eligibility criteria: no)

13. Have you ever been diagnosed with a genetic disorder (e.g,. Down syndrome, Fragile X syndrome, etc.)? YES / NO (eligibility criteria: no)

14. Are you taking any medications containing cortisone? YES / NO (eligibility criteria: no)

15. Are you taking any medications that can make you drowsy or sleepy? YES / NO

    If yes: Is it possible for you to refrain from taking the medication on the days of the study? YES / NO (eligibility criteria: yes)

16. I need to ask about drug and/or alcohol use, but you don't need to tell me which of these applies to you. I just need to know if you use either of them. Do you use drugs (e.g,. cocaine, heroin, marijuana) or alcohol on a <u>daily basis</u>? YES / NO (eligibility criteria: no[38])

17. *For controls only:* Has anyone in your immediate family (mother, father, brother, sister, son, daughter) ever been diagnosed with an ASD? YES / NO (eligibility criteria: no)

18. Do you have any allergies, sensitivities, or had previous reactions to cleaning or sanitizing agents (e.g,. Lysol wipes)? YES / NO (eligibility criteria: no)

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[38] Daily use of medical cannabis was permitted for autistic adults.

EEG-ELIGIBILITY QUESTIONS:

19. Do you have any allergies, sensitivities, or had previous reactions to gels, adhesives, medical tape, rubbing alcohol, peroxide, or other sanitizing agents (e.g,. Metricide)? YES / NO (eligibility criteria: no)

20. Do you have a personal or family history of epilepsy or seizures? In particular, a sensitivity to flashing light? YES / NO (eligibility criteria: no)

21. Do you have any sensory sensitivities (e.g,. touch, sight, sound, smell, etc.) that we should be aware of? YES / NO

    ____

    If touch sensitivities: The study I am currently running includes activities with EEG. This involves placing an EEG cap with electrodes on your head, and filling each of the electrodes with a water-based gel. In order for the gel to reach your scalp so we can pick up a good EEG brain wave signal, we use blunt-tipped syringes and have to wiggle the syringes on the scalp to move the hair out of the way. This process does not hurt and just feels like a weird head massage. If you were to participate in this study, you would have a chance to see what this feels like before the actual EEG part of the study. Given that you are sensitive to touch, do you think this is something you would be comfortable with? YES / NO (eligibility criteria: yes)

    If light sensitivities: Can you tell me more about your light sensitivities?

    ____

    ____

Appendix C: Exploring the Impact of Autistic Cognitive and Behavioural Traits in Face Fixation Patterns & Recognition Accuracy

Table C1. Descriptive and normality metrics for Autism-Spectrum Quotient (AQ) total and subscale scores ($N = 111$).

	Mean (*SD*)	**Range**	**Skewness**	**Kurtosis**
AQ (Total Score)	108.51 (14.64)	77 – 148	-0.05	-0.067
Subscales				
Attention to Detail	24.94 (4.45)	13 – 36	0.10	-0.38
Attention Switching	24.89 (3.55)	15 – 33	-0.27	0.26
Social Skill	20.09 (5.45)	11 – 35	0.47	-0.33
Communication	19.76 (4.70)	10 – 37	0.37	0.65
Imagination	18.93 (3.79)	12 – 30	0.61	0.45

Further examination of the cognitive and behavioural components of autistic traits revealed that the patterns outlined in Chapter 2 were largely driven by the Imagination subscale (for both incidental and intentional tasks), although Communication scores also played a minor role in incidental face recognition.

Fixation Patterns

Lower Imagination scores (i.e., better pretending and imagination skills) were associated with longer looking times and more fixations towards the left eye, as well as shorter (and fewer) fixations to the nose (**Table C2**). A marginal relationship was also identified for time spent looking at non-core features of the face and imagination traits during intentional encoding, although this pattern was not present for fixation counts. Communication scores also demonstrated a borderline association with nose looking times and fixation counts during incidental encoding but (pragmatic) communication skills were not related to left eye fixation patterns.

Table C2. Pearson correlations with bootstrapped 95% confidence intervals (5000 iterations; N = 111) examining the association between AQ scores and area-normalized looking time and fixation frequency to facial features. For the purposes of mediation, only face fixation measures that produced significant ($p \leq .05$) associations with incidental (*Top Panel*) and intentional (*Bottom Panel*) recognition accuracy were evaluated here.

Incidental Encoding

	Left Eye		**Nose**		**Nasion**
	Looking Time	**Fixation Count**	**Looking Time**	**Fixation Count**	**Fixation Count**
AQ (Total Score)	-.10	-.12	.15	.13	-.002
Subscales					
Attention to Detail	-.02	-.02	.003	.01	.11
Attention Switching	.06	.04	-.04	-.06	.02
Social Skill	-.10	-.13	.12	.11	-.03
Communication	-.04	-.06	.19	.17	-.04
Imagination	-.23*	-.21*	.21*	.20	-.07

Intentional Encoding

	Left Eye	**Non-Core Features**	
	Looking Time	**Looking Time**	**Fixation Count**
AQ (Total Score)	-.09	.09	.08
Subscales			
Attention to Detail	-.06	.07	.08
Attention Switching	.04	.05	.05
Social Skill	-.04	-.02	-.03
Communication	-.11	.05	.05
Imagination	-.15	.16	.14

* $p < .05$; ** $p < .01$

Incidental and Intentional Recognition Accuracy

Here, the relationship between self-reported autistic traits and *intentional recognition* reported in the main text, is further clarified to be a reflection of individual differences in *imagination* traits (**Table C3**). *Intentional d'* scores were strongly associated with the Imagination AQ subscale and weaker trends were also observed for Communication and Imagination traits during *incidental recognition*, although these latter patterns did not reach significance with 95% confidence.

Table C3. Pearson correlations with bootstrapped 95% confidence intervals (5000 iterations) examining the relationship between AQ scores and incidental/intentional face recognition accuracy (*d'*) in neurotypical adults (*N* = 111).

	Incidental d'			***Intentional d'***		
	r	***p***	**95% CI**	***r***	***p***	**95% CI**
AQ (Total Score)	-.16	.09	-0.34 – 0.01	-.21*	.03*	-0.39 – -0.01*
Subscales						
Attention to Detail	-.09	.38	-0.24 – 0.08	-.05	.61	-0.23 – 0.14
Attention Switching	-.01	.91	-0.22 – 0.19	-.14	.14	-0.32 – 0.04
Social Skill	-.08	.43	-0.28 – 0.12	-.15	.13	-0.32 – 0.05
Communication	-.18	.06	-0.37 – -0.003	-.07	.47	-0.27 – 0.12
Imagination	-.17	.08	-0.36 – -0.004	-.29**	.002**	-0.48 – -0.12**

* $p < .05$; ** $p < .01$

The Mediating Role of Imaginative Autistic Traits in Face Encoding Fixation Patterns and Recognition Accuracy

Here, the potential mediating effect of imagination traits on the relationships between featural gaze patterns and face recognition accuracy was evaluated, focusing on the significant relationships outlined in Chapter 2. Each model independently assessed the direct impact of fixation patterns to the feature of interest (left eye, nasion, nose, or non-core features) and face recognition accuracy (*d'*; original unmediated models) and when autistic Imagination scores were added into the basic regression models. Bootstrapped 95% confidence intervals (with 5000 samples) were applied to each model using the PROCESS package (Hayes, 2018).

The relationship between area-normalized looking time to non-core features and intentional face recognition accuracy was significantly mediated by Imagination traits ($t(107) = -2.95$, $p = .004$, $CI_{95\%} = [-0.015 - -0.01]$; **Figure C1**). Alternatively, gaze fixation patterns to the left eye, nasion, and nose were not explained by sub-clinical differences in Imagination.

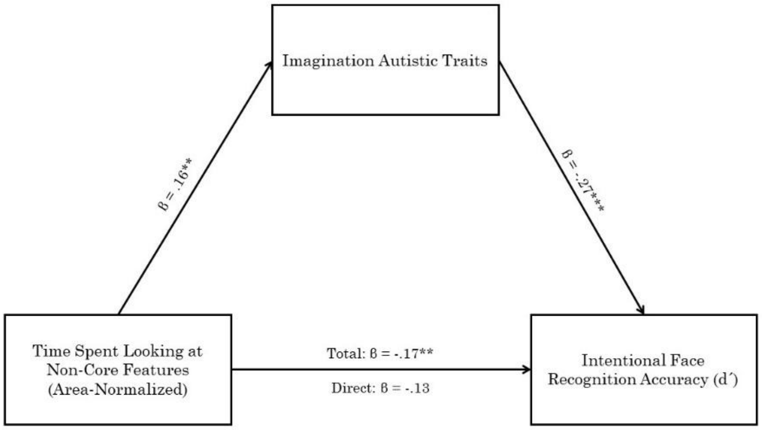

Figure C1. Mediation model illustrating the indirect impact of Imagination traits on the relationship between area-normalized looking time to non-core features during face encoding and intentional recognition accuracy. Path coefficients are standardized regression estimates (*β*). *** $p < .01$, ** $p < .05$.

Discussion

Although Total AQ scores did not impact fixation patterns to faces during encoding (Chapter 2), sub-scale analyses reveal a weak mediation of fixation to non-core features and recognition accuracy via Imagination (perspective taking) traits (Figure C1). These findings contrast with a recent study indicating recognition accuracy relates to attention to detail scores (Davis et al., 2017). It is important to consider, however, that in that study the researchers evaluated a composite social construct (averaged across social skill, imagination, and communication scores). Therefore, the potential impacts of individual social constructs (e.g., communication vs. imagination) was overshadowed in this previous case. By investigating each of the AQ subscales individually, the current study adds the body of literature evaluating face recognition mechanisms across the broader autism phenotype, providing refined insight into the individual contributions of autistic imagination tendencies.

Replication and extension are needed to confirm the validity and stability of these visuo-cognitive patterns; however, the current analyses provide promising evidence in support of autistic behavioural tendencies contributing to individual differences in face recognition abilities.

At first glance the influence of imagination may seem counter-intuitive: what does *imagination* have to do with face recognition? However, closer examination of the subscale items reveal that these statements tap into aspects of perspective taking (e.g., “I find it difficult to work out people’s intentions”, and “I find it difficult to imagine what it would be like to be someone else.”; Baron-Cohen et al., 2001). When considered within this framework, the current research suggests that the face, knowing this is where most social cues will be conveyed. Alternatively, adults with weaker perspective taking abilities may not be able to make this connection as easily and may spend more time attending to less informative parts of the face, thereby missing key identity-specific information. The current findings are consistent with research indicating that perspective taking behaviors play a major role in regulating autistic social cognition at the clinical level (Bishop-Fitzpatrick, Mazefsky, Eack, & Minshew, 2017; Dawson & Fernald, 1987; Scherf et al., 2015; Peters & Thompson, 2018) and provide the first demonstration of perspective taking traits partially explaining the relationship between gaze patterns to non-core features and intentional face recognition accuracy at the sub-clinical (AQ) level.

Appendix D: Descriptive and Normality Metrics for Neurotypical Face Fixation Patterns and Recognition Accuracy

Table D1. Descriptive and normality metrics for eye-tracking (area-normalized looking time and fixation counts) and recognition accuracy (d') measures for the *Incidental* ($N = 111$) and *Intentional* ($N = 112$) *Face Recognition Tasks*.

	Area-Normalized Looking Time							
	Incidental Task				***Intentional Task***			
	Mean (*SD*)	**Range**	**Skewness**	**Kurtosis**	**Mean (*SD*)**	**Range**	**Skewness**	**Kurtosis**
Left Eye	7.38 (3.81)	0.13 – 16.37	0.004	-0.68	7.27 (3.60)	0.00 – 14.95	0.20	-0.64
Right Eye	6.09 (3.32)	0.10 – 16.38	0.38	-0.23	6.03 (3.11)	0.32 – 13.96	0.48	0.04
Nasion	9.90 (6.73)	0.19 – 44.46	1.70	5.48	10.66 (6.82)	1.12 – 40.00	1.38	2.70
Nose	5.81 (4.41)	0.26 – 26.31	1.83	4.48	5.60 (4.02)	0.14 – 22.62	1.64	3.40
Mouth	2.91 (2.17)	0.00 – 9.67	0.89	0.34	3.01 (2.18)	0.00 – 10.37	0.91	0.52
Non-Core Features	0.51 (0.39)	0.02 – 2.05	1.83	3.51	0.45 (0.25)†	0.03 – 1.34†	0.99†	1.11†

	Area-Normalized Fixation Counts							
	Incidental Task				***Intentional Task***			
	Mean (*SD*)	**Range**	**Skewness**	**Kurtosis**	**Mean (*SD*)**	**Range**	**Skewness**	**Kurtosis**
Left Eye	8.18 (4.10)	0.19 – 16.42	-0.06	-0.75	8.11 (3.78)	0.00 – 15.85	0.03	-0.77
Right Eye	6.20 (3.25)	0.14 – 14.79	0.32	0.23	6.33 (3.15)	0.48 – 15.35	0.49	0.30
Nasion	12.69 (7.44)	0.42 – 46.70	1.16	2.80	13.33 (7.20)	1.40 – 39.23	0.89	0.90
Nose	6.96 (7.61)	0.38 – 27.30	1.59	3.42	6.68 (4.28)	0.28 – 22.19	1.31	1.94
Mouth	3.40 (2.43)	0.00 – 10.41	0.74	-0.22	3.53 (2.40)	0.00 – 11.26	0.80	0.39
Non-Core Features	0.60 (0.41)	0.04 – 2.23	1.76	3.47	0.58 (0.46)†	0.06 – 1.68†	1.38†	3.20†

	Face Recognition Accuracy							
	Incidental Task				***Intentional Task***			
	Mean (*SD*)	**Range**	**Skewness**	**Kurtosis**	**Mean (*SD*)**	**Range**	**Skewness**	**Kurtosis**
d'	0.73 (0.42)	-0.76 – 1.59	-0.19	0.60	0.75 (0.46)	-0.33 – 2.25	0.36	0.84

† Outlying cases (±2.5 *SD*) removed; N=108

Appendix E: Normality Metrics and Pearson Correlations Evaluating Autistic and Neurotypical Face Fixation Patterns and Recognition Accuracy

Table E1. Normality metrics for eye-tracking (area-normalized looking time and fixation count) and behavioural (*d'*) measures collected during the *Incidental and Intentional Face Recognition Tasks* with autistic (n = 24) and neurotypical (n = 21) adults (Chapter 4).

Autistic Adults

Area-Normalized Looking Time

	Incidental Task			***Intentional Task***		
	Range	**Skewness**	**Kurtosis**	**Range**	**Skewness**	**Kurtosis**
Left Eye	0.00 – 14.49	0.91	0.41	0.00 – 11.99	0.70	-0.47
Right Eye	0.23 – 13.03	1.23	1.57	0.12 – 14.81	0.83	2.03
Nasion	0.67 – 29.41	1.16	1.99	0.00 – 20.10	0.46	-0.61
Nose	0.42 – 15.92	0.68	0.33	0.00 – 14.95	1.25	1.43
Mouth	0.00 – 8.32	0.48	-1.05	0.00 – 7.21	0.69	0.47
Non-Core Features	0.05 – 2.58	1.79	4.16	0.14 – 2.21	1.46	2.26

Area-Normalized Fixation Count

	Incidental Task			***Intentional Task***		
	Range	**Skewness**	**Kurtosis**	**Range**	**Skewness**	**Kurtosis**
Left Eye	0.00 – 16.24	0.70	0.56	0.00 – 14.35	0.57	-0.28
Right Eye	0.34 – 10.84	0.58	-0.09	0.16 – 12.85	-0.01	-0.31
Nasion	1.22 – 33.67	0.69	-0.11	0.00 – 24.06	0.44	-0.77
Nose	1.12 – 15.41	0.32	-0.96	0.00 – 16.81	0.91	0.78
Mouth	0.00 – 11.93	0.78	0.10	0.00 – 7.06	0.17	-0.80
Non-Core Features	0.09 – 3.42	2.01	5.29	0.20 – 4.15	1.69	2.59

Face Recognition Accuracy

	Incidental Task			***Intentional Task***		
	Range	**Skewness**	**Kurtosis**	**Range**	**Skewness**	**Kurtosis**
d'	-0.32 – 1.61	-0.15	-0.73	-0.10 – 1.47	-0.28	-0.57

Neurotypical Adults

Area-Normalized Looking Time

	Incidental Task			*Intentional Task*		
	Range	**Skewness**	**Kurtosis**	**Range**	**Skewness**	**Kurtosis**
Left Eye	0.13 – 16.52	0.46	-0.07	0.00 – 13.44	0.51	-0.98
Right Eye	1.22 – 14.26	0.32	-1.22	2.04 – 13.70	0.35	-1.15
Nasion	0.41 – 24.07	-0.05	-0.73	2.04 – 25.15	0.64	0.36
Nose	0.26 – 19.46	1.11	1.59	0.81 – 22.62	1.00	0.04
Mouth	0.00 – 9.73	1.58	4.04	0.16 – 4.01	0.66	0.12
Non-Core Features	0.00 – 1.69	2.53	7.65	0.07 – 0.72	-0.29	-1.60

Area-Normalized Fixation Count

	Incidental Task			*Intentional Task*		
	Range	**Skewness**	**Kurtosis**	**Range**	**Skewness**	**Kurtosis**
Left Eye	0.19 – 14.95	0.12	-0.95	0.00 – 15.61	0.45	-0.68
Right Eye	1.60 – 14.79	0.60	-1.01	2.68 – 14.26	0.64	-0.63
Nasion	1.03 – 25.52	-0.30	-1.18	4.06 – 28.32	0.45	-0.33
Nose	0.38 – 20.28	0.59	0.43	1.19 – 22.19	0.64	-1.17
Mouth	0.00 – 11.52	1.55	3.83	0.22 – 6.24	0.78	0.04
Non-Core Features	0.00 – 1.87	2.64	8.28	0.09 – 1.34	0.71	1.26

Face Recognition Accuracy

	Incidental Task			*Intentional Task*		
	Range	**Skewness**	**Kurtosis**	**Range**	**Skewness**	**Kurtosis**
d'	-0.49 – 1.48	-0.16	-0.75	0.00 – 1.69	0.28	-1.00

Table E2. Pearson correlations (with bootstrapped 95% confidence intervals) examining the association between area-normalized fixation patterns and face recognition accuracy for autistic (n = 24) and neurotypical (n = 21) adults.

	Incidental d'					
	Autistic Adults			**Neurotypical Adults**		
	r	***p***	**95% CI**	***r***	***p***	**95% CI**
Normalized Looking Time						
Left Eye	.33	.12	-.12 – .65	.06	.79	-.38 – .51
Right Eye	.02	.93	-.39 – .40	-.17	.47	-.54 – .25
Nasion	.07	.76	-.38 – .43	.22	.33	-.12 – .59
Nose	-.07	.74	-.43 – .29	.004	.99	-.35 – .42
Mouth	-.22	.31	-.64 – .20	-.02	.94	-.33 – .37
Non-Core Features	-.16	.45	-.66 – .26	-.07	.77	-.36 – .47
Normalized Fixation Count						
Left Eye	.28	.19	-.23 – .63	.07	.76	-.33 – .47
Right Eye	-.02	.93	-.45 – .43	-.17	.46	-.53 – .21
Nasion	.03	.90	-.39 – .41	.18	.45	-.21 – .60
Nose	-.07	.73	-.43 – .30	.01	.97	-.35 – .42
Mouth	-.17	.42	-.61 – .25	-.01	.98	-.32 – .40
Non-Core Features	-.06	.79	-.59 – .32	-.02	.93	-.32 – .52

	Intentional d'					
	Autistic Adults			**Neurotypical Adults**		
	r	***p***	**95% CI**	***r***	***p***	**95% CI**
Normalized Looking Time						
Left Eye	.01	.95	-.34 – .37	.36	.11	-.01 – .68
Right Eye	.14	.53	-.37 – .56	-.05	.83	-.44 – .37
Nasion	.03	.90	-.37 – .39	-.24	.31	-.56 – .14
Nose	.22	.31	-.25 – .62	-.25	.28	-.59 – .14
Mouth	.11	.62	-.27 – .46	.12	.62	-.29 – .54
Non-Core Features	-.14	.51	-.46 – .33	-.08	.74	-.52 – .34
Normalized Fixation Count						
Left Eye	-.10	.64	-.43 – .24	.41	.06	.04 –.71
Right Eye	.12	.59	-.34 – .57	-.02	.92	-.42 – .37
Nasion	.02	.94	-.44 – .35	-.07	.78	-.44 – .35
Nose	.17	.44	-.32 – .58	-.25	.27	-.61 – .52
Mouth	-.04	.86	-.43 – .37	.07	.77	-.34 – .52
Non-Core Features	-.17	.44	-.48 – .21	-.01	.96	-.49 – .34