SOCIAL MOTIVATION, VISUAL EXPERIENCE, AND FACE RECOGNITION IN AUTISM SPECTRUM DISORDER

by

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Abstract

Autism spectrum disorder (ASD) is characterized by challenges in social communication, interaction, and repetitive and restricted behaviors and interests. Among these difficulties, individuals with ASD commonly exhibit moderate impairments in face recognition. In this thesis, we conduct three studies to examine competing experience- and perceptual-based accounts of face recognition challenges in ASD. The first study investigates a perceptual/genetic hypothesis that suggests a shared etiology of face recognition challenges between ASD and developmental prosopagnosia (DP), a condition characterized by severe face recognition impairments. We compare face recognition ability and social motivation in adults with ASD, DP, and a non-ASD, non-DP comparison group. Our findings revealed that a DP-like subtype within ASD cannot solely account for the face recognition challenges experienced across the diverse ASD population. The second study examines daily visual exposure to faces in adults with ASD in comparison to that of non-autistic adults. Experience-based accounts, such as the *social motivation hypothesis*, predict reduced attention to faces in ASD, which in turn give rise to challenges due to lack of experience. Consistent with this prediction, we observe reduced exposure durations to familiar faces in ASD, and atypical exposure faces viewed from farther distances and favoring profile pose over frontal, indicating patterns inconsistent with typical social interactions. In the third study, we examine whether this atypical exposure to profile poses is associated with improved encoding and recognition of faces viewed in this pose. However, our results do not support this prediction as individuals with ASD perform notably worse in profile face recognition compared to non-autistic controls. Collectively, this thesis contributes to the current understanding of face recognition abilities in ASD. It challenges the notion of a single etiological factor accounting for all face challenges in ASD, but rather suggests that a combination of experience-based and perceptual-based factors separately or in combination, lead to face recognition challenges in ASD. The results inform future investigations

and may pave the way for potential intervention strategies aimed at enhancing face recognition skills in individuals with ASD.

Lay Summary

In this thesis, we investigate face recognition challenges in autism spectrum disorder (ASD). ASD affects communication and social interactions and is often associated with difficulties in recognizing faces. Our research explores different theories regarding this issue. First, we compared adults with ASD to individuals with developmental prosopagnosia (DP), a condition where face recognition is impaired. Contrary to expectations, we found that face recognition abilities in ASD varied widely and didn't fit into a specific subgroup resembling DP-like challenges. In our second study, we assessed visual experience with faces in adults with ASD. We discovered that individuals with ASD had less exposure to faces and showed a preference for side views. However, this exposure didn't improve recognition of side-view faces, as demonstrated in our third study. Understanding these challenges can inform personalized interventions to enhance face recognition skills in ASD, thereby improving social interactions for individuals on the autism spectrum.

Preface

I planned and developed the experimental design, data collection, data analysis, and manuscript preparation with Dr. Ipek Oruc (IO) for work described in Chapter 2. Additionally, Dr. Grace Iarocci (GI) assisted with participant recruitment of individuals with autism spectrum disorder (ASD), and Dr. Tirta Susilo (TS) assisted with participant recruitment, data collection and confirmation of group membership for participants with developmental prosopagnosia. I wrote and edited the paper with assistance and feedback from IO, and feedback from GI and TS. A version of chapter two has been published: Kamensek, T., Susilo, T., Iarocci, G., & Oruc, I. (2023). Are people with autism prosopagnosic? *Autism Research, 1-10.* https://doi.org/10.1002/aur.3030

I planned and developed the experimental design, data collection, data analysis, and manuscript preparation with Ipek Oruc (IO) for work described in Chapter 3. Additionally, GI provided support for participant recruitment of individuals with ASD. I wrote and edited the paper, with feedback from IO. A version of Chapter 3 is in preparation for publication. A version of this material was presented at the Vision Sciences Society 2022 Annual Meeting as a talk.
I had the primary role for experimental design, data collection, data analysis, and manuscript preparation for work described in chapter 4. I wrote and edited the paper with feedback from IO. A version of chapter 4 is in preparation for publication. A version of this material was presented at the Vision Sciences Society 2023 Annual Meeting as a poster.

Dr. Ipek Oruc provided a supervisory role for all work described in Chapters 2-4, including experimental design, data collection, data analysis, and manuscript preparation.
The name of the specific UBC Research Ethics Boards, and the Certificate Numbers of the Ethics Certificates obtained for the research described in this thesis: UBC Behavioural Research Ethics Board H14-01021 (Chapter 3), H21-02873 (Chapter 2,4) and the Human Ethics Committee at Victoria University of Wellington 22199 (DP data collection; Chapter 2).

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To my dear parents and brothers, I am eternally grateful for your love, support, and encouragement throughout my academic journey. Your belief in me has been a constant source of motivation. I want to express a special thank you to my mom, whose kind advice and logical thinking have always had a profound impact, especially during times of stress. Your wisdom and guidance have been invaluable.

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Once again, I extend my heartfelt thanks to each and every person who has played a role in my academic journey. Your support and contributions have been instrumental in the completion of my PhD thesis, and I am deeply grateful for the impact you have had on my life.

This dissertation is dedicated to my wife, whose relentless pursuit for greatness inspires me each and every single day.

Chapter 1: Introduction

1.1 Autism spectrum disorder

1.1.1 History and diagnosis

In 1943, psychiatrist Leo Kanner wrote a condensed case study report on 11 children, 8 boys and 3 girls with what he called “autistic disturbances of affective contact” (Kanner, 1943). At the time, the term “autism” was used to describe a symptom of schizophrenia wherein patients replaced unsatisfying realities with a symbolic inner life of fantasies or hallucinations. However, in Kanner’s (and later Hans Asperger’s) cases, they used the term to describe a general disengagement from the external environment (Evans, 2013). Although the children in Kanner’s report differed individually in the degree of impact, expression of behavioural features, and development, a set of “essential common characteristics” inspired the formation of a unique syndrome. The children were not “feebleminded” or schizophrenic, common views at the time, they were reported to demonstrate good cognitive potential. Some spoke, while others appeared mute, but all children had difficulties relating themselves typically to others and their environment. A preference for “extreme aloneness” was demonstrated as an aversion to others, loud sounds, or motion, with a need to be left undisturbed. Aspects of the environment which did not interfere with the “aloneness” of the child were reportedly preferred, such as toys, while possible outside disturbances to the “maintenance of sameness”, like others, were ignored or treated with distress. From a young age, these children did not demonstrate the typical anticipatory posture to being picked up by caregivers, showed little interest in the conversations of adults, and seemed to avoid looking at the faces of others. Upon the acquisition of language, word meanings are taken literally and treated with inflexibility, the language of others is often repeated verbatim, and social aspects of language like pronoun usage or expressions of assent are delayed or difficult. However, several children had excellent rote memory, with no problem

memorizing the names of objects, long or unusual words, or even nursery rhymes, prayers, presidents, or poems.

Coincidentally, a year later, a separate report by Austrian physician Hans Asperger described another set of children with “common fundamental disturbances” for which he chose the label “autism” (Asperger, 1944). Asperger reported similar difficulties with social integration and shutting off from the outside world, also noting repetitive stereotyped behaviours such as hopping, fidgeting, spinning or rhythmic rocking. Despite overshadowing social problems, Asperger commented that almost all autistic children had a special interest, that when fostered, could lead to extraordinary levels of performance in a specific area, and that the condition was especially specific to boys. Four decades later, Hans Asperger’s original report (in German) was translated by London psychologist Lorna Wing and used to inform the eventual creation a separate diagnostic syndrome called Asperger’s Syndrome.

Autism was officially recognized as a diagnosable condition in 1980 with the release of the Diagnostic and Statistics Manual for Mental Disorders III (DSM-III) (*Diagnostic and statistical manual of mental disorders (3rd ed.)*, 1980) and was called *infantile autism*. It was placed within a new category of disorders: pervasive developmental disorders. As the name suggests, the diagnosis was focused on autism early in development and was criticized for not adequately considering the longer developmental impacts and trajectory of autism (Volkmar & McPartland, 2014). Before this, the concept of autism was poorly understood, and patterns of behaviour characterized by impairments of social interaction, repetitive and stereotyped activities, and abnormality of language development were variously termed childhood psychosis, childhood autism, or childhood schizophrenia (Wing & Gould, 1979). Wing and Gould (1979) sought to get a better understanding of children with these behavioural profiles by conducting a large epidemiological survey of children in a suburb London. The goal was to get an idea of the prevalence of these abnormalities, whether they occur together, and how they relate to intellectual disability. Overall, children could be subdivided into two groups: sociable children

with severe intellectual disability, and those who are socially impaired. All children with social impairment had concurrent repetitive stereotyped behaviour and almost all had abnormalities in language and symbolic activities (pretend play). Although Kanner's autism could be reliably identified, the authors found that subgrouping the children based on severity of social impairment was more predictive of other measured medical, psychological, and behavioural variables such as IQ, stereotyped repetitive activities, and speech atypicality (Wing & Gould, 1979). These social impairment subgroups included a group described as: 1) Socially *aloof*, which indicated the most severe impairments of social interaction, wherein children were aloof and indifferent in all situations but may make social approaches to obtain things they wanted, 2) *Passive*, which described children who did not proactively seek social interaction, but were amiable to the approaches of others, and 3) *Active-but-odd* which included children who would make spontaneous social approaches, but they were peculiar, one-sided, and often ill-received by others (Wing & Gould, 1979). The epidemiological study was important for two reasons. First, it established autism as a disorder characterized by a triad of impairments: social interaction, social communication, and repetitive and stereotyped behaviour. Second, the social subtypes were an early indication of the potential utility of identifying homogenous subgroups for characterizing common profiles of individuals falling within the same diagnostic category. The authors did however note substantial overlap of the variables across subgroups, suggesting a continuum, or spectrum of severity (Wing & Gould, 1979).

In 1987, with the release of the revised DSM-III-R (*Diagnostic and Statistical Manual of Mental Disorders (3rd ed., revised)*, 1987) *infantile autism* was renamed *autistic disorder*, was more developmentally focused, and included 16 detailed criteria across a triad of impairments (as alluded to by Wing and Gould (1979)), including qualitative impairments of social interaction, communication, as well as restricted interests. The DSM-III-R however was criticized for putting too little emphasis on developmental history and having too few details compared to early versions of the World Health Organization's International Statistical Classification of Diseases

and Related Health Problems (ICD-10). In response, a large international field trial was undertaken to improve consistency of diagnosis across countries and systems (Volkmar & McPartland, 2014).One hundred raters reviewed over 1000 cases from over 20 international clinical sites to compare the diagnostic utility of the ICD-10, DSM-III, DSM-III-R and a newly proposed DSM-IV (Volkmar et al., 1994). Interrater reliabilities, internal consistency scores, signal detection analysis, and factor analysis were used to compare diagnostic methods, and ultimately lead to the final versions of the DSM-IV (*Diagnostic and Statistical manual of Mental Disorders (4th ed.)*, 1994) and ICD-10 (Volkmar et al., 1994; World Health, 1992). The field study also led to the inclusion of several other syndromes under the banner of pervasive developmental disorders, including autistic disorder, Asperger's syndrome, Heller's syndrome, Rhett's syndrome, and pervasive developmental disorder – not otherwise specified (PDD-NOS: a subthreshold autism) in the DSM-IV (Volkmar & McPartland, 2014). Challenges to the clinically validity of these specific forms of the autism spectrum disorders however, eventually lead to the removal of these subcategories in the DSM-5 (Barahona-Corrêa & Filipe, 2015; Happe, 2011; Lord, 2011; Lord et al., 2012), although the decision was controversial (Ghaziuddin, 2010; Gillberg et al., 1998; Volkmar, Klin, Schultz, Rubin, & Bronen, 2000)

Autism spectrum disorder today is defined as a complex developmental condition involving persistent challenges with social communication and interaction, restricted interests and repetitive behaviour (American Psychiatric Association, 2013). As defined, autism spectrum disorder serves as an umbrella term for an array of previously individually defined developmental disorders, including Asperger's syndrome and pervasive developmental disorder – not otherwise specified. Diagnostic criteria, according to the diagnostic statistical manual, 5th edition (DSM-5), is split into two domains: the social communication and interaction domain and the repetitive and restrictive behaviour domain. Criteria within the social communication and interaction domain include 1) *Deficits of social emotional reciprocity* such as abnormality in social approach, failure of normal back and forth conversion, decreased sharing of interest,

emotions, affect and response, and total lack of initiation 2) *Deficits in non-verbal communicative behaviours* such as poorly integrated verbal and non-verbal communication, abnormal eye contact and body-language, difficulty in understanding and use of non-verbal communication, and complete absence of facial expression or gestures and 3) *Deficits in developing and maintaining relationships* such as difficulty making friends, apparent absence of interest in people, and difficulties adjusting behaviour to suit different situations. Within the repetitive and restrictive behaviour domain, criteria include 1) *Stereotyped or repetitive speech, motor movements, or use of objects* such as simple motor stereotypes, echolalia, repetitive use of objects, or idiosyncratic phrases 2) *Excessive adherence to routines, ritualized patterns of behaviour* including excessive resistance to change such as motor ritual, insistence on same route or food, and repetitive questioning or extreme distress at small changes 3) *Highly limited, fixed interests which are abnormal in intensity or focus* including strong attachment to and/or preoccupation with strange objects and excessively limited or narrow interests 4) *Hyper-or hypo- reactivity to sensory input* including unusual curiosity in sensory aspects of environment, apparent indifference to heat/pain/cold, adverse response to particular sounds or textures, excessive smelling or touching of objects, and fascination with lights or spinning objects (American Psychiatric Association, 2013). For a diagnosis of ASD under the DSM-5, children should demonstrate symptoms across all three subdomains of the social-communication domain, and 2 symptoms from any of the 4 subdomains of the restricted, repetitive behaviour domain. Individuals with existing well-established DSM-IV diagnosis of autistic disorder, Asperger's disorder or PDD-NOS should also be given a diagnosis of ASD. Functional impairments (social or occupational) must be present, and symptoms must not be explained by intellectual disability or global developmental delay. Included in the DSM-5 diagnostic framework are a number of specifiers, including 1) whether any known etiological factors are present, 2) a severity specifier indicating the amount of support required (on a scale of 1-3, 1 being need for support and 3 being very substantial need for support), 3) indication of

intellectual impairment and 4) indication of any language impairment. This thesis is focused on individuals on the autism spectrum who would be considered cognitively able, which we operationally define as an IQ score above 75.

The historical diagnostic framing of autism, from the subgrouping of pervasive developmental disorders as done in the DSM-IV, to the conceptualization of these disorders existing along a spectrum in the DSM-5, provides unique challenges for clinicians, researchers, and those on the autism spectrum. Specific diagnosis within clinically homogeneous subgroups can help focus research and policy planning, which can lead to more effective treatments or therapies, as well as possible special entitlements to services (Borden & Ollendick, 1994; Volkmar & McPartland, 2014). These subgroups, however, must be valid, and reliably determined, to effectively inform research. After all, there can be no meaningful comparison of groups if those groups are not mutually exclusive. While an observable pattern of behaviours has been agreed upon for diagnosis, an early issue as described by Lorna Wing still remains: these behavioural patterns are made up of multiple impairments which can each present at a different level of intensity, these manifestations can change with age, and can vary in different environments, they are influenced by individual personality, and all features occur at any level on a continuum of severity ranging from profound to minimal (Wing, 1989). A useful diagnosis should emphasize the needs, type of education, and possible accommodations required to improve an individual's quality of life and functional independence. Currently, in a time where people with ASD may have diagnoses based on different systems of classification, understanding heterogeneity in ASD, the sources of it, and whether subgroups can exist along different avenues of evaluation is an important challenge for researchers. If successful, strategies can be formulated that assist individuals based on similar phenotypic characteristics and, in turn, can better inform personalized interventions for the success of the individual.

Early estimates, coming from the UK in the 1960s, using Kanner's early clinical descriptions of autism estimated a prevalence of 4-5/10,000, or 0.05%. As autism was

recognized among individuals without intellectual deficits or language delays, those prevalence estimates rose to 0.6-0.7% (Fombonne, 2020). In North America, the current gold standards for assessment and diagnosis of ASD are the Autism Diagnostic Interview-Revised (ADI-R; Rutter, Le Couteur, and Lord (2003)), a parental questionnaire, and the Autism diagnostic observation schedule (ADOS; Lord et al. (2000)), a diagnostic method based on clinical observation. As of 2018, roughly 1/66 (~0.2%) Canadian children between the ages of 5 and 7 are estimated to have autism spectrum disorder (Canadian Government & Public Health Agency of, 2018), with estimated population costs around $3 billion/year for provincial health and social services systems in Canada (Hodgetts, Zwaigenbaum, & Nicholas, 2015). Current prevalence estimates represent a sharp upward trend in historical prevalence and are thought to reflect the increased dimensionality in diagnostic criteria, better awareness, and increased availability of services (Buxbaum & Hof, 2013; Fombonne, 2020). Historically, males have been roughly 4 times more likely than females to be diagnosed with ASD (Baio et al., 2018; Joon, Kumar, & Parle, 2021), however, a recent meta-analysis suggests that the male to female ratio may be closer to 3:1 (Loomes, Hull, & Mandy, 2017). A historically male driven diagnostic bias has been suggested to be a result of a “specific female autistic phenotype” which includes learned compensatory social communication abilities that mask autism related difficulties, lower levels of restricted behaviours and interests, and potential gender stereotypes that ASD is a male disorder (Bargiela, Steward, & Mandy, 2016; Dworzynski, Ronald, Bolton, & Happé, 2012; Frazier, Georgiades, Bishop, & Hardan, 2014; Frazier & Hardan, 2017; Lai et al., 2011). These findings indicate that the current systems of diagnosis have room for improvement, especially for the detection and diagnosis of females. These are challenges for a disorder that is behaviourally defined and relies on professional observation or parental report. There have yet to be any reliable biomarkers discovered for accurate diagnosis of autism.

1.1.2 Heterogeneity & subgrouping

Due to the inherent heterogeneity of severity and presentation of ASD, attempts have been made to understand and parse differences between individuals on the autism spectrum. The switch from the DSM-IV to the DSM-5 represents a switch from a more traditional categorical classification to a dimensional framework, with differences between individuals sharing the same diagnostic label conceptualized along a spectrum. A weakness of the more classical categorical method in autism is that it largely ignores the variability between individuals with the same diagnosis (Beglinger & Smith, 2001). In addition, contrary to classical categorical models, it is suggested that common behavioural disorders may reflect a set or subset of behaviours that fall at the extreme end of the normal distribution in the general population (Plomin, 1999). A dimensional approach, therefore, might be most appropriate in conceptualizing autism, where individuals fall along a continuous spectrum that shades into a range of normal behaviours (Beglinger & Smith, 2001). That is not to say that there is no utility in a categorical threshold or boundary when a certain level of behaviour may lead to functional impairment (Volkmar & Klin, 2005). A dimensional approach, in addition to leading to a better understanding of variability within autism itself, could also be beneficial to individuals who may have an isolated impairment in one domain of autism (e.g. social interaction), but do not meet the diagnostic criteria for ASD (Happé, Ronald, & Plomin, 2006). A goal of the dimensional approach is, in fact, to reveal subtypes along the autism spectrum, where individuals share a *dimensional identity* (Von Eye & Bergman, 2003). In short, those who share a dimensional identity, would fall within a homogenous subgroup and would likely share a common etiological pathway, and demonstrate similarity in treatment and response (Von Eye & Bergman, 2003; Yager & Iarocci, 2013). The value in deriving more homogenous samples is the ability to predict differences in social behaviour, which clinically, can aid planning and delivery of treatment services, and non-clinically, can focus research. One way of identifying a homogeneous subgroup is to identify common profiles with respect to a single domain of interest (Yager &

Iarocci, 2013). In a review of attempts at subtyping in ASD, Beglinger and Smith (2001) outline several domains of interest that have been investigated, including social/communication subtypes, level of intellectual impairment, adaptive functioning, development level, and biological (those with a known medical condition playing a causative role). The authors indicate that across the different attempts, most studies support a dimensional conceptualization of autism, autism is reliably differentiated from other related disorders regardless of the method, and that developmental level and social functioning seem to account for large portions of variance in autistic symptomology (Beglinger & Smith, 2001). With the theoretical potential of several subtypes existing along many different domains of interest, it is important for researchers to keep this in mind when conducting classic case-control studies with small samples. Lombardo, Lai, and Baron-Cohen (2019) outline a scenario where interesting differences between subgroups can be averaged out and disappear if the group is considered as a single entity, and heterogeneity is not accounted for. Assuming the existence of subtypes in a population, studies with small samples will be more likely to have a biased sample, with an overrepresentation of one specific subtype (Lombardo et al., 2019). Should one study be overrepresented by a subtype that has exceptional ability on a dependent variable of interest, and another by a subtype that shows deficits, the literature may appear at odds, when the difference between the two are due to un-defined heterogeneity within the population. It is not always feasible for a research group to include massive samples of individuals belonging to a specific population like ASD, which is why understanding heterogeneity, even for a specific aspect of the behavioural phenotype of autism is so important. The domains of interest this thesis seeks to better understand is social competence and an important social cognitive process related to social competence: face recognition.

1.1.3 Social Competence in ASD

Social interaction style and social competence is a common avenue, down which dimensional and categorical approaches have been taken to organize and understand autism spectrum disorder. As discussed, a large case study of children with developmental disorders in London, England found that those with ASD could be subtyped based on social interaction styles in three ways, which would become known as the Wing subtypes: Aloof, passive, and active-but-odd (Wing & Gould, 1979). These subtypes had good predictive value for other behavioural, medical, and psychological manifestations of autism, however, significant overlap between subtypes was observed. Investigations of the validity of the subtypes have been mixed, with one finding that the subtypes are strongly related to IQ and development (Volkmar, Cohen, Bregman, Hooks, & Stevenson, 1989) and another finding good validity and utility for the aloof and active-but-odd subtypes, but less support for a distinct passive subtype (Borden & Ollendick, 1994).

To Trevisan, Tafreshi, Slaney, Yager, and Iarocci (2018) the Wing subtypes represent a continuum of social abilities where social difficulties in autism may intersect with variability of social competence in the general population. Thus, they created the multidimensional social competence scale (MSCS) to identify and characterize fine grained social competence profiles for autistic and non autistic individuals (Trevisan et al., 2018; Yager & Iarocci, 2013). Social competence is assessed across seven domains consisting of social motivation, social inferencing, empathic concern, social knowledge, verbal conversation skills, non-verbal sending skills, and emotion regulation. Dimensional approaches such as the MSCS indicate strengths and weaknesses across a variety of social competency measures that can help create a more comprehensive profile for person-centered care. The MSCS has been validated, but is relatively new, and therefore, it is important to understand how social competence profiles relate to behavioural variables of interest. In this thesis, we are particularly concerned with the subscale of social motivation. Social motivation is defined as an individual's desire to interact with others,

including the degree to which individuals initiate social contact, has apparent interest in friendships and other relationships, their desire to be accepted by peers, and whether one derives enjoyment from social interactions (Yager & Iarocci, 2013). Results from the 77-item parent report (used for children and adolescents) and self-report (designed for adults) versions of the MSCS indicate that SM scores, on average, are significantly lower in autism (roughly 2 standard deviations) compared to non-autistic controls, however, there is an overlap, and not all individuals with autism score below control means (Oruc, Shafai, & Iarocci, 2018; Yager & Iarocci, 2013). Social motivation is theorized to be fundamentally related to face recognition ability in ASD (Chevallier, Kohls, Troiani, Brodkin, & Schultz, 2012; Dawson, Webb, & McPartland, 2005; Schultz, 2005), an important aspect of social cognition that, as I will outline in the following section, is also largely impacted in autism spectrum disorder.

1.2 Face Processing in ASD

1.2.1 General History

Although Kanner's initial descriptions of autism included a boy who "had an unusual memory for face and names" there is a rich literature suggesting that on average, those with ASD do in fact struggle with various aspects of face perception. A core diagnostic characteristic of autism is an avoidance of faces and eye contact (American Psychiatric Association, 2013; Kanner, 1943). It should be noted that studies completed before a common diagnostic criterion was agreed upon should be considered with a grain of salt, but atypicalities in face recognition processing have been observed since before the DSM-III. In 1978, Langdell compared familiar face recognition of 20 autistic children, defined by ritualistic and stereotypic behaviour, delayed speech development, aloofness, and an insistence on sameness to 20 age-matched non-autistic controls with a masking paradigm. Subjects were shown pictures of their classmates, with different portions of their faces masked and asked to identify their peers. Langdell (1978) observed that compared to non-autistic controls who had an advantage for recognizing the top

halves of faces, younger children with autism demonstrated an advantage for recognizing the bottom halves of faces. Older autistic children, however, were able to demonstrate equivalent performance for upper face recognition as controls. The author suggested that an advantage in lower face recognition in younger subjects results from a compensation strategy for social communication challenges where focusing on the mouth can help the child understand what is being said. As the child develops and becomes more social, they are able to shift attention to the upper halves of faces (Langdell, 1978). It was an early indication that face recognition processes may be altered in ASD, and since then, a wealth of research has gone into understanding this important aspect of social cognition.

1.2.2 Expression Recognition

To date, the literature investigating the extent to which expression perception is impaired in autism, and which expressions are impaired, remains heterogenous. While some research groups report no impairments in recognizing facial expression in ASD (Adolphs, Sears, & Piven, 2001; Baron-Cohen, Wheelwright, Jolliffe, & Therese, 1997; Rutherford & Towns, 2008) others report selective impairments, often limited to more negative emotional expressions such as anger, fear or disgust (Ashwin, Chapman, Colle, & Baron-Cohen, 2006; Bal et al., 2010; Howard et al., 2000; Wallace, Coleman, & Bailey, 2008b). In a review of facial emotion recognition in autism, Harms, Martin, and Wallace (2010) suggest that equivalent behavioural performance between autistic and non-autistic participants is more likely to occur under standard viewing conditions, with prototypical facial expressions, and longer stimulus exposure times. Deficits in ASD become more apparent in studies requiring discrimination of more subtle changes in expression, (Humphreys, Minshew, Leonard, & Behrmann, 2007; Oruc et al., 2018). Recognition of identity is also impacted across changes in expression in ASD (Wolf et al., 2008). A meta-analysis from Uljaravic et al., (2013) provides supporting evidence for a general

impairment in emotional expression perception in ASD, while noting that much of the existing literature is underpowered due to low sample sizes.

1.2.3 Identity Recognition

In addition to the core socio-communicative deficits associated with autism, and difficulties with interpreting expression, studies indicate selective impairments in recognition of facial identity (Arkush, Smith-Collins, Fiorentini, & Skuse, 2013; Griffin, Bauer, & Scherf, 2021; Oruc et al., 2018; Tang et al., 2015; Weigelt, Koldewyn, & Kanwisher, 2012; Wolf et al., 2008). Participants with ASD do not show deficits in recognition of control stimuli such as houses or cars, demonstrating a face specific nature of impairments (Arkush et al., 2013; Oruc et al., 2018; Wallace, Coleman, & Bailey, 2008a; Wolf et al., 2008). In a review of 90 behavioural studies investigating face perception in autism, it was noted, however, that roughly half found no difference between autistic and non-autistic participants (Weigelt et al., 2012). It appears that face impairments in autism are more likely to be observed in face recognition tasks involving memory demands such as the Cambridge Face Memory test (CFMT; Duchaine and Nakayama (2006)), or face perception tasks involving slight delays between stimulus presentations (Tang et al., 2015; Weigelt et al., 2012). On standardized tests of face recognition memory, including the CFMT, reductions in face recognition performance are consistently observed (Croydon, Pimperton, Ewing, Duchaine, & Pellicano, 2014; Dwyer, Xu, & Tanaka, 2019; Ewbank et al., 2017; Hedley, Brewer, & Young, 2011; Kamensek, Susilo, Iarocci, & Oruc, 2023; Lynn et al., 2018; Scherf, Elbich, Minshew, & Behrmann, 2015). The CFMT is a validated test of face recognition, shown to assess face-specific memory (Duchaine & Nakayama, 2006; Germine, Duchaine, & Nakayama, 2011; Wilmer, Germine, Chabris, Chatterjee, Williams, Loken, et al., 2010; Wilmer, Germine, Chabris, Chatterjee, Williams, Nakayama, et al., 2010) and is the gold standard for diagnosing prosopagnosia, a disorder characterized by severe impairments of face recognition (Susilo & Duchaine, 2013). The CFMT requires participants to invoke a mental

representation of a target identity over a delay from having visual access to that target. This type of paradigm, along with “old/new”, “n-back”, and other standardized tests of face memory involving a delay between learning and recognizing a face are the types of paradigms that Weigelt et al. (2012) hypothesize are more likely to reveal poor face recognition performance in ASD. In contrast, face identity discrimination paradigms, which require perceptual discriminations between two simultaneously presented stimuli such as simultaneous “match-sample”, “same/different”, or sorting tasks, often show ASD subjects performing as well as typical subjects (Griffin et al., 2021; Weigelt et al., 2012). Griffin et al. (2021) recently completed a large meta-analysis of the literature to assess the extent of face recognition processing deficits in ASD and whether methodological factors contribute to the patterns of group differences observed in the literature. The comprehensive quantitative meta-analysis reviewed 112 empirical studies from the last four decades of empirical research on identity recognition in ASD, including 172 effect sizes, with data from 2,612 individual with ASD and 2,778 control participants. Of the 172 effect sizes, 119 estimated group differences in face identity recognition and 53 of face identity discrimination. The meta-analysis revealed a large summary effect size (Hedge’s g = -0.86) for face identity recognition, which was robust against small-study effects (inflation of effect size estimates by smaller studies with extreme effect sizes) and was not significantly moderated by methodological factors including age, IQ, sex, or choice of recognition paradigm. In contrast to the Weigelt et al. (2012) hypothesis that deficits of face recognition are related to memory and not perceptual processes, Griffin et al. (2021) also observed a large summary effect size for face identity discrimination behaviour (Hedge’s g = -0.82), which also was robust against small study effects, and was not significantly moderated by the same methodologically factors previously listed. In summary, the meta-analysis shows that on average, those with ASD perform nearly 1 standard deviation below their non-autistic counterparts on tests of both face identity recognition and face identity discrimination, revealing representational and perceptual deficits of face identity processing on the autism spectrum.

1.2.4 Potential impacts of identity recognition deficits on social function

It is not difficult to imagine how challenges in face recognition could impact a typical social interaction. Even taking a moment to analyse a person's face after they have said hello to confirm their identity could make one appear awkward, confused, or stand-off-ish, negatively impacting the subsequent interaction. Those with typical face recognition abilities have probably experienced seeing someone at a grocery store who acts as if they have met you, but you are unsure if they are familiar or not. Not wanting to seem rude you fumble through some friendly small talk, before spending the afternoon pondering who that person could have been. You hope that the person was not offended that you may have seemed unsure of who they were, and you replay the conversation in your head to examine if you acted appropriately. Perhaps next time you visit that store you might keep your head down to avoid any future awkward interactions. Griffin et al. (2021) point out that in autism, core social difficulties like abnormal social approach, or the inability to initiate social interactions could be related to challenges in face identity recognition. Indeed, connections between face recognition ability and social interaction/communication abilities for individuals on the autism spectrum have been explored. In school children, Corbett, Newsom, Key, Qualls, and Edmiston (2014) found that better performance on a face recognition memory task was associated with increased social interactions with peers for those with ASD. Stronger face memory has been associated with stronger adaptive functioning, stronger social skills, and fewer social difficulties in children with ASD (McPartland, Webb, Keehn, & Dawson, 2010; Neuhaus, Kresse, Faja, Bernier, & Webb, 2016). Lastly, a large, longitudinal study of 87 individuals with ASD followed from childhood to adolescence found that better performance on a face recognition task (a basic 4-alternative force choice, target present vs target absent, match-to-sample paradigm) in childhood, predicted significantly lower ASD symptom severity scores 7 years later (Eussen et al., 2015). These studies demonstrate the potentially reciprocal relationship between face recognition ability and social interaction challenges for those on the autism spectrum. Just as impairments

in one could lead to challenges of the other, resulting in a positive feedback loop and downward spiral in overall social cognition, the reverse is true as well, wherein improving face recognition abilities, or social interaction skills could potentially drive an upward spiral in cyclical reciprocation (Hopkins et al., 2011).

1.2.5 Investigations of early visual processing in ASD

What if face recognition challenges in ASD are related to fundamental differences in early visual processes mechanisms that make processing complex visual stimuli like faces difficult or less efficient? These mechanisms include basic functioning of the retina and low-level basic visual processing in the primary visual cortex, where processing is tuned for orientation and spatial frequency (F. W. Campbell & Robson, 1968; Hubel & Wiesel, 1959; Nauhaus, Nielsen, Disney, & Callaway, 2012). Differences in visual acuity could provide obvious challenges to face recognition if individuals are systematically less able to resolve details in the face. For example, people with macular degeneration and poor visual acuity struggle with tests of face recognition such as the CFMT (D. J. Taylor, Smith, Binns, & Crabb, 2018) and recognition of famous faces. Barring one study that suggested eagle eye visual acuity in ASD (Ashwin, Ashwin, Tavassoli, Chakrabarti, & Baron-Cohen, 2009) that was later shown to have key methodological errors leading to these results, there have been no indications of systemic differences in visual acuity between autistic and non autistic individuals (Falkmer et al., 2011; Kéïta, Mottron, & Bertone, 2010).

A locally biased, feature-focused perceptual style, driven by enhanced early visual cortical processing has also been argued to be a perceptual phenotype of autism (Mottron, Dawson, Soulières, Hubert, & Burack, 2006). Proponents of the theory argue that a heightened ability to detect and analyze details can result in an inclination to prioritize local elements of a visual scene and potentially overlook the global context (Mottron et al., 2006). Expert face recognition ability relies on the fast and automatic processing of both face features (local

elements), and their relations to each other (global form)(Carey & Diamond, 1994; Mondloch, Le Grand, & Maurer, 2002; Mondloch, Maurer, & Ahola, 2006; Tanaka & Sengco, 1997). A perceptual style that is biased towards features may be less sensitive to, or less likely to automatically process the important spatial relations between features that are unique to each face identity. Previous studies have systematically assessed two basic aspects of early visual cortical processing: orientation processing and spatial frequency processing. First, using robust psychophysical methods with a well-characterized group of adults with autism, Shafai, Armstrong, Iarocci, and Oruc (2015) assessed three separate aspects of orientation perception: precision of orientation perception with an orientation discrimination task, accuracy of orientation perception with a veridical method of adjustment task, and sensitivity of orientation perception with a contrast detection task. All three assessments revealed quantitatively and qualitatively similar orientation processing between those with autism and age-, IQ-, and sex-matched neurotypical controls (Shafai et al., 2015). These results were consistent with a report from one year earlier which found similar vertical and horizontal sine wave grating labelling ability in young adults with and without ASD (Meilleur, Berthiaume, Bertone, & Mottron, 2014). In a follow up to the Shafai et al. (2015) study, using similar methodology, I systematically assessed spatial frequency processing in adults with ASD across a broad range of spatial frequencies (1 – 24 cycles per degree). Higher spatial frequencies carry more detailed visual information, so a visual system tuned for higher spatial frequencies could contribute to a perceptual system that is biased towards more local details in a visual scene. Precision, accuracy, and sensitivity of spatial frequency perception was comparable between participants with ASD, and age-, IQ-, and sex-matched neurotypical controls (Kamensek, Shafai, Iarocci, & Oruc, 2018). Our results were in-line with other research groups who also observed typical contrast sensitivity to similar ranges of spatial frequency values (Behrmann, Avidan, et al., 2006; Guy, Mottron, Berthiaume, & Bertone, 2016; Jonge et al., 2007; Koh, Milne, & Dobkins, 2010).

The evidence provided suggests that the most basic aspects of visual perception are not enhanced in ASD, and therefore do not contribute to a local processing bias, which may impact face recognition processing on the autism spectrum. Given that early visual processing mechanisms appear largely normal for individuals with ASD, challenges with face recognition may more likely result from differences in higher order visual processing mechanisms. Before we can understand those differences however, we first must consider what is known about face recognition processing in typically developed individuals.

1.3 Typical development of face recognition abilities

1.3.1 Behavioural hallmarks of expert face recognition

All typical adult observers are said to be experts of face recognition (Diamond & Carey, 1986; Tanaka, 2001; Tanaka & Gauthier, 1997). But what does it mean to be a *face expert*? Colloquially, expertise is most often considered in the context of subject matter, where an expert is one with specialized and extensive knowledge regarding a specific subject (Garrett, Caldwell, Harris, & Gonzalez, 2009). In the realm of visual science, perceptual expertise relates to the speed and level at which objects are recognized and categorized (Gauthier, Tarr, Bub, & Collection, 2010; Tanaka & Gauthier, 1997). The ability to rapidly recognize and categorize objects is fundamental to the successful navigation of the visual environment (Gauthier et al., 2010). A visual object can be recognized across various levels of abstraction. For example, a dog can be recognized as a dog, more generally as an animal, or more specifically as a certain breed, such as a golden retriever. In a set of seminal experiments, Rosch, Mervis, Gray, Johnson, and Boyes-Braem (1976) demonstrated that across these different levels of abstraction, there exists a *basic-level* of categorization at which most objects are automatically recognized. This *basic-level* is defined as the category containing the most information, containing the highest cue validity, and thus is the most differentiable from other categories at the same level. In the example of the dog, the categorization of dog would represent the basic-

level abstraction as it contains the maximum number of category specific traits, i.e., it is the most inclusive level at which all or most members of the category share common attributes. Although a more subordinate level of classification (i.e., the golden retriever) also shares the same number of common attributes, these attributes overlap, or are shared with members of other categories at this level (e.g., a German Shepherd). Superordinate levels of abstraction (i.e., animal) share fewer common attributes among members of different categories (e.g., a bird vs a dog). Rosch et al. (1976) demonstrated that objects at their basic level generate the highest number of descriptive attributes, are most automatically named, and are most readily and quickly recognized compared to super- or sub-ordinate levels of abstraction. They posited that expertise, which would be mediated by experience, may shift the basic-level natural abstractions to more subordinate levels.

With a group of bird and dog experts, Tanaka and Taylor (1991) tested how expertise impacted human observer categorization behaviour. In a feature naming (attribute listing) task, experts produced as many subordinate feature descriptors as basic level features for their domain of expertise. The increased differentiability of expert's subordinate categories was linked to a higher likelihood to use subordinate level names in a free naming task and quicker reaction times when verifying the category of subordinate level objects in a category verification task (Tanaka & Taylor, 1991). Thus, patterns of recognition and naming that Rosch et al. observed at the basic-level were shifted to subordinate levels of abstraction for stimuli in the domain of expertise of the viewer. Consistent with Rosch's finding on basic level categories, novices listed the most feature descriptors at the basic level, used basic level names for identifying objects, and were the fastest to verify the categorize objects at the basic level (Rosch et al., 1976; Tanaka & Taylor, 1991). In a series of follow up experiments, Johnson and Mervis (1997) ran a similar set of experiments with bird and fish experts, however, their experts were split into intermediate and advanced levels. The authors also demonstrated that preferred naming occurred at more specific levels of abstraction for bird and fish experts in their domain of

expertise. Intermediate experts used names at subordinate levels of classification and advanced experts used names at sub-subordinate levels of classification. Further, expertise afforded the same speed and efficiency of recognition and verification for objects at subordinate levels of classification as the basic level. Together these studies demonstrate that expertise increases the differentiability of stimuli at increasingly subordinate levels of classification, which leads to a higher likelihood for those objects or stimuli to be recognized and named with higher specificity. It is suggested that extensive levels of practice and increased conceptual knowledge may allow an individual to be more sensitive to subtle perceptual features most important or necessary for more subordinate levels of categorization (K. E. Johnson & Mervis, 1997).

Given this framework of expertise, it may come naturally to assume that all adult human observers are experts of face recognition. Indeed, for familiar faces, faces are naturally categorized at the most specific level possible, the individual. It is less imaginable to view a face and think "a human face" than “it's Todd”. Tanaka et al. (2001) confirmed these intuitions in a set of experiments that demonstrated that while common visual objects are first recognized at the basic level, faces are first recognized at the subordinate level of the unique identity. In one experiment, participants were most likely to name faces of celebrities and politicians with their respective unique identities, compared to common objects first named at the basic level. Participants could verify the identities of faces as fast as their basic level category, compared to non-face objects which had a basic-level advantage in category verification in a second experiment. In a third experiment, Tanaka et al. (2001) showed that participants could accurately recognize the unique identities of faces with short presentation durations that disrupted the subordinate level identification of common objects. The authors posited that expertise results in the development of *perceptual routines* which allow for the rapid analysis of domain specific objects (Tanaka, 2001). In a final experiment, participants showed greater priming effects at subordinate levels of categorization for faces, compared to objects where priming had equivalent facilitation effects for recognition of subordinate and basic-level

categorizations. Here, the authors suggest human observers have access to fine-grained visual representations of familiar faces which results in greater priming effects for unique identity proper name labels. Together, these experiments demonstrate that experience (in the form of a potential lifetime of social interactions with faces, or extensive training with respect to bird or dog experts) and task demands (i.e., identifying bird species or identifying familiar faces) can result in downward shifts in automatic, fast recognition. Classification behaviour, however, is not the only signature of expertise.

In 1969, Yin observed that faces, compared to houses, planes, and men-in-motion, were easiest to remember in an old/new recognition memory task, but hardest to remember when test stimuli were inverted. Faces were also disproportionately impacted in a mental inversion imagery task. In other words, faces were especially hard to remember and imagine in an inverted orientation compared to other visual objects. The authors concluded that while all mono-oriented visual objects are harder to remember when inverted, there might be a factor specific to faces, that make them especially difficult (Yin, 1969). The authors speculated that a whole-face general impression strategy was used exclusively for upright faces, and that inverting the face interrupted this process, forcing a distinguishing-feature based strategy that was shared for other non-face objects. Indeed, the Thatcher illusion (Thompson, 1980) demonstrates that configural or spatial relations of features used for the recognition of upright faces are not as apparent when faces are upside down.

To investigate whether a face specific factor could explain the observed *inversion effect,* Diamond & Carey (1986) completed a new set of experiments. First, the inversion effect for faces was replicated with Yin's old/new memory recognition task. Participant's recognition of faces was disproportionately impacted by inversion compared to recognition of landscapes. Although landscapes had a similar number of distinguishable features, and were familiar like faces, the authors noted an important difference in the stimuli. Faces all share what the authors call *first order relational properties*. In other words, all faces share the same general

configuration of features (i.e., two eyes located above the nose, with a mouth underneath). *Second order relational properties*, or distinct relations between features sharing a common configuration, therefore, are used to individuate this stimulus class (Diamond & Carey, 1986). In comparison to landscape images, whose *first order relational properties,* for example,` the location of a rock in comparison to a tree, vary randomly between images, and therefore can be used to individuate this stimulus class (Diamond & Carey, 1986). To compare the inversion effect for faces and another class of stimuli which share an overall configuration of features, the authors investigated expert and novice recognition of dogs. Recognition of dogs belonging to a breed of expertise had comparable inversion effects as observed for faces. Novices however, had no difference between recognition accuracy for upright and inverted dog images. This result suggested that the “face specific factor” suggested by Yin as an explanation for the inversion effect may not be face specific. The authors suggested that a pronounced inversion effect results for image classes with three properties: 1) members of the image class must share the same configuration, 2) it must be possible to individuate members of the image class based on second order relations and 3) subjects must have expertise in that image class to recognize those relational features (Diamond & Carey, 1986). For an in-depth review of the early face inversion literature, see Valentine (1988).

Since, the inversion effect has been replicated by several authors for faces (Albonico, Furubacke, Barton, & Oruc, 2018; Civile, McLaren, & McLaren, 2016; Diamond & Carey, 1977; X. M. Guo, Oruç, & Barton, 2009; McKone & Yovel, 2009; Scapinello & Yarmey, 1970; Tanaka & Farah, 1991; Valentine & Bruce, 1986), objects of expertise such as birds (A. Campbell & Tanaka, 2018; Gauthier, Skudlarski, Gore, & Anderson, 2000), cars (Gauthier et al., 2000) and artificial objects called Greebles where perceptual expertise has been trained (Gauthier & Tarr, 1997; Gauthier, Williams, Tarr, & Tanaka, 1998). Notably, Albonico et al. (2018) observed a greater inversion effect on the perceptual efficiency of processing faces compared to words (which are thought to also be processed by expert mechanisms) and houses. Perceptual

efficiency is estimated by comparing human performance (in the form of contrast thresholds) against an ideal observer (see Pelli and Farell (1999)). In short, the ideal observer is typically implemented as a computer program which makes a maximum likelihood choice in a given recognition task and represents optimal human performance (Pelli & Farell, 1999). When visual noise is added to a stimulus, it degrades both the human and ideal observer's abilities to perform the recognition task. If there is no noise added to the image, the ideal observer performs perfectly, and the human observer is limited by what is termed equivalent input noise which reflects the degradation of signal within the human observers' visual system (Albonico et al., 2018; Pelli & Farell, 1999). The resulting ratio of human vs. ideal observer performance with and without noise, therefore, indicates the human observer's ability to use the information at hand to make a decision, with the difficulty of the task controlled for. Variations in efficiency are said to reflect changes in strategies used by the human observer to extract valuable information from the image (Gold, Bennett, & Sekuler, 1999; Shafai & Oruc, 2018; N. Yang, Shafai, & Oruc, 2014). Albonico et al. (2018) demonstrated that inversion profoundly impacted efficiency for processing faces compared to words and houses but had little impact on internal noise. These results suggest that a change in strategy used to exact information is the explanation for the inversion effect for faces but not for another class of expertly processed stimuli, words or for non-expert stimuli such as houses. Perhaps because each word differs in first order relations, rather than second order relations, expertise does not result in an inflated inversion effect for these stimuli. The use of second order relations (or the relative spacing of features that share a common configuration) to make distinctions between visual stimuli is referred to as *configural processing* or *configural encoding* in the literature (Carey & Diamond, 1994; Maurer, Le Grand, & Mondloch, 2002).

The inversion effects detailed here have been generally reported to develop over the lifetime (Bruce et al., 2000; Carey & Diamond, 1994; Hills & Lewis, 2018; Mondloch et al., 2002). Early work on the developmental trends of the face inversion effect (FIE) has been

criticized, mainly for methodological limitations of studying children including floor effects, ceiling effects, cohort effects from using of cross-sectional experimental designs with small samples, and low power due to low sample sizes (Flin, 1983; Hills & Lewis, 2018). Additionally, children tend to have poorer performance than adolescents and adults in any task, meaning that investigators must compare relative performance across age groups (Hills & Lewis, 2018). Despite these limitations, a consistent observation is that upright face processing continues to improve throughout development when there are no floor or ceiling effects (Carey & Diamond, 1994; Hills & Lewis, 2018; Mondloch et al., 2002), when task difficulty is adjusted with age (Bruce et al., 2000; Hills & Lewis, 2018), and when cohort effects are controlled for with within-subject, longitudinal design (Hills & Lewis, 2018). Carey and Diamond (1994) demonstrated that 6- and 10-year-old children are slower than- and make more errors than adults when recognizing familiar and unfamiliar upright faces. Importantly, adult's reactions times were significantly slowed by inversion, compared to 10-year old's, who recognized upright and inverted faces at the same speed. This result shows improvement with age, accompanied by an inversion effect that occurs sometime between 10 years of age and adulthood. Mondloch et al. (2002) investigated whether these types of improvements are related to an improvement in configural processing by testing face recognition in children and adults with face stimuli that differed based on the spacing of internal features (spacing set), shape of internal features (features set) and faces that differed based on the shape of the outer contours of the face (contour set) (Jane recognition paradigm). Again, an overall increase in performance for upright faces was shown based on increased accuracy with age, and decreased reaction times with age for faces where all manipulations were made. However, when observing performance for each face set individually, accuracy was adult-like for contour-adjusted faces by age 6, adult-like for feature-adjusted faces by age 10, but inferior at age 10 compared to adults for the spacing set. Furthermore, an inflated inversion effect was observed at age 10 and in adults for the spacing set of faces, compared to the feature or contour sets. Inversion impacted performance

across all ages, and all stimulus sets, but disproportionately impacted recognition of inverted faces from the spacing set for 10-year-old children and for adults (Mondloch et al., 2002). Together, these results show that aspects of face recognition that rely on the processing of the spacing of internal features (configural processing) develop more slowly compared to feature-based, or contour-based processing, and it is not until adequate levels of expertise are acquired (roughly ten years) for inversion to disproportionately impact this type of performance. Finally, Hills and Lewis (2018) recently demonstrated, with both age-matched and adult face stimuli, and a large cross-sectional cohort of participants aged 5-18, that upright face recognition improves with age and that the inversion effect appeared between ages 9 and 11. Follow up assessment of the nine-year-old children at ages 10 and 11, showed a detectable relative face inversion effect at 10 and 11, but not at 9 years. Overall, the studies described provide consistent evidence that the inversion effect, which is used a behavioural signature for visual-perceptual expertise, takes roughly ten years to develop and is likely a result of an increased reliance on configural processing following years of practice individuating faces.

Often used interchangeable with *configural processing*, *holistic processing* is also a term used as an explanation for the inversion effect, and for expert face recognition performance. The conflation of configural and holistic encoding is due, in part, by multiple definitions of holistic encoding/processing used in the literature (see Richler, Palmeri, and Gauthier (2012)). For example, the term has been used interchangeably with configural processing (Robbins & McKone, 2007), or has been used to describe a process in which faces are processed, or represented in memory as undifferentiated wholes (i.e., face perception relying on more holistic or gestalt representations than representations of individual parts/features) (Farah, Wilson, Drain, & Tanaka, 1998). Two experimental paradigms argued as evidence for expert holistic processing of faces in humans include the *composite face test* (Young, Hellawell, & Hay, 1987) and the *Parts/Whole face recognition test* (Tanaka & Farah, 1993). The original composite face test involved combining the top and bottom halves of faces from highly familiar famous identities

to form a new unfamiliar face configuration called a composite. Participants had to identify the identity belonging to the top or bottom half of the face when the halves are aligned perfectly (forming a new unfamiliar face configuration) and when the halves are misaligned (the two halves appear distinct). Participants were slower to recognize composite faces demonstrating that when the typical configuration of the identities face was altered, it interfered with the ability to recognize individual features (Young et al., 1987). Further, inversion removed the interference effect of composite faces, supporting the notion that configural face information is removed with inversion, forcing more feature-based recognition strategies (Diamond & Carey, 1986; Yin, 1969). The findings have since been replicated using faces of familiar acquaintances (Carey & Diamond, 1994) as well as unfamiliar faces (Carey & Diamond, 1994; Le Grand, Mondloch, Maurer, & Brent, 2004; Michel, Rossion, Han, Chung, & Caldara, 2006; Robbins & McKone, 2007).

The developmental trajectory of the composite face effect however is not consistent with that observed for the inversion effect. First, Carey and Diamond (1994) replicated Young et al.'s (1987) findings with familiar faces of acquaintances and learned unfamiliar faces in adults, but also in children aged 6 and 10. Although general improvements in task performance were observed with age, as shown by decreased reaction time and decreased error rates, the composite effect was independent of age, with all age groups making more errors with- and taking longer to identify the top halves of composite faces as compared to non-composites (Carey & Diamond, 1994). By ten-years, inverting the stimuli removed the interference effect of the composite faces, also providing evident that inversion disrupts holistic, or configural processing. In an alternate version of the composite face test, composite interference effects were observed again in children aged 6 (Mondloch, Pathman, Maurer, Le Grand, & de Schonen, 2007), then in children as young as four (de Heering, Houthuys, & Rossion, 2007). These authors used an unfamiliar face paradigm that requires participants to make same-difference judgements of a cued half of the face with pairs of composite or non-composite faces. Expert

face processing, when operationalized with by ‘holistic processing’, as evidenced by the composite face effect, could therefore be an innate ability, or is dependent on early visual experience before the age of 4.

The part/whole paradigm has also been used as a means of testing whether faces are recognized based on individual parts, or more holistically (Tanaka & Farah, 1993). With the assumption that all types of pattern or object recognition rely on some combination of feature-based and holistic processing, the part/whole paradigm assesses the extent to which face recognition relies on holistic visual representations. The part/whole paradigm asks participants to first learn the identities of target stimuli, and then in a forced-choice recognition task, identify either isolated features from the target stimuli, or features presented within the context of whole stimuli. Should features be better recognized in the context of the whole stimuli, the authors would argue that participants are relying more heavily on holistic representations (representations that include all individual features bound together as a unified whole) for that stimulus. If the identities of the stimuli are recognized as or more effectively by their constituent features presented in isolation, then it is argued that representations of features are playing a stronger role in recognition. The first application of the part/whole paradigm compared recognition of faces to recognition of scrambled faces (features switch spots with each other), inverted faces, and houses (Tanaka & Farah, 1993). Faces always showed a whole-face advantage, meaning that recognition of identities based on features presented in the context of their whole faces was more accurate than recognition based on their parts/features presented in isolation. Scrambled faces showed the inverse effect, where parts were better recognized when presented on their own than within a scrambled face, and part-whole recognition was roughly equivalent for inverted faces and houses (Tanaka & Farah, 1993). The results supported the notion that face recognition relies more heavily on holistic representations than feature representations. They also demonstrated that face representations affected by inversion are relatively holistic representations (Tanaka & Farah, 1993). In a follow up experiment Tanaka

and Sengco (1997) tested the part/whole effect for faces where the second order relations of facial features were manipulated by adjusting the distance between the eyes. The researchers found that recognition of face parts (including the mouth and nose) was most accurate when presented in faces in their original configuration compared to when presented in a new configuration (spacing between eyes manipulated), or in isolation (Tanaka & Sengco, 1997). This pattern was not replicated with inverted faces, or with houses, demonstrating that the spacing between features, as well as the features themselves are encoded together into a holistic representation of the face (Tanaka & Sengco, 1997).

The part/whole effect is observed in children as young as six, and the magnitude of the effect is similar through development providing evidence consistent with the composite face effect that holistic processing develops early or may be innate (Tanaka, Kay, Grinnell, Stansfield, & Szechter, 1998). Also consistent with the developmental observations of the composite face effect, overall recognition accuracy for upright whole faces and features improves with age (as observed with 6-, 8-, and 10-year old's), however, performance with inverted faces and features has not been shown to vary with age. Importantly, there was no difference between upright and inverted performance at age 6, but one observed at age 10, revealing the development of an inversion effect in this age range, possibly due to increased experience with upright faces over this period (Tanaka et al., 1998).

The inversion effect, composite face effect, and part-whole effect are all behavioural signatures, suggested to be evidence for the use of holistic/configural strategies for expert face recognition.

1.3.2 Neuropsychological & Neurophysiological signatures of face recognition

The first indication of the neural localization of face recognition processing were revealed by observations of individuals with acquired prosopagnosia. The condition, characterized by the inability to recognize others based on visual perception of their faces

following brain injury, was observed to be commonly accompanied by left visual field defects, a symptom of right hemisphere lesions (Hecaen & Angelergues, 1962). Early post-mortem analysis revealed occipitotemporal lesions in the right hemisphere in all cases, however, accompanying left hemispheric lesions led researchers to believe that bilateral lesions may be necessary for the deficits observed in prosopagnosia (Damasio, Damasio, & Van Hoesen, 1982; Meadows, 1974). The advent and improvement of neuroimaging techniques like magnetic resonance imaging (MRI), computerized tomography (CT), and positron emission topography (PET), allowed researchers to confirm dominance of face recognition processes to the right occipitotemporal cortex (De Renzi, Perani, Carlesimo, Silveri, & Fazio, 1994). Various levels of sparing of face recognition in patients with similarly sized and located lesions suggested inter-individual differences in the level of hemispheric lateralization and that a healthy left hemisphere can support some face recognition abilities (De Renzi et al., 1994). By testing various aspects of face perception and recognition memory in 10 patients with acquired prosopagnosia, Barton (2008), confirmed that prosopagnosia is more severe in patients with bilateral lesions (suggesting a minor contribution of the left hemisphere), lesions to right fusiform gyrus impact the perception of facial structure configuration, and more anterior lesions on the temporal lobe are most likely to disrupt access to face memories.

Early functional imaging studies with healthy subjects using PET, which measures changes in regional cerebral blood flow, helped to confirm that select regions of the right occipitotemporal cortex, specifically within the fusiform gyrus are activated during behavioural tasks involving viewing faces and not objects (Haxby et al., 1991; Sergent, Ohta, & Macdonald, 1992), or locations (Haxby et al., 1991). Since, further technological advancements including functional magnetic resonance imaging (fMRI), and electroencephalogram (EEG) recording, have revealed more precise signatures of face recognition processing and expertise. In a follow up to the Haxby et al. (1991) study, Clark et al. (1996) revealed similar areas of activation with fMRI, which reveals metabolic activity via difference estimates of blood oxygenation without the

use of radioactive markers needed for PET. The activation signals were more precise revealing increased activation of a discrete ribbon of cortex extending from the ventrolateral occipital cortex in the inferior occipital sulcus to ventral occipitotemporal cortex in the fusiform gyrus in response to faces that was highly consistent between subjects and testing sessions (Clark et al., 1996). The investigation also revealed significant individual differences in the precise topographical locations of the activated regions of interest (ROI) demonstrating the superior spatial resolution, and anatomic specificity for the imaging technique (Clark et al., 1996). Although evidence was building for a region of cortical specialization for face processing, Kanwisher, McDermott, and Chun (1997) argued that previous studies had not adequately ruled out alternative explanations such as the impact of low level feature extractions, visual attention, and recognition of different exemplars of subordinate level categories. In response to these limitations the authors compared activation responses during passive viewing of multiple views of faces, animate (human hands) and inanimate objects (houses, which also served as multiple within category exemplars), and two-tone scrambled faces (controlling for luminance differences). A consecutive matching task was also completed for faces and human hands which had participants indicate each time two of the same images were presented in a row, controlling for visual attention. All comparisons revealed selective activation to faces, in a region of the right fusiform gyrus, aptly deemed the fusiform face area (FFA), which the authors argued as strong evidence for cortical specialization (Kanwisher et al., 1997).

Improvements in the spatial resolution of fMRI technology have revealed a core network of connected brain regions associated with the processing of faces (Ishai, Schmidt, & Boesiger, 2005). These regions include the occipital face area (OFA), an area located in the inferior occipital gyri, the FFA of the lateral fusiform gyrus, and the superior temporal sulcus (STS) (Fox, Iaria, & Barton, 2009; Haxby, Hoffman, & Gobbini, 2000; Ishai et al., 2005). Early models suggested the OFA serves as an entry point for face processing, responsible for early perception of facial features, proceeded by a segregation of processing mechanisms, with

dynamic aspects of faces such as perception of eye gaze, expression, or lip movement handled by the STS, and invariant aspects of faces such as face identity handled by the FFA (Haxby et al., 2000), although absolute segregation of these processing mechanisms has been challenged (Fox et al., 2009). A systematic review of 44 cases of acquired prosopagnosia using a technique called lesion mapping found that in all 44 cases, lesions intersected with, or were functionally connect to the right FFA suggesting a predominant role of the FFA in processing face identity (Cohen et al., 2019).

A question that remains is whether the FFA is innately specified for the processing of faces, or rather, more generally represents an area of cortical space that is prepared to acquire expertise for any class of object, given enough motivation, and extensive visual experience (Kanwisher et al., 1997). Evidence that the FFA and OFA are recruited following acquisition of expertise in non-face stimuli such as birds (Gauthier et al., 2000; Xu, 2005; N. T. Yang, Kung, & Chu, 2019), cars (Gauthier et al., 2000; Ross et al., 2018; Xu, 2005), novel objects like greebles (Gauthier, Tarr, Anderson, Skudlarski, & Gore, 1999), or radiographic images (Harley et al., 2009) suggests the latter. It has been proposed that automatic subordinate level processing in experts, typically accompanied by holistic or configural processing may be the key for recruitment of the FFA (Gauthier et al., 2000). Regardless of arguments surrounding the FFA's specificity for faces vs. objects of perceptual expertise, its recruitment for perceiving faces suggests typically developed adults are well-practiced experts in face perception.

A final signature of expert face processing I will briefly describe are specific event-related potentials (ERPs) measured by electrodes in response to faces. An ERP is a measurable voltage change resulting from the summation of electromagnetic activity generated from synchronously active neurons in the brain responsive to a specific stimulus (*The Oxford Handbook of Event-Related Potential Components*, 2011) The resulting pattern of positive and negative voltage deflections can provide an electrical signature for certain types of cortical processing. An early observation of a negative voltage deflection, roughly 170ms after the visual

presentation of a face (called the N170) with electrodes placed on the lateral posterior scalp, has become a electrophysiological hallmark of face processing in humans (Bentin, Allison, Puce, Perez, & McCarthy, 1996; Rossion & Jacques, 2008). Initial investigations observed large N170 deflections for human faces compared to several categories of objects, including scrambled faces, cars, scrambled cars, butterflies, human hands (showing N170 is face specific, not human specific), and animals faces (showing the N170 is human face specific) (Bentin et al., 1996). A case study of an individual (PHD) with severe prosopagnosia following a brain injury revealed that in comparison to 24 healthy controls who demonstrated a reliable N170 response to faces, PHD lacked a face-specific N170 component (Eimer & McCarthy, 1999). The findings are consistent with the notion that the N170 reflects processes involving human face analysis, however, the precise anatomical origin of the signal was unknown. Dalrymple et al. (2011) were able to determine with five patients with prosopagnosia, and lesions spanning different combinations of the core face-processing network that the N170 likely originates from a combination of at least two components of the network rather than any single cortical component alone. With respect to development, typically the latency decreases, and amplitude increases for the N170 response to faces with age (M. J. Taylor, Batty, & Itier, 2004; M. J. Taylor, McCarthy, Saliba, & Degiovanni, 1999).

Holistic and configural processing have been proposed as processing mechanisms associated with the most commonly observed behavioural and physiological indicators of expertise in face processing (for review see: Yovel (2016)). For example, increased activation to the fusiform face area has been shown for upright vs. inverted faces, demonstrating a neurophysiological inversion effect (Gilaie-Dotan, Gelbard-Sagiv, & Malach, 2010; Yovel & Kanwisher, 2005) although not always (Epstein, Higgins, Parker, Aguirre, & Cooperman, 2006; Kanwisher, Tong, & Nakayama, 1998). A larger and slightly delayed N170 response to inverted faces, compared to upright faces (Rossion & Gauthier, 2002; Rossion, Gauthier, et al., 2000) is also suggested as evidence for an electrophysiological inversion effect (Yovel, 2016). However,

it is not the intent of this thesis to argue for or against these proposed explanations. Rather, outlining these observed signatures of face expertise and their development is meant to convey that an expert face processing mechanism has been defined for healthy adults, which can establish context for investigations of face expertise in populations who have challenges with face perception.

1.3.3 Innate dispositions

In 1975, Goren, Sarty, & Wu observed an innate “preference” for schematic faces over scrambled or blank face shapes, operationalized by increased eye and head turns in infants just 9 minutes old. These fascinating observations were later replicated by M. H. Johnson, Dziurawiec, Ellis, and Morton (1991), suggesting an innate disposition for attending to face-like stimuli. In combination with twin studies, which consistently show higher correlations of face recognition ability between monozygotic twins (MZ; those sharing the 100% of their genes and same environment) than dizygotic twins (DZ; those who share 50% of the genes the same environment), these findings suggest a strong genetic component to expert face recognition (Wilmer, Germine, Chabris, Chatterjee, Williams, Loken, et al., 2010; Wilmer, Germine, Chabris, Chatterjee, Williams, Nakayama, et al., 2010; Zhu et al., 2010). Zhu et al. (2010) tested face specific recognition abilities in 102 MZ twins and 71 DZ twins, aged 7-19. Heritability of a specific skill is demonstrated by higher correlations of abilities for MZ twins than DZ twins. Face specific recognition ability, operationalized as the difference between accuracy scores in an old/new recognition memory task completed for faces and houses, face inversion effect, and composite face effects all showed higher correlations for MZ than DZ twins (Zhu et al., 2010). Notably, substantial variance in face recognition abilities were left unexplained by heritability, suggesting an influence of experience as well. Performance in an adjusted Navon letters task (Navon, 1977), which tests for the attentional privilege of global vs. local information (global processing has been linked to holistic processing of faces) was not shown to be heritable,

suggesting that face perception is not linked to a more general heritability of a global visual processing style (Zhu et al., 2010). Face perception requires the rapid integration of several local elements (features) into a global configuration (whole). Hence, a perceptual style biased towards the global configuration has been suggested to be related to face recognition (Behrmann, Avidan, et al., 2006). Upright face recognition performance on all tasks did not correlate with IQ, however inverted face recognition (from the face inversion test), and misaligned face recognition (from the compound face test) did correlate with IQ, suggesting face recognition/perception abilities belong to a specific and distinct domain of cognition. Using the CFMT as the measure of choice Wilmer, Germine, Chabris, Chatterjee, Williams, Loken, et al. (2010) have also compared face recognition ability for MZ (164) and DZ (125) adult twin pairs (aged 18-57). Face recognition memory was highly correlated ($r = 0.70$) and significantly larger for MZ twins compared to DZ twins ($r = 0.29$). The authors concluded, based on the "ACE" twin model, which states that an MZ correlation at least double the DZ correlation indicates 100% of family resemblance is genetic, that variability in face recognition abilities as tested by the CFMT is largely accounted for by genetic differences. A modest difference between reliability estimates for the CFMT and the MZ correlation was interpreted as a "non-trivial non-familial environmental contribution to CFMT performance" (Wilmer, Germine, Chabris, Chatterjee, Williams, Loken, et al., 2010). Low observed correlations between CFMT scores and two control non-face memory tests (a non-visual linguistic word pair memory test and an abstract art memory test) in a large non-twin cohort ($n > 1500$) and a subset of the twins ($n = 120$) led the authors to conclude that face recognition ability and its genetic basis depend on face specific mechanisms, rather than factors such as general memory or general visual processes (Wilmer, Germine, Chabris, Chatterjee, Williams, Loken, et al., 2010). Genetic investigations of face recognition abilities highlight two important messages. One, face recognition ability is highly heritable, and two, face recognition is a highly specific cognitive ability.

These studies also painted a developmental story of face recognition ability. Zhu et al. (2010) tested face recognition abilities in children aged 7-19 and found that substantially more variance in face recognition ability was explained by genetic factors in older children (13-19 years) than younger children (7-12 years). Wilmer, Germine, Chabris, Chatterjee, Williams, Loken, et al. (2010)'s study with adults found that familial resemblance in face recognition ability was primarily accounted for by genetic factors, and that nonfamilial experiential factors make just a modest contribution. Results with adults, although with a different cohort of twins, demonstrate a continuation of the developmental trend observed for children, that genetic factors account for more variance of face recognition ability with age. Together, the developmental patterns suggest that genetic influences may have a larger influence on the final level of achieved performance, with experience potentially modulating the time course of development (Zhu et al., 2010). Interruptions to the typical time course of development of face recognition processes via altered visual experience could prevent or limit the achievement of a more genetically determined potential final ability.

Familial studies of individuals with congenital prosopagnosia also contribute to the observed heritability of face recognition abilities. Duchaine, Germine, and Nakayama (2007) outlined a case study of 10 family members, including a mother, father, their 7 children, and a maternal uncle who all had severe deficits of face recognition, including clear deficits with famous face identification, poor performance on the CFMT, accompanied by difficulty with face perception indicated by poor performance on the Cambridge face perception test (CFPT). The authors were also able to test object recognition, emotion perception of faces, and assess the Navon letters task. Despite severe deficits of face recognition, the prosopagnosic siblings performed normally with facial emotion recognition, had typical cognitive abilities illustrated by their professions, and demonstrated a typical global processing bias as measured with the Navon task, indicating that general deficits with global processing were not the root cause of their face recognition challenges (Duchaine et al., 2007). The siblings did perform poorly with

within-class object recognition as well, leading the authors to conclude that their impairments resulted from a genetic condition that selectively impacted high-level face and object recognition (Duchaine et al., 2007). A separate family study of 7 family members across 4 generations demonstrated similar findings, suggesting a common genetic factor leading to observed face recognition deficits (Schmalzl, Palermo, & Coltheart, 2008).

1.3.4 Experiential influences

A common explanation for the protracted development of expert face recognition is the need for extensive experience individuating faces (Nelson, 2003; Richler, Cheung, & Gauthier, 2011). Indeed, recognition of other stimulus classes, such as birds, or dogs, requires high levels of motivation and practice by a novice viewer to reach expert levels, as indexed by fast and automatic subordinate levels of classification, the inversion effect, or activation of the FFA. The question remains, however, what kind of experience with faces is necessary for the development of expert face recognition? Counter to the protracted development hypothesis, holistic processing of faces has been shown to be fully mature, i.e., qualitatively present and quantitively at adult strength for all measures of holistic/configural processing by 5 years of age (Crookes & McKone, 2009; McKone, Crookes, Jeffery, & Dilks, 2012). Here, I will outline evidence from the literature linking visual experience to the development of expert face recognition processes, and address concerns regarding the face specificity of these processes.

Genetic investigations of face recognition performance suggested that experience may play an important role in the time course of the development of expert face recognition processes (Wilmer, Germine, Chabris, Chatterjee, Williams, Loken, et al., 2010; Wilmer, Germine, Chabris, Chatterjee, Williams, Nakayama, et al., 2010; Zhu et al., 2010). A major contribution to understanding the role of experience comes from a group who investigated the impacts of early visual deprivation for patients whose dense congenital cataracts blocked visual input to the retina until they were removed early in infancy (de Heering & Maurer, 2014; Le

Grand et al., 2004; Maurer, Brent, Grand, & Mondloch, 2003; Maurer, Le Grand, Mondloch, & Brent, 2001). Initial investigations revealed significant impairments in distinguishing faces with subtle configural differences (differing in the spacing of internal facial features) for adolescents (mean age = 14) who had had dense, centrally located bilateral cataracts removed in infancy (Maurer et al., 2001). In contrast, these patients had no difficulty distinguishing faces differing in the shape of individual features, showing that years of compensatory visual input can lead to normal feature perception, but early visual deprivation can restrict the typical development of configural processing (Maurer et al., 2001). Impaired performance discriminating faces with small configural alterations between features, with spared performance for feature altered, or contour altered faces observed for patients with unilateral dense cataracts removed from the left eye (blocking visual input predominantly to the right hemisphere in infants, due to the faster development of sensitivity to stimuli in the temporal visual field than the nasal visual field in the first six months (T. L. Lewis & Maurer, 1992)) showed that the right hemisphere was especially important for the development of face specific configural processing (Maurer et al., 2003). Next, the research group tested holistic processing with an in-house validated version of the composite face task, where participants were required to make same/different judgements for the top halves of two faces presented simultaneously, whose bottoms halves always belonged to different-identities and could be presented either in-alignment with each top half or misaligned with the top halves (Le Grand et al., 2004). In this version of the *composite face task,* a composite face effect is demonstrated by increased accuracy and decreased reaction times making same judgements for misaligned faces compared to aligned faces (where the bottom half of the face is combined with the top half, creating the compound face and the perception of a new identity which makes discrimination of the top half of the face more difficult). Participants with early visual deprivation (mean age = 15) showed little evidence of a composite face effect. Rather, these participants performed significantly better than non-deprived controls in same, aligned trials, suggesting that aligned faces were not being processed holistically and thus, not

causing interference while comparing the top halves of the faces. The results suggest that holistic processing has not developed for individuals with early visual deprivation (Maurer et al., 2002).

In 2014, de Heering & Maurer extended the investigation of face recognition for individuals with bilateral cataract reversals to an older cohort of adult participants (mean age = 21) with a battery of tests, including tests of face recognition memory (famous faces test, and CFMT), a test of face perception (a Monkey-Jane test that requires same/different responses for sequentially presented upright and inverted human and monkey faces altered by the spacing of internal features) and the composite face task. The authors observed significantly lower face recognition memory for familiar and recently learned unfamiliar faces tested by the famous faces test and CFMT, respectively, demonstrating profound impacts of early visual deprivation on the ability to remember faces. Although participants were overall slower for the Monkey-Jane, and composite face tasks, deficits were limited to upright human face recognition in the Monkey-Jane task showing impairments specific to upright human faces, and surprisingly, cataract-reversal participants demonstrated typical composite face effects (de Heering & Maurer, 2014). An apparent composite face effect in adults but not adolescents (Le Grand et al., 2004) reflects a delay in acquisition, rather than a permanent deficit for cataract reversal patients. Indeed, three participants who were tested in both the Le Grand et al. (2004) and the de Heering and Maurer (2014) experiments showed an increase in the magnitude of their compound face effects by 20% over the 8-9 year period (de Heering & Maurer, 2014). Overall, these experiments reflect the importance of early visual input for the normal development of expert face recognition processes, and importantly, that prolonged visual experience can recover holistic face processes.

Although attention seems to be inherently wired for faces in newborns (Goren et al., 1975), faces have been presumed to make up important early visual experience, and little was known empirically regarding the basic face exposure statistics. These assumptions were

confirmed, and exposure statistics described in a study characterizing early visual input for infants in 2015 (Jayaraman, Fausey, & Smith, 2015). Twenty-two infants from 1-11 months old wore a head-mounted camera for an average 4.5 hours of a routine day, from which over 70,000 images were coded for faces. Faces were highly frequent in the visual fields of very young infants, present in a quarter or more of collected frames (Jayaraman et al., 2015). For young infants, these faces belonged to just a few unique individuals, were likely to be within 2 feet of the infant observer (making them visible based on typical infant visual acuity), with viewing distances increasing over time, and across all ages faces typically presented with both eyes visible (Jayaraman et al., 2015). The waking hours of younger infants were more densely filled with faces, compared to older infants implying a frontloading of visual experience with prototypically large, frontal view faces. A follow up study with 36 infants, extending the age range to 1-24 months, replicated Jayaraman et al. (2015)'s findings, demonstrating that for infants less than 3 months old, faces were in view for 14 minutes per hour (Jayaraman, Fausey, & Smith, 2017). These exposure durations were substantially reduced for infants older than 18 months who only had faces in view for less than 5 minutes per hour. The reduction in face exposure was not due to few individuals in view of the infants, as the number of bodies remained consistent, suggesting older infants receive more non-face visual information about people, or are busy looking at other objects like toys.

Dense visual experience with faces in infants less than 3 months old is consistent with accounts suggesting that early visual experience is central to the development of specialized face processing mechanisms (Jayaraman et al., 2015; Le Grand et al., 2004; Maurer et al., 2003; Maurer et al., 2001). The authors also suggest an answer to the nature (genetically driven) vs. nurture (experience driven) debate regarding face recognition expertise in adult humans: early environmentally constrained visual experience with faces combined with an experience-expectant innate template that guides attention to faces together are necessary for observed visual expertise with faces in adulthood (Jayaraman et al., 2015).

While early visual experience seems to set the cortical foundation for the typical development of expert face recognition processes, a common and robust behavioural phenomenon called the *Other Race Effect* (ORE; also called the own race effect, own race bias, or cross race effect) demonstrates a key environmental factor that fine-tunes human face recognition expertise (Golby, Gabrieli, Chiao, & Eberhardt, 2001; Malpass & Kravitz, 1969; Meissner & Brigham, 2001; Michel, Rossion, et al., 2006). Three decades of investigations reviewed in a meta-analysis by Meissner and Brigham (2001) demonstrate this robust phenomenon, wherein individuals are better able to remember faces belonging to their own, familiar race, compared to other, less familiar races. The ORE is assumed to reflect differences in experience with own-race and other-race faces (Malpass & Kravitz, 1969; Meissner & Brigham, 2001). Indeed, several investigations have demonstrated that increased experience with other races can reduce or diminish the ORE (Hancock & Rhodes, 2008; Mousavi & Oruc, 2020; Rhodes et al., 2009; Sangrigoli, Pallier, Argenti, Ventureyra, & de Schonen, 2005). Sangrigoli et al. (2005) observed a reversal of the ORE for a group of Korean adults who were adopted to Francophone Caucasian families as children and raised in western Europe, demonstrating that the race of the individual is actually irrelevant. Rather, an individual's visual system is honed and tuned to the types of faces they experience during development. Further, Hancock and Rhodes (2008) demonstrated an association between self-reported exposure to other race faces and the degree of the ORE for Caucasian and Chinese adults in Australia, and Mousavi and Oruc (2020) have shown that East Asian individuals in Vancouver who self-reported sustained high levels of exposure to both Caucasian and East Asian faces can reach native-level face expertise for both Caucasian and East Asian faces. These studies demonstrate that the visual system is not limited to developing expertise for recognizing one type of face.

Signatures of expert face recognition are also shown to be more pronounced for own race faces than other race faces, including the inversion effect (Mousavi & Oruc, 2020; Sangrigoli & De Schonen, 2004), whole-parts recognition advantage (Michel, Caldara, &

Rossion, 2006; Tanaka, Kiefer, & Bukach, 2004), the composite face effect (Michel, Rossion, et al., 2006), and fusiform gyrus activity (Golby et al., 2001). With increased experience with other race faces however, observers have been shown to gain native-like inversion effects (Mousavi & Oruc, 2020), whole/part recognition advantages (Michel, Caldara, et al., 2006; Tanaka et al., 2004) and composite face effects (Bukach, Cottle, Ubiwa, & Miller, 2012). The literature on the other race effect demonstrates that face recognition abilities are honed and tuned by visual experience.

Importantly, reduced or diminished OREs revealed by improvements in recognition memory for-, and increased or improved configural/holistic processing with other race faces as a product of experience, demonstrates that these improvements are likely not due to general improvements in memory or general visual processing. Rather, these improvements are face specific and related to visual input.

Balas and Saville (2015, 2017) have shown that small town observers (individual growing up in communities with fewer than 1000 individuals) have significantly poorer face recognition abilities as assessed by the CFMT than large-town observers (those growing up in more dense communities with greater than 30,000 individuals). These *hometown population density* findings were replicated by Sunday, Dodd, Tomarken, and Gauthier (2019) with a sample from a different region, and importantly did not extend to recognition tests of non-face objects. Together, these studies suggest that face recognition abilities are sensitive to the level of exposure, as well as the type of exposure as demonstrated by the *other race effect*.

I have previously discussed the developmental timelines for behavioural signatures of face recognition, showing that configural and holistic processing is observed early in childhood. However, the presence of these signatures does not mean that face recognition ability ceases to improve. Rather, upright face recognition abilities continued to improve in a quantitative fashion through development. We also have observed that visual experience can result in improvements of recognition with specific face subtypes, like improvements of other race face

recognition with exposure. But when do face recognition abilities peak, and are those abilities specific to faces, or more general attentional or memory improvements? A large online cross sectional study completed by Germine et al. (2011) with three separate, large cohorts (*n* = 44,680, 14,822, and 4,280), aged 12-65, observed peak face recognition abilities between 30 and 34 years old, with 2 different testing procedures (CFMT and an old/new face recognition task), and 4 different sets of face stimuli. These abilities improved from adolescence and continued to improve throughout young adulthood, compared to name recognition and inverted face recognition abilities which peaked at 23-24 years and remained stable or declined into adulthood. The authors noted that the dissociation between upright face recognition and inverted face recognition/name recognition demonstrates that improvements in face learning abilities are not due to more general factors relating to attention, memory, or self-selection bias in the sampling method. Instead, they suggest that daily life may provide the training and experience necessary to fine tune and continue to drive improvements in upright face recognition in early adulthood (Germine et al., 2011). But what does the daily life of a typical adult look like with respect to face-related visual input?

The answer to this question comes from another study utilizing an eyewear embedded camera, worn on a routine day by 30 healthy adults living in Vancouver (Oruc, Shafai, Murthy, Lages, & Ton, 2019). The naturalistic observation of face exposure via this first-person perspective footage found that faces have a prominent presence in the daily adult visual experience, with 12 minutes of every waking hour spent exposed to faces (Oruc, Shafai, Murthy, et al., 2019). This level of exposure is similar to those observed in infants in their first three months (Jayaraman et al., 2015; Sugden, Mohamed-Ali, & Moulson, 2014). Oruc, Shafai, Murthy, et al. (2019) face exposure statistics showed that the adult face-diet predominantly consists of familiar faces, which are viewed at close distances. Median face size was 6°, corresponding to a median viewing distance of 128 cm, with median face size of familiar faces significantly larger (7.1°) than unfamiliar median face size (4.9°)(Oruc, Shafai, Murthy, et al.,

2019). The face sizes predominant in typical exposure align well with behavioral findings showing efficient recognition of faces greater than 6° (N. Yang et al., 2014). With respect to face pose, other faces are most frequently encountered in three-quarters pose, followed by frontal, then profile (Oruc, Shafai, Murthy, et al., 2019). Observed pose exposure patterns favoring ¾ view faces are consistent with a well-established "¾ pose advantage" for encoding and recognizing faces (Krouse, 1981; O'Toole, Edelman, & Bülthoff, 1998; Troje & Bülthoff, 1996; Van der Linde & Watson, 2010a). The adult "face-diet" confirms a dense, rich and diverse daily experience with faces in adulthood that likely contributes to improvements and late maturation of face recognition observed by Germine et al. (2011). The relationship between exposure statistics to faces and various perceptual effects reported in the literature suggest that face expertise is adapted viewing conditions consistent with social interactions with familiar persons.

A question that remains debated to this day is whether expert face recognition is determined by a qualitative shift in encoding and recognition strategies or whether observed levels of expertise are achieved through quantitative improvements throughout development. Depending on one's definition of expertise, or whether configural strategies or holistic strategies are considered, the argument can shift from one side of the fence to the other. For example, given that the composite effect can be observed in children as young as 4, it could be suggested that innate face processing abilities improve quantitatively through development. On the other hand, one could argue that early development (ages 0-4) is crucial in developing holistic processing. Developmental changes in children so young, however, could be challenging to operationalize. The inversion effect can also be challenging to use as evidence for qualitative or quantitative shifts in expertise as inversion effects are observed for common objects, but only become inflated or exaggerated with so called expertise. Does the inflation of the inversion effect represent a qualitative shift in strategy, or a honing of an immature process for upright faces? These questions have important implications when we discuss hallmarks of expertise in autism spectrum disorder. For example, if those with autism demonstrate qualitative

face processing differences, potential explanations of those differences are dependent on whether you believe that expert face recognition results from a qualitative or quantitative shift in recognition processes. If you support the notion that adult-like expertise for faces is achieved early, through a qualitative shift in processing that emerges early and is genetically determined, failure to develop or demonstrate expert level qualitative signatures of face processing (such as holistic processing) indicates atypical or deficient visual perception of that stimuli. However, if you believe that the development of face recognition expertise is a qualitative *and* quantitative process and is achieved gradually with prolonged visual experience and practice, observing a qualitative difference in autism may results from limited practice or experience. As long as there is disagreement in the typical development of these processes in the literature, the lens with which the autism literature is interpreted is interchangeable. Therefore, I believe that any observed differences in face recognition abilities in autism should be considered from multiple angles, with consideration of parsimony, and recognizing that improving the functional independence of those on the autism spectrum are the fundamental objectives of research in this field.

1.4 Markers of face expertise in Autism

1.4.1 Behavioural signatures of expertise in ASD

Bird, dog, and car experts have demonstrated the impact that a special interest and years of experience can have on perception and expertise. Those with autism, however, represent a group whose expertise, when it comes to faces, is studied for the opposite reason. Those on the autism spectrum constitute a group who are described as appearing uninterested in faces, and as established in Section 1.2, have well-established and described challenges with face recognition and perception (Dawson et al., 2005; Griffin et al., 2021; Oruc et al., 2018; Simmons et al., 2009; Tang et al., 2015; Webb, Neuhaus, & Faja, 2017; Weigelt et al., 2012). The question that remains debated, is why those on the autism spectrum have challenges with

faces. Do these challenges represent perceptual or genetic differences unique to those with ASD or do they stem from reduced/atypical experience with faces? Understanding the causes and factors related to the challenges of face perception experienced by those on the is both necessary for the development of effective therapies or training programs and can also inform basic science questions surrounding the acquisition of expert recognition mechanisms. In the next section, I will review the hallmarks of face expertise in autism spectrum disorder.

1.4.1.1 The face inversion effect

Reduced or diminished face inversion effects in ASD could indicate atypical face processing for those on the autism spectrum. The difference between upright and inverted face recognition is argued by some to represent a qualitative switch from a general recognition process which focusses on features, to a face specific expert recognition mechanisms involving configural processing (Carey & Diamond, 1994; Hills & Lewis, 2018; Yin, 1969). It could be argued however, that inversion effects represent a quantitative, rather than qualitative difference in processing resulting simply as a bi-product of orientation dependent experience with upright faces (Sekuler, Gaspar, Gold, & Bennett, 2004). Interpretation of differences in face inversion effects in ASD may therefore change depending on one's views of the phenomenon. Initial reports investigating inversion effects for those with ASD suggested children and young adults with ASD may have strengths in recognizing expression and identity with inverted faces (Hobson, Ouston, & Lee, 1988; Tantam, Monaghan, Nicholson, & Stirling, 1989). The studies, while very exciting, were not without their flaws. Superior processing in young adults with ASD was concluded with a comparison group of individuals with intellectual disability in Hobson et al. (1988). This study is often cited incorrectly, suggesting superior performance is in comparison to typically developing individuals. In addition, both investigations included tasks of face emotion perception, which may include different perceptual mechanisms from face identity perception. In contrast, Hedley, Brewer, and Young (2015) recently compared inversion effects for a group of

adults with autism (*n* = 26, mean age roughly 29 years old) to a non-autistic control group matched for age and IQ with an old/new face recognition memory test with expression-neutral stimuli. Group-level deficits in face recognition were observed for both upright and inverted faces in ASD, suggesting both groups were similarly impacted by face inversion (Hedley et al., 2015). These findings echo several investigations of the face inversion effect from the last 20 years, which have demonstrated overall reduced face recognition performance, but similar magnitudes of inversion effects to non-autistic individuals for children (Scherf, Behrmann, Minshew, & Luna, 2008), adolescents (Teunisse & de Gelder, 2003), and adults (Barton, Hefter, Cherkasova, & Manoach, 2007; Lahaie et al., 2006; Rutherford, Clements, & Sekuler, 2007; Scherf et al., 2008). Of note, Nishimura, Rutherford, and Maurer (2008) used Mondloch et al. (2002)'s Jane recognition paradigm, which assesses sensitivity to featural, configural and contour alterations made to a common identity (Jane's face) to test perception of upright and inverted faces for adults with ASD (*n* = 17, roughly 20 years of age). Previous investigations with this paradigm demonstrate disproportionate inversion effects for faces with configural alterations, compared to faces with featural or contour alterations (Mondloch et al., 2002). Although those with ASD were slower than age- and IQ-matched controls in the simultaneous same/different discrimination paradigm, their accuracy was the same as controls across all conditions, and similar patterns of inversion were observed, with greater inversion effects for faces with alterations to 2nd order relations (configural changes), and much smaller inversion effects for feature or contour altered faces (Nishimura et al., 2008). These studies demonstrate that when the confound of expression is controlled, inversion effects are consistently observed in ASD. Further, these studies demonstrate typical inversion effects in several different cohorts of participants, indicating that a signature of face recognition expertise is still present for many individuals with ASD, although many are generally less skilled at discriminating and recognizing faces.

1.4.1.2 The composite face effect

Using a version of the composite face task where participants were instructed to recognize the top halves of faces (and the bottom half always differed in identity), a group of adolescents with ASD were less sensitive to misalignment (i.e., did not show as large of an advantage in misaligned trials) compared to a group of undergraduate controls (Teunisse & de Gelder, 2003). The study fell under scrutiny, however, for not matching their groups on IQ, or age, for only using incongruent faces (where the bottom halves were always different from the top halves), and for not testing bottom half face recognition. So, Gauthier, Klaiman, and Schultz (2009) completed another study of the composite face effect for age- and IQ- matched adolescents with ASD (*n* = 24, roughly 12 years of age). The investigation, which utilized a "complete" version of the composite task, meaning that congruent trials were included, and the top and bottom halves of the faces were both cued, found that compared to controls who performed better with congruent aligned faces, and were sensitive to alignment (stronger congruency effects for aligned than misaligned faces), the group with ASD demonstrated similar congruency effects for aligned and misaligned trials. The results suggest that while holistic processing is interrupted for controls when faces are misaligned, misalignment does not reduce holistic processing for the group with ASD. Nishimura et al. (2008), in addition to testing inversion effects in adults with ASD as described earlier, tested for congruency effects with the complete composite face task. The authors observed reduced overall performance, but typical congruency effects in their cohort, with similar performance when attention was cued to the top and bottom halves of faces. Lastly, and most recently, Ventura et al. (2018) observed typical holistic face processing mechanisms for adults with ASD (*n* = 14, roughly 27 years of age), and unlike Gauthier et al. (2009), found misalignment attenuated congruency effects in ASD. The authors suggest these alternate findings with adults indicate a developmental delay in the acquisition of typical holistic processing, perhaps due to reduced attention to faces (Ventura et

al., 2018). Overall, the literature suggests that those with ASD can process faces holistically, although this ability may develop more slowly, or atypically.

1.4.1.3 The part/whole effect

Investigations of the part/whole effect have led to mixed findings in the autism literature, although overall, there is evidence for holistic processing in some form, across most studies (Faja, Webb, Merkle, Aylward, & Dawson, 2009; Joseph & Tanaka, 2003; López, Donnelly, Hadwin, & Leekam, 2004; Wolf et al., 2008). As a reminder, holistic processing is operationalized here as better recognition of face parts within the context of the whole face than when presented in isolation. Studies have shown reliable whole face-advantages for children with and without ASD, with ASD performance seemingly driven by performance when recognition is dependent on the mouth, but not the eyes (Joseph & Tanaka, 2003; Tanaka et al., 2012). In Joseph and Tanaka (2003)'s initial study of children (n = 27, roughly 10 years of age), holistic processing was demonstrated for upright faces for those with ASD in conditions contingent on mouth recognition but not eyes. In a comprehensive examination of face recognition in a large cohort of children with ASD (n ~ 66, roughly 11 years of age), Wolf et al. (2008) demonstrated normal holistic processing in children with ASD for the eyes, and mouth, with better performance in eye conditions across groups. Poorer performance discriminating configural and featural changes for eyes, but not mouths compared to controls in a separate task however, led authors to agree that those with ASD may have selective impairments restricted to the processing of eyes (Wolf et al., 2008). In contrast, (López et al., 2004) did not observe holistic processing in adolescents with ASD (n = 17, roughly 13 years of age), unless cued for eyes and mouths, and Faja et al. (2009) demonstrated that adults with ASD, although less accurate overall, had typical whole face advantages strictly in eye recognition conditions only. The authors suggested that age differences or choice of stimuli (photographs of real faces in previous studies and line drawings in the current study) could have contributed to these

alternate findings. Overall, these studies suggest that holistic processing is measured by a whole face advantage in the part/whole task is spared in ASD, although may be applied atypically, or less automatically, depending on the cohort assessed.

As outlined, behavioural investigations of classic signatures of expert face processing in ASD largely demonstrate that those on the autism spectrum are capable of and do apply configural and holistic processing strategies for face recognition. These findings are consistent with a review of behavioural studies by Weigelt et al. (2012) who found quantitative reductions in face recognition abilities, but no qualitative differences (although see Tang et al. (2015)).

1.4.2 Physiological signatures of expertise in ASD – conflicting findings

1.4.2.1 The fusiform face area

In 2005, Schultz published a review of the neuroimaging literature to date (at the time) using fMRI, citing 15 reports, including a total sample size of 157 persons with ASD that found hypoactivation of the FFA in response to faces (Schultz, 2005). The author proposed that the failure to demonstrate typical FFA activation represented a failure to demonstrate an intrinsic interest for faces in ASD. This speculated failure, suggested to be related to abnormal amygdala function in autism (Critchley et al., 2000; Pierce, Müller, Ambrose, Allen, & Courchesne, 2001; Schultz, 2005) that reduces the saliency of faces, limits the ability to accumulate sufficient experience to develop perceptual expertise for faces. Since, the literature has been mixed, with certain authors finding reduced face-specific FFA activity in ASD (Dalton, Gernsbacher, et al., 2005; Humphreys, Hasson, Avidan, Minshew, & Behrmann, 2008; Pierce & Redcay, 2008; Pinkham, Hopfinger, Pelphrey, Piven, & Penn, 2008), and others reporting regular face-related activation (Bird, Catmur, Silani, Frith, & Frith, 2006; Dapretto et al., 2006; Hadjikhani, Joseph, Snyder, & Tager-Flusberg, 2007; Kleinhans et al., 2008). Scherf et al. (2015) suggested that these discrepant findings may be due to differences in symptom severity between cohorts, observing that those reports with normal FFA response to faces had higher proportions of

individuals with PDD-NOS or Asperger's compared to compared to those reporting hypoactivity, who had participants mostly diagnosed with the typically more severe, autistic disorder. The authors investigated this hypothesis by measuring fMRI response in core and extended face processing regions in the brains of high functioning adolescents between the ages of 10 and 18 (n = 20) with ASD and a typically developing control group. Overall, Scherf et al. (2015) observed reduced face-specific activity in the right FFA, bilateral OFA, and bilateral STS in the cohort with ASD compared to adolescent controls who showed extensive activation of these core face processing regions. In addition, higher symptom severity based on the social responsiveness scale (SRS) was associated with weaker activation of the right FFA in ASD, supporting the hypothesis that discrepant findings in the literature may be due to differences in symptom severity between recruited cohorts. Lastly, Scherf et al. (2015) found increased activation of the left FFA, an area suggested to be more involved in feature-based processing of faces (Meng, Cherian, Singal, & Sinha, 2012; Rossion, Dricot, et al., 2000), supporting notions that those with ASD may use a more feature-based strategy to process faces (Behrmann, Thomas, & Humphreys, 2006). An alternative explanation was provided by Dalton, Gernsbacher, et al. (2005) who found that in addition to reduced fixation times on eyes for individuals with ASD, there was a strong (r = .76), and moderate positive correlation (r = .56) between time fixating on the eye region of faces, and right FFA activity/right amygdala activity respectively for adolescents males with ASD, but not controls. The results suggest that gaze patterns while attending faces may help explain functional brain activity differences observed between those with and without ASD (Dalton, Gernsbacher, et al., 2005). Conversely, a study of 24 adults with ASD found typical reactivity of the FFA to faces, but abnormal functional connectivity between the so-called "social brain network" (Baron-Cohen et al., 1999; Dawson et al., 2005; Klein, Shepherd, & Platt, 2009), including weaker functional connectivity between the right FFA and left amygdala (Kleinhans et al., 2008). Eye movements, however, did not correlate with this reduced functional connectivity. The evidence thus far suggests that FFA

activation is reduced in response to faces for many, but not all people with ASD. It could be that heterogeneity in face recognition ability corresponds to heterogeneity in neurological response to faces, i.e., those with typical face recognition abilities have typical FFA response, and those with poor face recognition have weaker FFA responses. Scherf et al. (2015) found that although upright CFMT performance was not correlated with FFA activity, it was associated with right anterior temporal lobe activity, an area implicated in face individuation by linking biographical information to perceptual representation (Haxby et al., 2000; Kriegeskorte, Formisano, Sorger, & Goebel, 2007). Using a technique called representational similarity analysis, O'Hearn, Larsen, Fedor, Luna, and Lynn (2020) found that similarity scores (representing shared patterns of activation across different exemplars of a particular stimulus category within a region of interest) in the right FFA were correlated with CFMT performance for controls and individuals with ASD. Left FFA similarity scores and face recognition was also correlated in the ASD group, supporting the notion that adults with ASD rely more on feature-based processing strategies (Happé & Frith, 2006; O'Hearn et al., 2020). More research is needed to determine the relationship, if one exists, between FFA activity and face recognition abilities in ASD.

1.4.2.2 N170

A neuro-electrophysiological signature of the temporal characteristics of face processing, the N170 consists of two components, latency, which describes how close to the 170ms mark the peak of the negative voltage deflection is observed, and amplitude, which describes the magnitude of the negative deflection from baseline. Because the N170 is well described in the typically developed population, consistent atypicalities of the N170 signal in response to faces could provide a reliable biomarker for ASD. Recently Kang et al. (2018) completed a meta-analysis on the extensive literature investigating the N170 in ASD, including 18 studies of latency (n = 319 total individuals with ASD, n = 304 controls) and 18 studies of amplitude (n = 349 total individuals with ASD, n = 332 controls), and tested for study-level moderators such as

age, IQ, sex ratio, and symptom severity based on diagnostic measures. First, significant heterogeneity was observed for across studies (Kang et al., 2018). With respect to amplitude, the authors found no significant differences between groups, but did observe smaller amplitudes in adults with ASD compared to children with ASD, and for those with higher cognitive ability with ASD than those with lower cognitive ability with ASD. In non-autistic populations, N170 amplitudes tend to increase with age, not decrease (Batty & Taylor, 2006; Hileman, Henderson, Mundy, Newell, & Jaime, 2011; Itier & Taylor, 2004; M. J. Taylor et al., 1999). The reverse pattern observed in ASD was suggested to result from compensatory, effortful social cognitive processes applied by older and higher IQ individuals on the autism spectrum, rather than more automatic processing of faces in typical development (Kang et al., 2018). With respect to latency assessments, the authors detected significantly longer N170 latency in ASD described by small effect sizes (roughly 10ms (McPartland, Dawson, Webb, Panagiotides, & Carver, 2004; O'Connor, Hamm, & Kirk, 2007)). The results of the meta-analysis suggest that similar basic neural resources are applied for face processing (as demonstrated by similar N170 amplitudes), but these processes are slightly slower as demonstrated by delayed N170 latencies. The authors suggest that specialization of face processing mechanisms may be disrupted for those with ASD, perhaps due to reduced interactions with the social world (Kang et al., 2018). The results of the meta-analysis are consistent with an earlier review from Dawson et al. (2005) who also noted slower responses to faces in those with ASD, as shown by latency lag in the N170, suggesting those with ASD do not exhibit the typical speed advantages for processing faces over objects.

1.4.3 Theories of face recognition difficulties in ASD

1.4.3.1 Social motivation hypothesis

The cause of deficits in face abilities in autism remains unclear. Heterogeneity across the autism spectrum and the diversity of research findings add to the challenge of explaining

atypicalities of face processing in autism. Early neuro-imaging studies indicating hypoactivation of the fusiform gyrus in response to faces suggested that some individuals with autism may lack cortical expertise for faces (Hubl et al., 2003; Schultz, 2005; Schultz et al., 2000). The social motivation hypothesis posits that face processing impairments observed in behavioural and neurophysiological studies are secondary to primary deficits in social motivation (Dawson et al., 2005). Reduced social motivation is expressed via early onset impairments in social attention which deprive individuals with autism of the necessary experience to develop behavioural and cortical expert face processes (Chevallier et al., 2012; Dawson et al., 2005; Schultz, 2005).

Schultz (2005) proposes that early developmental failures of the amygdala in autism may be the driving force behind reduced social motivation. One role of the amygdala established in typically developed individuals is to guide attention to biologically relevant stimuli by associating reward with and attaching emotional valence for social aspects of the visual environment (Adolphs & Spezio, 2006; Klein et al., 2009). Indeed, hypoactivation of the amygdala has been observed in ASD while viewing faces by some (Critchley et al., 2000; Pierce et al., 2001; Scherf et al., 2015) and reduced functional connectivity between the amygdala and right FFA is observed by others (X. Guo et al., 2016; Kleinhans et al., 2008). Research investigating reward circuitry aberrations in ASD are few, and inconsistent (Bottini, 2018), yet a recent meta-analysis of fMRI data does show atypical processing of social and non-social rewards, suggesting a more general reward processing anomaly in ASD (Clements et al., 2018).

The social motivation hypothesis is inspired in part by the social impairments core to autism, beginning with descriptions from Kanner, and then those that remain a part of the diagnostic criteria for the condition (Schultz, 2005). These include an apparent disinterest in the conversations of adults, avoiding the faces of others (Kanner, 1943), poor eye contact, impairments in the interpretation of non-verbal behaviour like eye gaze or facial expression, and failure to seek spontaneously to share enjoyment, interests, or achievements with others (*Diagnostic and statistical manual of mental disorders : DSM-5*, 2013). Empirically, naturalistic

retrospective observation studies of home videos of children later diagnosed with ASD demonstrate reduced social behaviour, including looking at others and responding to their name, compared to non-autistic children by the first birthday (Osterling & Dawson, 1994; Osterling, Dawson, & Munson, 2002). Eye-tracking studies show that compared to non-autistic controls, faces do not, to the same degree, capture the attention of those on the autism spectrum (Fletcher-Watson, Leekam, Benson, Frank, & Findlay, 2009; Riby & Hancock, 2009; C. E. Wilson, Brock, & Palermo, 2010), and attention remains reduced and/or atypical in childhood (C. E. Wilson et al., 2010), adolescence (Riby & Hancock, 2008, 2009) and into adulthood (Fletcher-Watson et al., 2009; Sasson et al., 2007). A review of social visual engagement in infants and toddlers shows that preferential orientation to biological motion and preferential attention to the eyes of others are considerably disrupted in ASD (Klin, Shultz, & Jones, 2015). These pre-symptomatic (occur before symptoms of ASD are visible) patterns of social attention predict both categorical diagnostic outcome, and individual levels of symptom severity in ASD (Klin et al., 2015). Furthermore, attentional bias to faces later in childhood has been shown to predict face recognition ability and symptom severity in ASD. C. E. Wilson et al. (2010) demonstrated that during a 10-second viewing of an image containing people and objects, children with ASD took three times as long, on average, to make a fixation to a face as controls and spent half the amount of time looking at faces. Notably, the number of trials where individuals with ASD made a first fixation to a person vs. an object strongly correlated with ability on a 2-alternative forced-choice sequential face match-to-sample task (C. E. Wilson et al., 2010). Riby and Hancock (2009) found that it took individuals with ASD (n = 24; aged 6-17) significantly longer to find embedded faces in images of land- and cityscapes, as well as faces in scrambled images. Once located, those with ASD were much faster to fixate away from faces (roughly 500 ms compared to 1500 ms for controls), and fixation durations for faces were positively correlated with level of functioning as assessed by the Childhood Autism Rating Scale (Riby & Hancock, 2009). In free viewing paradigms, first fixations were not biased towards

people for adolescents with ASD, compared to controls who show strong biases to attend preferentially to people (Fletcher-Watson et al., 2009) and more time is spent fixating on backgrounds or bodies compared to faces (Riby & Hancock, 2008). Not all eye tracking studies reveal atypical fixation patterns in ASD. McPartland, Webb, Keehn, and Dawson (2011) and Sterling et al. (2008) both observed similar fixation patterns between autistic and non autistic adolescents, and adults respectively. Both studies used static, grey scale images of faces, which may not have the same ecological validity as the use of dynamic videos (Jones, Carr, & Klin, 2008) or naturalistic, colourized depictions of social scenes (Riby & Hancock, 2008). The majority of studies outlined here demonstrate that social stimuli do not seem to hold similar attentional priority for autistic and non autistic individuals. Gaze fixation styles of those on the autism spectrum suggest reduced interest for faces, which is consistent with reasoning provided by the social motivation hypothesis and could stunt experience needed for the typical protracted development of expert face processes.

Does social motivation have a measurable relationship with face recognition abilities? Oruc et al. (2018) recently demonstrated a positive association between social motivation (SM) scores on the Multidimensional Social Competence Scale (MSCS), a validated self-report assessment of social competence, and face processing ability in adults with autism with low social motivation (defined as SM scores below the autistic sample mean) (Oruc et al., 2018). In line with the social motivation hypothesis, the authors suggest that low SM may curtail visual experience with faces, leading to reduced face perception abilities. While not all individuals with autism have low SM, the account provides a means by which some individuals demonstrate weaknesses in face perception while others do not.

1.4.3.2 The eye avoidance hypothesis

The eye avoidance hypothesis is related to the social motivation hypothesis in that it attributes challenges with face processing in ASD as secondary impairments to a primary

cause, however, in this case that primary cause is purposeful avoidance of eye contact (Tanaka & Sung, 2016). Avoiding the eyes in this case is not necessarily an indication of reduced social interest, rather it is a compensatory behaviour to avoid uncomfortable visceral stress responses associated with direct eye contact (Tanaka & Sung, 2016). Avoiding the eyes, which constitutes an important area of the face for efficient face identity recognition (Peterson & Eckstein, 2012; Royer et al., 2018; Vinette, Gosselin, & Schyns, 2004) leads to reductions in face recognition abilities, and compensatory strategies for face processing. Support for the eye avoidance hypothesis stems from early observable behavioural manifestations of autism, including reduced eye contact (Zwaigenbaum et al., 2005), atypical attention measured via eye tracking (Jones et al., 2008; Pelphrey et al., 2002), and measures of arousal in response to looking at the eyes (Dalton, Davidson, et al., 2005; Kylliainen & Hietanen, 2006). Jones et al. (2008) compared gaze fixations of toddlers with and without ASD watching dynamic videoclips of caregivers playing games like pat-a-cake while looking directly at the camera. The authors found that those with ASD spent less time fixating on the eye regions of the actors compared to non-autistic controls who demonstrated a strong preference for the eyes. Further, decreased time spent fixating on the eyes was associated with greater social disability for toddlers with ASD based on ADOS scores (Jones et al., 2008). For adolescents and young adults with autism, the same research group has observed reduced attention to the eyes of actors and increased attention to mouths, bodies, and objects during viewings of socially complex 30-60 clips from a 1967 television show “Whose afraid of Virginia Wolf” (Klin, Jones, Schultz, Volkmar, & Cohen, 2002). Verbal IQ-matched controls fixated on the eye region two times more than those with ASD, making percentage of fixation time on the eyes the best predictor of group membership. In ASD, longer fixation durations for mouths were associated with higher levels of social adaptation and lower levels of social impairment. Longer fixation durations for objects, on the other hand, were associated with lower social adaptation and greater autistic social impairment. The authors suggested that perhaps, greater attention to mouths is a compensation strategy for more

socially able individuals to understand speech and better understand the social situation (Klin et al., 2002). In a small group of male adults (*n* = 5), Pelphrey et al. (2002) has shown that this attention style may persist into adulthood, as individuals on the autism spectrum spent less time fixating on the internal features of a face during a free viewing task, especially the eyes. These studies indicate attention may not be as likely to be oriented to the eyes of others in autism, however the reason for this behaviour is unclear. In an fMRI study, adolescents with and without autism completed an emotion detection task and a face recognition task, both with eye tracking, Dalton, Davidson, et al. (2005) observed a correlation between time spent fixating on the eyes, right fusiform gyrus activity ($r = 0.76$) and amygdala activity ($r = 0.55$) for those with ASD, but not for controls subjects. Increased amygdala activity while viewing the eyes during both behavioural tasks was interpreted as a heightened emotional arousal response to eyes in ASD. Kylliainen and Hietanen (2006) have also observed higher skin conductance responses, a measure of sympathetic (fight of flight) nervous system activity in response to direct gaze, compared to indirect gaze in ASD. Together these studies suggest that for individuals with ASD, the eyes potentially represent an emotionally triggering, stressful visual stimulus. Hence, attention is allocated to other socially informative areas of the face when needed (i.e., the mouth), and discriminations involving the eye region are challenging for those with ASD (Tanaka & Sung, 2016).

1.4.3.3 The local processing bias account

Alternatively, face recognition impairments in autism may not be secondary to a primary social-cognitive deficit, rather, face recognition impairments may be related to a specific anomalous perceptual style of those on the autism spectrum. This perceptual style is characterized as a local processing bias, or tendency to encode visual information locally on a part-by-part basis (Behrmann, Thomas, et al., 2006; Jemel, Mottron, & Dawson, 2006; Mottron et al., 2006). A perceptual style biased to feature-by-feature processing would not do well on a

task like face recognition because efficient processing depends on the rapid perception of the spatial relationships between facial features. Evidence for a local processing bias stems, in part, from observations of a specific perceptual strength of those with autism for completing detail oriented visual tasks including superior performance in visual search (Kemner, van Ewijk, van Engeland, & Hooge, 2007; O'Riordan, 2004; O'Riordan, Plaisted, Driver, & Baron-Cohen, 2001), locating simple shapes embedded in complex figures (Christopher Jarrold, Gilchrist, & Bender, 2005; A. Shah & Frith, 1983), the block design subtest of the Wechsler Abbreviated scale of intelligence (WASI) IQ test (A. Shah & Frith, 1993) and an absence of global interference with the Navon letters task (Van der Hallen, Evers, Brewaeys, Van den Noortgate, & Wagemans, 2015). Two theories proceeding from these observations include the *Weak Central Coherence* theory (Happé & Frith, 2006) and the *Enhanced Perceptual Functioning* theory (Mottron & Burack, 2001; Mottron et al., 2006).

The *Weak Central Coherence* account refers to a detail-focused processing style proposed to characterize ASD (Happé & Frith, 2006). Originally, the name stemmed from the idea that those with ASD fail to process incoming information for the ‘big-picture’, gist, or gestalt form because of a cognitive style biased towards local information (Happe, 1999). The authors note however, that an increased trend in assessing within-group differences shows that weak coherence may be characteristic of only a subset of individuals in the ASD population (Happé & Frith, 2006; C. Jarrold & Russell, 1997; Scheuffgen). Further, evidence indicating that those with ASD are able to perceive global information typically when primed, or properly instructed (Iarocci, Burack, Shore, Mottron, & Enns, 2006; Stevenson et al., 2016; L. Wang, Mottron, Peng, Berthiaume, & Dawson, 2007), has shifted focus from deficits of central coherence to biases towards local processing (Happé & Frith, 2006) that could explain superior performance on detail oriented tasks in ASD. However, several meta-analyses of studies employing these tasks have challenged the notion of biased superior local processing in ASD (Kaldy, Giserman, Carter, & Blaser, 2016; Muth, Hönekopp, & Falter, 2014; Van der Hallen et al., 2015). Muth et

al. (2014) for example demonstrated significant heterogeneity in studies investigating embedded figure detection, and when outliers were removed, the ASD advantage disappeared. A separate meta-analysis by Van der Hallen et al. (2015) found no superiority in search, embedded figures, or block design in ASD. Typical performance in these tasks does not necessarily mean a locally oriented perceptual style does not exist in ASD (Mottron, Burack, Iarocci, Belleville, & Enns, 2003). In the Navon letters task people with autism tend to show local-to-global interference, rather than the typical global-to-local interference, demonstrating a local bias or preference (Behrmann, Avidan, et al., 2006) although these differences may be negligible (Muth et al., 2014; Van der Hallen et al., 2015) or non-existent (Baisa, Mevorach, & Shalev, 2021).

The *Enhanced Perceptual Functioning* theory attributes a locally biased perceptual style to superior low-level visual processing. Low-level visual processing however has been shown to be largely typical in autism, including typical visual acuity (Falkmer et al., 2011; Tavassoli, Latham, Bach, Dakin, & Baron-Cohen, 2011), normal orientation processing (Meilleur et al., 2014; Shafai et al., 2015), normal spatial frequency processing (Guy et al., 2016; Jonge et al., 2007; Kamensek et al., 2018; Koh et al., 2010) and normal first order motion perception (Pellicano, Gibson, Maybery, Durkin, & Badcock, 2005). In addition, and counter to the *Enhanced Perceptual Functioning* theory, chromatic perception has been shown to be impaired in ASD across a variety of studies (Simmons et al., 2009). A local perceptual bias does not seem to be a result of enhanced low level perceptual processes so the reason for a potential feature based perceptual style remains unknown.

Support for these types of local-processing bias hypotheses in the face and object recognition literature contends with evidence to the contrary. If face recognition ability suffers in ASD due to general perceptual biases, then these biases should be apparent for recognition of non-face objects too. Behrmann, Avidan, et al. (2006) completed a robust set of investigations of configural processing and its relationship to a local perceptual bias with 14 high functioning adults with ASD and two control subjects per ASD participant matched by gender, age, and

education level. First, participants completed a timed, same/difference judgement task for faces, where discriminations had to be made for the more general category of gender, and the exemplar category of the individual. The idea is that as perceptual discriminations become more fine-grained, i.e., for more subordinate levels of categorization, a bias for local processing will be more detrimental to performance. ASD participants were slower than controls discriminating across both category levels than controls, and the authors claimed increased difficulty for individual level discriminations in ASD, although the group x condition interaction was not significant ($p < .07$)(Behrmann, Avidan, et al., 2006). A slower, feature-by-feature perceptual style is suggested to explain these differences. Twelve of the fourteen participants also completed a similar task for common objects, and for greebles, a novel stimulus class that is meant to mimic the processing demands of faces (i.e., greebles can be categorized by family, gender, and individual, and these differences depend increasingly on the spatial relationships of features for more subordinate levels of classification (Behrmann, Avidan, et al., 2006; Gauthier et al., 1998). For objects and greebles, individuals with ASD were significantly slower in making same/different judgements across all levels of categorization, although a similar pattern of slowing was also evident in the non-autistic control group. This time, the group x condition interactions were significant and revealed a disproportionate drop in performance in ASD, from basic to gender category level discriminations for greebles, and from basic to subordinate in object discrimination. Both analyses did not reveal differences in performance reductions between groups from subordinate to exemplar discriminations for objects, or gender to individual discriminations for greebles. Participants did show a local advantage in a Navon letters task (with letters and shapes), and relative superiority of processing local information was correlated with slowing in face and greeble processing (Behrmann, Avidan, et al., 2006). While the interpretation of these results as reflecting perceptual differences across groups for face and object processing, or simply reflecting general slower task completion in ASD is up for debate, this account has received considerable attention in the literature.

In contrast, when Wolf et al. 2008 put a large cohort of children with ASD (*n* = 66*)* through the *Let's Face It!* Skills battery and compared performance of face and object recognition to age- and IQ- matched non-autistic children, they found results that were not consistent with a local processing bias. In their face dimensions task, participants with ASD demonstrated normal performance discriminating configural and featural changes of the mouth region, but not the eyes. Similarly, in a part/whole task, ASD participants were impaired with recognition of the eyes when presented in isolation and whole face but had typical part and whole recognition of mouths. Importantly, overall, those with ASD showed spared holistic processing via better recognition of face parts when presented in the context of the whole face than in isolation. When the dimensions task was applied for houses, where participants had to discriminate between images with minor variations to the configurations or features of either two small windows, or the large door, those with ASD demonstrated a processing advantage for discriminating configural and featural changes (Wolf et al., 2008). Those with ASD also demonstrated typical memory for cars presented across changes in viewpoint, compared to face-memory, which was impaired across changes in viewpoint. The authors argue that when task demands are held constant (i.e., car vs. face memory and face vs. house dimensions), perceptual and cognitive processes that lead to equivalent or even superior processing of objects are impaired for faces (Wolf et al., 2008). A local perceptual bias account predicts that regardless of stimulus class, configural representations should be weakened, leading to poorer recognition memory across viewpoints, and less sensitive discrimination ability for changes to 2nd order relations compared to featural changes. The differences in findings could be due to a number of factors. Berhmann's (2006) study had just 14 participants, so their interpretation of a locally biased perceptual style could be a feature of a subtype of those on the autism spectrum revealed by sampling variability. Behrmann, Avidan, et al. (2006) also emphasized their results on reaction time with performance near ceiling, compared to Wolf et al. (2008) who used

accuracy measures. Lastly, Behrman, Avidan, et al. (2006) investigated adults, while Wolf et al. (2008) investigated children.

Scherf et al. (2008), completed a study that addressed some of these methodological differences. In an examination of the development of face and object recognition perception, children and adults with and without autism completed a 2-alternative forced-choice sequential (target presented for 250ms before a target-distractor choice screen) match-to-sample task for faces (upright and inverted), common objects and greebles. This time, accuracy was assessed. Like Behrmann et al. (2006), target-distractor discriminations were compared for differences across gender/individual (for faces and greebles) and subordinate/exemplar category levels. First, despite reduced face recognition abilities overall, classic inversion effects were shown for both adults and children with ASD, demonstrating visuo-perceptual expertise for faces in ASD. Furthermore, patterns of face recognition ability (individual discriminations more difficult than gender discriminations), and improvements through development (adults better than children) were similar between groups. For common objects, similar patterns of results were observed, although adults with autism performed as well as controls, compared to children with autism who were overall slightly poorer at making subordinate and exemplar level discriminations than controls. Notably, for greebles, no differences between children with and without autism were observed. However, adults with autism did not improve in their ability to make individual level discriminations like adults without ASD did. The authors suggest that the perceptual homogeneity of greebles made the task especially difficult for adults with autism, and these types of difficulties were not detected for faces, as adults with ASD had most likely developed compensatory strategies from years of experience (experience not possible with a novel object category like greebles)(Scherf et al., 2008). The authors concluded that the primary factor in determining face recognition difficulties in ASD is therefore a generalized deficit in fine-grained visuo-perceptual processing which interferes with the ability to do configural processing (Scherf et al., 2008). These conclusions, however, assume that adults without ASD, who demonstrated

superior individual-level discrimination ability for greebles, are gaining this advantage from applying configural type processing, which is a processing strategy not typically applied to object recognition.

It is difficult to resolve these methodological differences. On one hand, children with ASD are already showing superior sensitivity to configural changes to an arguably homogenous stimulus set of houses (Wolf et al., 2008). On the other, adults with ASD are not showing typical developmental patterns for a homogenously designed greeble. The questions become: is there evidence of configural processing of greebles in adults without any type of expertise training, and can adults with ASD demonstrate configural processing for greebles? In a related study, Damiano, Churches, Ring, and Baron-Cohen (2011) compared the trainability of configural processing for greebles by comparing the effects of perceptual expertise training for autistic and non autistic adults. In their study, both groups achieved perceptual specialization for upright greebles, defined as the demonstration of an inversion effect (faster recognition of upright vs. inverted greebles), in the same amount of training sessions. The investigation demonstrates that inversion effects did not exist for individual-level discriminations prior to training, and importantly, that those with ASD are able to demonstrate configural processing of Greebles. Importantly, greeble perceptual expertise training in both groups was not associated with any changes in face processing abilities suggesting that 1) the development of expertise for non-face objects does not negatively impact face recognition abilities and 2) the ability to use configural processing strategies for greebles is not related to face processing abilities. Behrmann, Avidan, et al. (2006), Scherf et al. (2008), and Damiano et al. (2011) all had relatively small sample sizes (n = 14, n = 15, n = 12, respectively), so variability in results and conclusions could be due to sampling variability of groups with different visuo-perceptual strengths and weakness. To determine whether a local perceptual strategy is related to face processing in ASD, studies with larger cohorts may be necessary.

1.4.3.4 The prosopagnosia subtype account

A recent observation of an over-representation of prosopagnosia-like face recognition challenges for those on the autism spectrum, compared to the prevalence of these challenges in the neurotypical population has suggested that perhaps impaired face identity recognition is a marker for a reliable sub-type of ASD (Minio-Paluello, Porciello, Baron-Cohen, & Pascual-Leone, 2020). In a large sample of adults with ASD (n = 80, M_{age} = 31.3 years) Minio-Paluello et al. (2020), 36% of individuals met the clinical cut-off for developmental prosopagnosia based on the CFMT test score. Typically, rates of developmental prosopagnosia sit between 2 and 3 percent in the non-autistic population (Susilo & Duchaine, 2013). Splitting of the group with ASD between those with clinically impaired face recognition abilities, and those without, was independent of symptom severity, autistic traits, IQ, general memory skills, empathy, and alexithymia, which suggested to the authors that the causes of face memory difficulties in ASD are not specific to autism. These findings suggest that face identity recognition abilities may constitute a genetically meaningful avenue of subtyping those with ASD, leading to a better understanding of autism.

1.4.4 Face training paradigms

Several lines of investigation have indicated the potential relationship between face ability, and experience with faces. In ASD, face training paradigms provide further evidence of this relationship in children and adults. In young children aged 4-7, Golan et al. (2010) demonstrated that presenting emotional faces in an autism friendly context (an animated series called “the Transporters” on DVD) improved expression recognition in ASD to levels equivalent of non-autistic controls. In school-aged children with autism, Hopkins et al. (2011) trained participants to attend to the eyes and practice holistic face processing strategies using a computer-based social skills intervention with realistic avatar assistants, called “Face-Say”. Following the intervention, high functioning children with autism demonstrated improvements in

face recognition, emotion recognition, and positive social behaviours such as sharing (Hopkins et al., 2011). Another study using a computer-based intervention program called “Let’s Face It!”, demonstrated improvements in face recognition in children with autism, after just 20 hours of training (Tanaka et al., 2010). In adults with ASD, Faja et al. (2012) showed that training leads to improvements in processing of upright faces, an increase in the face inversion effect (a sign of configural processing), and better performance on standardized measures of face recognition. Behavioural manifestations of face expertise following training in ASD suggest that face processing is a practiced skill that improves following focused experience.

Current hypotheses surrounding face recognition abilities in autism seem to fit two separate categories: nature (perceptual) vs. nurture (experiential). One the one hand, perceptual explanations, including the local processing bias and prosopagnosia subtype account suggest face recognition challenges are not secondary effects of the social-cognitive aspects of autism, but result from primary anomalies of the perceptual systems of individuals on the autism spectrum. On the other hand, experience-centered theories place face recognition challenges as secondary to the primary social-cognitive related impairments core to ASD. It is likely that these theories are not mutually exclusive and may each contribute to various degrees on an individual-to-individual basis. It is a primary focus of this thesis to shed light on which explanation may be occurring first, as the most effective intervention should target the primary impairment. If the primary impairment is social motivation, then effective interventions might aim to make social interactions and attention aimed at social stimuli more rewarding, perhaps through classical conditioning. The goal would be to increase attention to faces and increase meaningful experiences with faces through development (Dawson et al., 2005). Alternatively, if face recognition challenges are perceptual or genetic in nature, with primary impacts occurring directly to the visual processing system, via an inherent perceptual bias, or say a dysfunctional FFA, interventions focused on facilitating efficient face processing strategies, with attention to all

features of the face and their configuration might be most successful in improving face processing abilities and the portion of social deficits secondary to these (Dawson et al., 2005).

1.5 – Objectives

It is well-established that those with ASD, on average, have difficulties with various aspects of face perception. Given that ASD is a condition characterized by impairments of social interaction and communication, it is critical to understand the causes of difficulties with an especially important aspect of social cognition like face recognition. Improving face recognition ability for those with impairments can alleviate some of the social challenges of those on the autism spectrum, but the underlying cause of those impairments must be well understood. To maximize the success of a particular solution, the causes of the problem must be addressed. Currently there are several proposed causes of face recognition challenges for those with ASD. The social motivation hypothesis suggests that reduced social motivation in ASD leads to a lack of visual experience with faces, which over time, leads to deficits of face perception (Chevallier et al., 2012; Dawson et al., 2005; Schultz, 2005). An overarching goal of this thesis is to critically assess competing hypotheses of face recognition challenges in ASD by testing the predictions of experiential vs. perceptual accounts. Is visual experience, specifically with faces, fundamentally different in ASD? Do those differences relate to visual processing in ASD? Given the wide range of face recognition abilities that exist on the autism spectrum, and the relationship between face recognition and social cognition, it is also possible that face recognition ability can serve as a variable by which subgroups of those along the autism spectrum can be organized. But can face recognition abilities define categorically distinct sub-types in ASD, or are they better characterized along a continuous spectrum? Lastly, how does face recognition ability relate to social motivation in populations without core impairments of social interaction and communication? Can impaired face recognition exist independently of low social motivation?

1.5.1 – Chapter 2 objectives – Are people with autism prosopagnosic?

The *prosopagnosia subtype account* suggests that a subset of individuals with ASD may share a common etiology of face recognition impairments as those with developmental prosopagnosia (Minio-Paluello et al., 2020). Developmental prosopagnosia (DP) is a condition characterized by lifelong impairments of face recognition despite normal social and cognitive functioning (Barton & Corrow, 2016; Behrmann & Avidan, 2005; Duchaine, 2011; Susilo & Duchaine, 2013). People with DP do not have autism (Duchaine, Murray, Turner, White, & Garrido, 2009), and family studies seem to indicate a hereditary cause for their face recognition challenges (Duchaine et al., 2007), although it should be noted that there are no confirmed genetic or structural markers for DP, and individuals with DP may represent the low end of a normal distribution of face recognition abilities (Barton & Corrow, 2016). Nonetheless, face recognition ability has a strong genetic component (Wilmer, Germine, Chabris, Chatterjee, Williams, Loken, et al., 2010; Wilmer, Germine, Chabris, Chatterjee, Williams, Nakayama, et al., 2010; Zhu et al., 2010), and a shared etiology of face recognition impairment of between ASD and DP, would suggest a perceptual/genetic cause of face recognition challenges in ASD. In Chapter 2, we investigate the utility of the *prosopagnosia subtype account* by comparing face recognition and social motivation between a group of individuals with ASD, DP, and a non-ASD/non-DP comparison group. Results consistent with the prosopagnosia subtype account would provide a manner by which to delineate two meaningful subgroups of individuals with ASD: those with severe face recognition challenges, and those with typical face recognition. The *social motivation hypothesis* would predict that face recognition ability would be impacted in individuals with ASD in a continuous fashion, ranging from mild to severe, depending on the relative degree of experience with faces. In addition, as face recognition challenges in DP are perceptual in nature, face recognition ability should not correlate with social motivation in DP, and those with DP should have equivalent social motivation to the non-ASD/non-DP comparison group.

1.5.2 – Chapter 3 objectives – The face-diets of adults with autism spectrum disorder

The *social motivation hypothesis* suggests that face recognition challenges in autism results from insufficient experience attending to social stimuli (i.e., faces) during development. While lab-based eye tracking studies, and home videos of toddlers later diagnosed with ASD suggest atypical and reduced attention to faces, there is currently little empirical evidence regarding whether people with autism experience insufficient exposure to faces as part of their visual input in daily living. Here, we will be the first to address what the face-diet of individuals with ASD looks like on a routine day, with ecologically valid, natural viewing conditions. The face-diets of autistic and non autistic adults were collected with an eye-wear embedded camera worn during a routine day. The same procedure was recently used to characterize the face-diets of 30 healthy adults and revealed daily exposure statistics to faces that were highly consistent with several well-established behavioural phenomena in the literature including the three-quarter pose recognition advantage, size related expertise, and the other race effect. Using social motivation scores based on the MSCS (Yager & Iarocci, 2013) as a proxy for visual experience with faces, Oruc et al. (2018) demonstrated an association between face processing abilities and social motivation for a subset of individuals on the autism spectrum with low social motivation. It has yet to be shown however, whether a central tenant of the *social motivation hypothesis*, that visual experience with faces is reduced and/or atypical in ASD is true. In Chapter 3, we collected and examined daily visual exposure statistics to faces of adults with and without ASD to determine whether those with ASD are in fact not receiving adequate visual exposure for the typical protracted development of expert face processes. We predicted quantitative and qualitative differences between the face diets of those with ASD, and the non-autistic control group. More specifically, these predictions included reduced exposure to faces in a routine day for those with ASD, atypical pose exposure patterns, and atypical viewing distances, inferred by the sizes of faces in the visual fields of our participants.

1.5.3 – Chapter 4 objectives - Pose-dependent face exposure and recognition in autism spectrum disorder

Results from Chapter 3 indicated that the face diet of those with ASD is quantitatively reduced and qualitatively atypical. We observed pose exposure patterns that favoured profile pose faces, regardless of familiarity. For comparison, our control group's pose exposure patterns favoured frontal pose faces over profile pose faces, especially for familiar faces. Our lab's previous investigation of the adult face diet suggested that face recognition abilities are tuned to viewing conditions consistent with social interactions with familiar persons (Oruc, Shafai, Murthy, et al., 2019). For those with ASD, familiar face exposure was characterized by increased proportions of profile pose faces, compared to frontal, perhaps suggesting a preference for these types of faces during social interactions, which would support Tanaka and Sung (2016)'s *eye avoidance hypothesis*. Direct eye gaze is associated with negative arousal, and stress responses in ASD (Dalton, Gernsbacher, et al., 2005; Tanaka & Sung, 2016) so faces in profile pose would be ideal to avoid eye contact during social encounters. Increased exposure to profile-pose faces throughout development as a compensatory strategy to avoid direct gaze would give those on the autism spectrum a unique visual history, and potentially lead to strengths in processing this stimulus type. To assess whether a visual exposure pattern biased for profile faces leads to better encoding and recognition of these types of faces, I designed a pose dependent face recognition task to compare profile and frontal face recognition, modelled after the CFMT. Results consistent with an experiential account of face recognition challenges in ASD would be shown by a profile pose recognition advantage (reflecting their visual exposure patterns for familiar faces), with recognition performance for profile faces equal to or greater than recognition performance for frontal faces. Conversely, the neurotypical control group would perform better with frontal faces, as compared to profile faces, reflecting their visual exposure patterns for familiar faces. A perceptual account might predict that face recognition abilities are independent of visual experience in ASD, and rather, depend

on the ability to extract and recognize meaningful facial features. Thus, face recognition might be difficult across changes in pose, and when access to facial features is limited, such as with faces in profile pose. Lastly, we hypothesized that overall, face recognition performance would be better for the non-autistic control group than our group with autism. While this hypothesis does not help distinguish between an experiential or perceptual account for face recognition challenges on the autism spectrum, it would be consistent with the overall literature on face recognition performance in ASD.

Chapter 2 – Are people with autism prosopagnosic?

2.1 Introduction

Autism Spectrum Disorder (ASD) is a developmental disability characterized by difficulties in social communication and interaction in addition to restricted and repetitive behaviours and interests (American Psychiatric Association, 2013). The manifestations of autism differ widely between individuals, including substantial heterogeneity in behavioural and cognitive functioning, course, and response to intervention (Fein & Helt, 2017; Masi, DeMayo, Glozier, & Guastella, 2017; McCormick et al., 2020). This heterogeneity is conceptualized in two ways. Dimensional models represent heterogeneity on a continuous scale, with abilities and symptoms varying on a spectrum (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001; Frith, 1991; Tunç et al., 2021). In contrast, categorical models divide populations into subgroups that share a common etiology, symptom presentation and course (Beglinger & Smith, 2001; Lombardo et al., 2019). These two models are not necessarily mutually exclusive, and both have had partial success in accounting for various aspects of heterogeneity in ASD. Improved understanding of how these two modes of diversity co-occur in the broad autism phenotype will allow more precise diagnoses and personalized interventions aimed at increasing the functional independence of those on the autism spectrum.

One example of phenotypic diversity in ASD is observed in the ability to process faces. Impaired face processing is prevalent in autism, though the range of severity is wide, including individuals with mild and moderate impairments, alongside those who are unimpaired as well as those who excel at this task (Barton et al., 2004; Oruc et al., 2018; Stantić, Ichijo, Catmur, & Bird, 2022). Although it is not part of the core diagnostic criteria, face processing ability may serve as a helpful indicator in parsing the heterogeneity in the disorder. The selective deficits in the processing of faces include recognition and perception of identity (Behrmann, Thomas, et al., 2006; Boucher & Lewis, 1992; Dwyer et al., 2019; Griffin et al., 2021; Joseph & Tanaka,

2003; Minio-Paluello et al., 2020; Simmons et al., 2009; Stantić et al., 2022; Tang et al., 2015; Weigelt et al., 2012; Wolf et al., 2008) and expression (Ashwin et al., 2006; Baron-Cohen, Wheelwright, Hill, Raste, & Plumb, 2001b; Harms et al., 2010; Oruc et al., 2018; Tanaka et al., 2012; Uljarevic & Hamilton, 2013; Wallace et al., 2008b; Weeks & Hobson, 1987; Wolf et al., 2008), however, the underlying cause of these deficits remains unclear. Broadly speaking, two frameworks have been commonly considered. Perceptual/genetic accounts argue that perceptual aberrations, independent of social function, underpin face processing deficits in ASD (Behrmann, Thomas, et al., 2006; Minio-Paluello et al., 2020). An alternate account argues that alterations in social motivation and reward processing for social stimuli, including faces, lead to an insufficient level of exposure to achieve typical levels of ability for face processing (Chevallier et al., 2012; Dawson et al., 2005; Grelotti, Gauthier, & Schultz, 2002; Oruc et al., 2018; Schultz, 2005). It is possible that both diminished social motivation and perceptual aberrations operate simultaneously, mutually influencing each other and leading to negative outcomes for both face processing and social motivation. Finally, it is also possible that the differences in the underlying mechanism(s) is integral to some aspect of the heterogeneity in autism where the primary pathogenetic factor for face deficits may be perceptual/genetic in origin for some individuals, and social/experience-based for others. Such pathogenetic differences would potentially delineate meaningful subcategories within the autism spectrum.

Face recognition impairment that is thought to be perceptual/genetic in origin is central to another disorder, developmental prosopagnosia (DP). Individuals with DP are diagnosed based on a severe impairment in face identity processing in the absence of social or cognitive deficits (Behrmann & Avidan, 2005; Cook & Biotti, 2016; Germine et al., 2011; P. Shah, Gaule, Sowden, Bird, & Cook, 2015; Susilo & Duchaine, 2013). DP can run in families and is thought to have a strong genetic component. Thus, face deficits are unlikely to be due to experience-based factors, such as low social motivation. Nevertheless, it is plausible that certain aspects of social function, such as social motivation, may be negatively affected in DP due to impairments in the

ability to identify faces. This is especially true given the fact that face identification impairments are severe in DP. Recently, it has been suggested that one third of the ASD population may also have DP, accounting for the group-level face deficits commonly observed for ASD (Minio-Paluello et al., 2020) . Indeed, if the presence of a DP-like subgroup is responsible for the common finding of face processing deficits in the broad ASD population, this would potentially explain the variability of findings across studies as well as the relatively moderate group-based mean deficits typically reported for ASD (around 1SD below typical, as suggested by meta-analyses (Griffin et al., 2021) compared to the more severe deficits that define DP. This is because group-level findings across studies would vary based on the different proportion of such DP-like individuals across samples randomly drawn from the broad ASD spectrum (e.g. see Lombardo et al. (2019)).

Here, we test this *prosopagnosia subtype account* of ASD by comparatively examining social motivation and face recognition ability in adults with autism spectrum disorder, adults with developmental prosopagnosia, and a group of typical adults, i.e., without ASD or DP. We examine whether any DP-like subpopulations were present within the ASD group, and whether presence of such a subgroup can account for face deficits in the broad ASD population. Lastly, we assess whether social motivation is impacted in DP, a condition that is characterized by severe impairments of face recognition in the absence of social or cognitive deficits.

2.1.1 Preview

Our analysis revealed a continuous graded distribution of face recognition ability within the ASD group with no indication of clustering or clear delineation of subtypes. Face recognition performance for one third of the ASD group is consistent with what would be seen in DP. However, this did not mark a clear boundary segregating hypothesized subgroups. Rather, the remaining 2/3 of the ASD group also showed significantly lower face recognition performance

compared to the comparison group. These results suggest that the *prosopagnosic subtype account* cannot solely explain face processing deficits in ASD.

2.2 Methods

We examined face recognition ability and social motivation in adults with ASD, adults with developmental prosopagnosia (DP) and adults without ASD or DP. The protocol was approved by the UBC Behavioural Research Ethics Board and Vancouver Coastal Health Research Institute. Informed consent was obtained in accordance with the Declaration of Helsinki.

2.2.1 Participants

36 participants with ASD (16 females; age: *M* = 25.28, *SD* = 9.08), 64 participants with DP (40 females; age: *M* = 40.27 years, *SD* = 8.81) and 41 participants without ASD or DP (16 females; age: *M* = 26.37, *SD* = 6.57) took part in the study. Participants with ASD were all previously diagnosed by a clinician. DP diagnosis was confirmed based on clinically impaired scores on the 20-item prosopagnosia index 20 (PI20; a self-report measure for quantifying prosopagnosia traits (P. Shah et al., 2015)), the CFMT (Duchaine & Nakayama, 2006), and a famous face test (Duchaine et al., 2007). The autism spectrum quotient (AQ) test (Baron-Cohen, Wheelwright, Skinner, et al., 2001), a fifty-item, self-administered questionnaire used to assess traits associated with the autism spectrum was completed by all participants. A score of 32 represents the cut-off for distinguishing individuals who have clinically significant levels of autistic traits (Baron-Cohen, Wheelwright, Skinner, et al., 2001). We used a cut-off score of 20 as exclusion criteria for comparison participants to maintain the greatest separation between adults with ASD and the adults in the non-ASD, non-DP comparison group, while still allowing for individuals who tend to have higher scores, such as those in mathematics or sciences (Baron-Cohen, Wheelwright, Skinner, et al., 2001).

2.2.2 Procedure

Assessment of face recognition ability was based on upright face recognition performance accuracy on the Cambridge Face Memory Test (CFMT) (Duchaine & Nakayama, 2006). The CFMT is a validated tool for measuring face recognition, and the predominant assessment tool used for diagnosing prosopagnosia (Corrow, Albonico, & Barton, 2018; Duchaine & Nakayama, 2006). Social motivation, an indication of an individual's enjoyment, comfort and interest in social interactions, was assessed through the Multidimensional Social Competence Scale (MSCS) (Trevisan et al., 2018). The 77-item MSCS questionnaire assesses social competence across seven distinct domains: social motivation, social inferencing, demonstrating empathic concern, social knowledge, verbal conversation skills, nonverbal sending skills and emotion regulation (Yager & Iarocci, 2013). Here, we extracted scores from the *social motivation domain* for analysis. Participants in the ASD group and the comparison group completed the CFMT on a Dell laptop (model 3750) equipped with a 17-in. antiglare LED screen. Participants sat approximately 57 cm from the screen. DP participants completed the CFMT online. The 77-item MSCS, and 50-item AQ was completed either online or on paper by all participants.

2.2.3 Data Analysis

2.2.3.1 Univariate

CFMT scores were submitted to a one-way ANOVA with a single group factor with 3 levels (Comparison, ASD, DP) followed by post-hoc pair-wise comparisons. The Social Motivation (SM) scores were extracted from the MSCS and submitted to a one-way ANOVA with a single group factor with 3 levels (Comparison, ASD, DP) followed by post-hoc pair-wise comparisons.

2.2.3.2 Bivariate

Normalized scores for both the CFMT and the SM were calculated based on the Comparison group mean and standard deviation for all three groups. A support vector machine was trained to determine a linear boundary that classifies the Comparison group from the DP group in a space that spans normalized CFMT and SM using a leave-one-out procedure, which yielded 98.78% cross-validation accuracy. The ASD data were then compared to this boundary to assess if and what proportion of ASD participants' data were consistent with that of the DP group.

2.3 Results

2.3.1 Univariate

There was a significant main effect of group for CFMT score ($F(2, 138) = 113.22$, $p << .001$). Mean face recognition accuracy (% correct) was 81.37 ($SD = 10.97$) for the Comparison group, which was significantly higher than the ASD group ($M = 66.51$, $SD = 16.42$; $p < .001$; $d = 1.06$) and the DP group ($M = 47.89$, $SD = 7.22$; $p << .001$; $d = 3.6$). Further, face recognition performance in the ASD group was significantly higher than the DP group ($p << .001$; $d = 1.47$). There was also a significant main effect of group on the SM score ($F(2, 138) = 22.99$, $p << .001$). Social motivation was significantly higher in the control group ($M = 40.66$, $SD = 6.23$) than the ASD group ($M = 32.19$; $SD = 9.69$; $p < .001$; $d = 1.04$) and the DP group ($M = 32.95$, $SD = 3.46$; $p << .001$; $d = 1.53$), however, the difference between the ASD and DP groups was not significant ($p = .57$; $d = 0.1$). The distributions of face recognition ability (upright CFMT scores) and social motivation scores are visualized in Figure 1. There was no correlation between the face recognition score and social motivation score for the Comparison group ($r = 0.12$, $p = .47$), the DP group ($r = -0.11$, $p = .41$), or the ASD group ($r = -0.28$, $p = .10$).

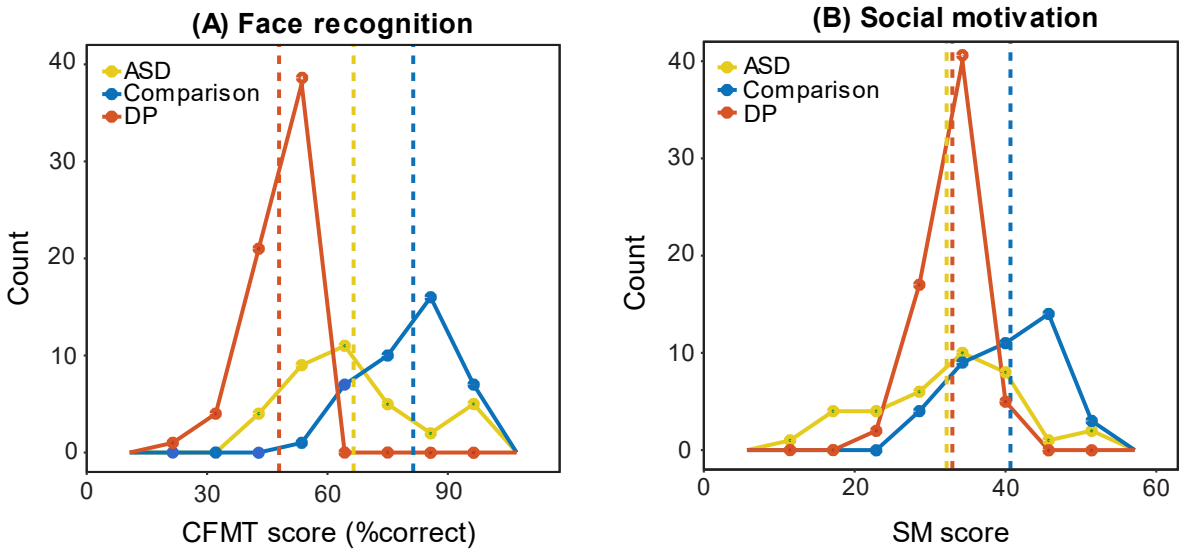


Figure 1. Frequency polygons of (A) upright CFMT scores (%correct) for the group with ASD (green), the group with DP (red) and the comparison group (blue) and (B) social motivation scores for the group with ASD (green), the group with DP (red) and the comparison group (blue). Vertical dashed lines indicate the group mean for upright CFMT (A) and SM (B) for each group.

Next, to examine the idea that the ASD group might include a prosopagnosic subgroup, we separated the ASD group into two mutually-disjointed subgroups based on a normalized CFMT score threshold of -2. The group with CFMT scores equal to or below -2 were labeled ASD_{DP} and the group with scores above -2 were labeled ASD_{nonDP}. Note that a diagnosis of prosopagnosia would involve other measures beyond CFMT, therefore, this separation would not guarantee that any participants categorized into the ASD_{DP} subgroup is, in fact, prosopagnosic. However, assuming the presence of a prosopagnosic subgroup, a score two standard deviations below the norm would be a necessary minimum condition. In other words, any prosopagnosic participants in the ASD group would be in the ASD_{DP} subgroup although the converse is not necessarily true. This resulted in 13 (out of 36) ASD participants in the ASD_{DP} group (i.e., 36.11%), and the remaining 23 (out of 36) ASD participants in the ASD_{nonDP} group. Face recognition score (CFMT) for the ASD_{DP} group (M = 51.6%, SD = 6.3) was significantly

lower than that of the Comparison group (*M* = 81.37%, *SD* = 10.97, *p* << .001; *d* = 3.33) and the ASD_{nonDP} group (*M* = 74.94%, *SD* = 14.2, p << .001; *d* = 2.12). The CFMT score of the ASD_{nonDP} group was significantly greater than that of the DP group (*M* = 47.89%, *SD* = 7.22; *p* << .001; *d* = 2.4), and importantly, it was still significantly lower than that of the Comparison group (*p* = .047; *d* = 0.51). Figure 2A shows the CFMT scores for the four groups.

Social motivation score (SM) for the ASD_{DP} group (*M* = 31.69, *SD* = 12.45) was significantly lower than that of the Comparison group (*M* = 40.66, *SD* = 6.23, *p* = .001; *d* = 0.91), however, it did not differ significantly from the ASD_{nonDP} group (*M* = 32.48, *SD* = 8.04, p = .82; *d* = 0.08), and the DP group (*M* = 32.95, *SD* = 3.46; *p* = .49; *d* = 0.14). The SM score of the ASD_{nonDP} group was also significantly lower than that of the Comparison group (*p* < .001; *d* = 1.14) and did not differ from the DP group (*p* = .70; *d* = 0.08). Figure 2B shows the SM scores for the four groups.

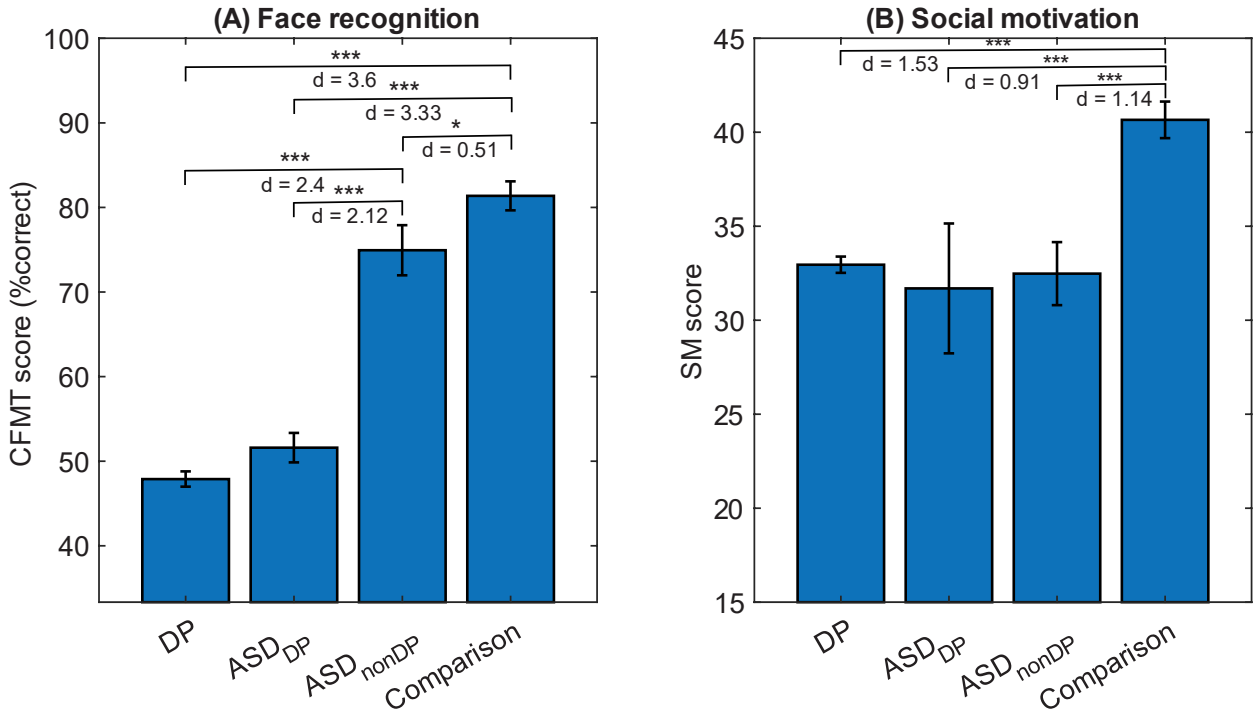


Figure 2. (A) Face recognition ability measured via the CFMT plotted as a function of group: those with DP, those with ASD who's normalized CFMT scores were equal to or below -2 with respect to the comparison group (ASD_{DP}), those with ASD whose CFMT scores were greater than -2 with respect to the

comparison group (ASD_{nonDP}), and the neurotypical comparison group. (B) Social motivation scores assessed via the MSCS plotted as a function of experimental group. Error bars represent the standard error of the mean. *** $p < .001$, * $p < .05$.

2.3.2 Bivariate

Figure 3A shows normalized face memory scores as a function of normalized social motivation scores for the DP group (red triangles) and the Comparison group (blue circles). The best fitting linear boundary that separated the DP and Comparison groups (100% sensitivity, 97.56% specificity) is shown in green. We compared the ASD data (yellow asterisks) to this boundary, which classified 38.89% of the ASD group as belonging to the DP category (Figure3B). Based on this alternate bivariate classification (see Figure 3B green boundary), we again separated the ASD group into two mutually disjointed subgroups: ASD_{DP} and ASD_{nonDP}.

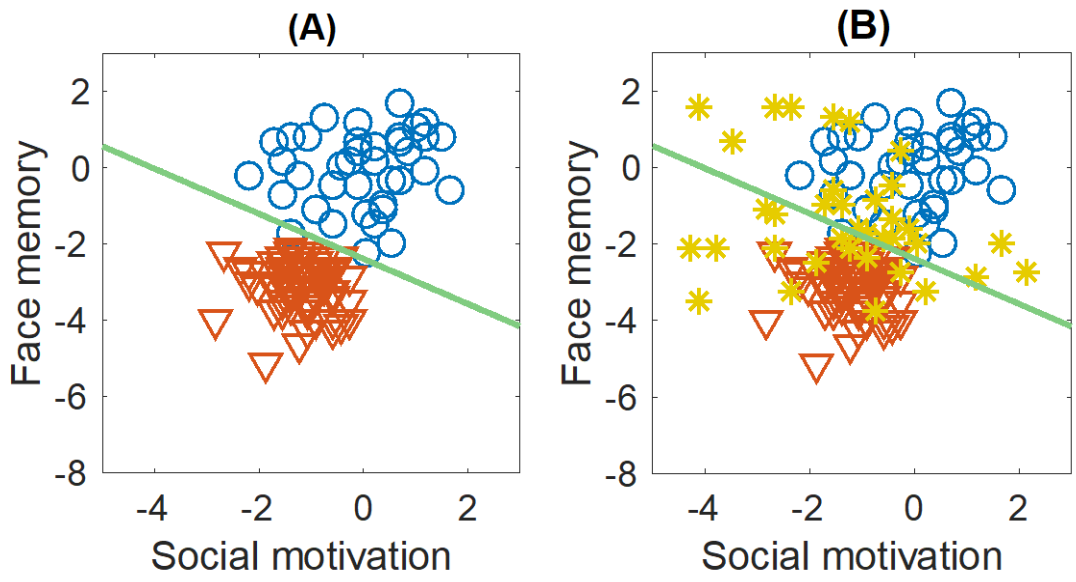
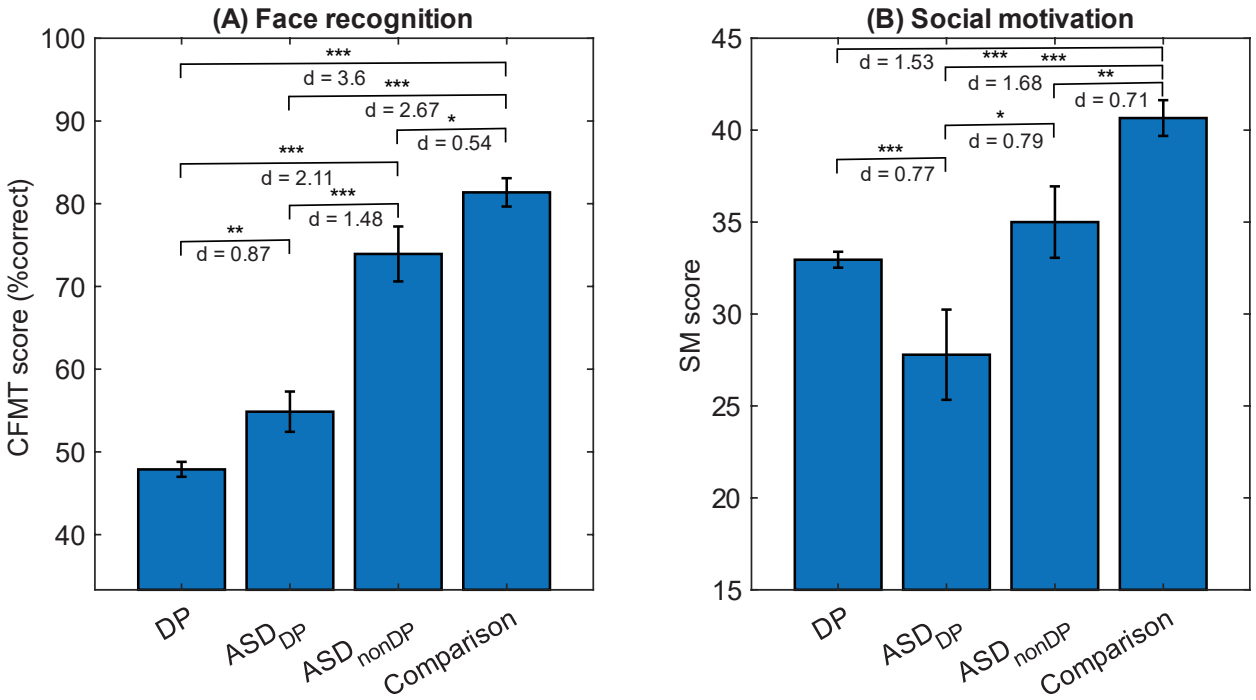


Figure 3. (A) Normalized face memory scores plotted as a function of normalized social motivation scores for participants with DP (red triangles) and participants from the comparison group (blue circles) separated by a best fit linear boundary line in green. (B) ASD participant (yellow asterisks) data superimposed on A. ASD participants below the best fit linear boundary in green were classified in the ASD_{DP} group and those falling above the line were classified in the ASD_{nonDP} group.

To examine whether face recognition challenges in ASD are exclusive to an ASD_{DP} subgroup based on our bivariate classification model, once again we carried out pair-wise comparisons (see Figure 4). This analysis revealed that all pair-wise differences in face recognition were significant. Specifically, the CFMT score for the ASD_{DP} group (*M* = 54.9%, *SD* = 8.78) was significantly higher than that of the DP group (M = 47.89%, SD = 7.22, *p* = .002, *d* = 0.87), and significantly lower than that of the Comparison group (*M* = 8 1.37%, *SD* = 10.97, *p* << .001; *d* = 2.67) and the ASD_{nonDP} group (*M* = 73.93%, *SD* = 15.93, p < .001; *d* = 1.48). The CFMT score of the ASD_{nonDP} group was significantly greater than that of the DP group (*p* << .001; *d* = 2.11), and importantly, it was significantly lower than that of the Comparison group (*p* = .033; *d* = 0.54). Figure 4A shows the CFMT scores for the four groups.

Social motivation score (SM) for the ASD_{DP} group (*M* = 27.79, *SD* = 8.85) was significantly lower than that of the Comparison group (*M* = 40.66, *SD* = 6.23, *p* < .001; *d* = 1.68), the ASD_{nonDP} group (*M* = 35.0, *SD* = 9.32, *p* = .027; *d* = 0.79), and the DP group (*M* = 32.95, *SD* = 3.46; *p* < .001; *d* = 0.77). The SM score of the ASD_{nonDP} group was significantly lower than



that of the Comparison group (p = .006; d = 0.71) and did not differ from the DP group (p = .14; d = 0.29). Figure 4B shows the SM scores for the four groups.

Figure 4. (A) Face recognition ability measured via the CFMT plotted as a function of group: those with DP, those with ASD sorted into the DP-like group based on our alternative bivariate classification model (ASD_{DP}), those with ASD sorted into the non-DP group based on our alternative bivariate classification model (ASD_{nonDP}), and the neurotypical comparison group. (B) Social motivation scores assessed via the MSCS plotted as a function of experimental group. Error bars represent the standard error of the mean. *** p < .001, ** p < .01, * p < .05.

2.4 Discussion

Our results on face recognition and social motivation measures replicate norms reported in the literature. Average CFMT score for the Comparison group of 81.37% (SD = 10.97) is consistent with Duchaine and Nakayama (2006) who showed 80.4% (SD = 11.0) as well as others in the literature who used the CFMT (Bowles et al., 2009; Dwyer et al., 2019; Hedley et al., 2011). The average CFMT score for our ASD group (M = 66.51%, SD = 16.42) was approximately one standard deviation below that of the Comparison group, also consistent with previous reports in the literature (Dwyer et al., 2019; Hedley et al., 2011) as well as a meta-analysis (Griffin et al., 2021). The DP group CFMT scores were also consistent with the literature, though this is not surprising given a score equal to or below 42 (out of 72) was part of the criteria for inclusion in the group. Social motivation scores for the Comparison group (M = 40.66, SD = 6.23) closely matched the reported norms (Yager & Iarocci, 2013) for typical participants without ASD (M = 40.10 SD = 6.28). Similarly, the SM scores for the ASD group (M = 32.48, SD = 8.04) were consistent with ASD norms reported in Yager and Iarocci (2013) (M = 29.02 SD = 8.33).

Our study is the first to assess social motivation via the MSCS in a group of individuals with DP. It is interesting to see that contrary to our expectation, SM scores in the DP group were low, similar to those of the ASD group. This is an important contrast to previous research from

Duchaine et al., (2009) who assessed social cognition in a group of adults with DP and found no signs of impaired social cognition in all but one of their DP participants, concluding that social cognition mechanisms can develop normally in the context of developmental face processing impairments. It is possible that when aspects of social cognition are assessed in contexts other than the diagnostic criteria for ASD, such as ADOS and AQ, social impacts of face deficits may appear. Although challenges in the social domain are not considered to be a primary impairment in DP, our results suggest that a severe life-long impairment of face recognition can impact social motivation in DP to levels associated with ASD. Indeed, semi structured interviews of children and adults with DP demonstrate that the inability to recognize faces can be a constant source of stress and anxiety, discouraging some individuals from placing themselves in social situations (Dalrymple et al., 2014; Yardley, McDermott, Pisarski, Duchaine, & Nakayama, 2008). These psychosocial consequences of DP vary between individuals, and the generalizability of these accounts is unknown, however, it seems plausible that social motivation could be impacted. The use of a validated assessment tool (i.e., MSCS) for social motivation provides a quantitative compliment to the qualitative descriptions of the psychosocial impacts of DP described by Yardley et al., (2008) and Dalrymple et al., (2014), including difficulties participating in social activities and increased anxiety. Further quantitative characterizations of the impact of DP on social competence can improve identification and support for the widespread occupational difficulties described by those with DP (Yardley et al., 2008). Reduced social motivation in DP shows that perceptual aberrations impacting face recognition can negatively impact social motivation, a notion that is consistent with a perceptual-based account of face recognition challenges in ASD.

Face recognition ability is dependent on experience with faces. This is suggested by a prolonged developmental trajectory (Bruce et al., 2000; Carey & Diamond, 1994; Germine et al., 2011; Hills & Lewis, 2018) as well as the exposure-dependent characteristics such as the so called other-race effect (Mondloch et al., 2010; Mousavi & Oruc, 2020; Rhodes, Hayward, &

Winkler, 2006; Walker & Tanaka, 2003; Zhao, Hayward, & Bülthoff, 2014) which is seen as a level of expertise that develops selectively for the types of faces encountered most frequently as part of daily exposure, often to “own-race” faces (Oruc, Shafai, Murthy, et al., 2019). Social motivation can modulate the frequency and degree to which individuals are exposed to others and enjoy opportunities to gain experience recognizing faces in a social interaction context. In this grain, an association between face abilities and social motivation may be expected. Although face ability is shown to be associated with symptom severity in ASD (Dawson et al., 2005; Webb et al., 2017) as well as the severity of autistic traits in the general population (Halliday, MacDonald, Scherf, Sherf, & Tanaka, 2014), studies that specifically examine social motivation have been sparse. One study that looked at face perception measures and social motivation as assessed by the MSCS found an association between the two, but only among participants with low social motivation (Oruc et al., 2018). In the present study, no group showed a correlation between social motivation and face recognition. The lack of correlation observed between SM and CFMT scores in both the DP and ASD groups may help distinguish between experiential and perceptual hypotheses pertaining to face recognition challenges in ASD. A correlation between SM and CFMT scores in DP would suggest that primary perceptual challenges are associated with social motivation, so an observed correlation for both the DP and ASD groups would be more consistent with a perceptual account. Conversely, a correlation between SM and face recognition ability exclusively in ASD, but not DP would be more consistent with the social motivation hypothesis, as it would demonstrate that social challenges on the autism spectrum are related to face recognition ability, but perceptually based face recognition challenges are not related to social motivation in DP. The lack of correlation observed in both groups, therefore, does not necessarily favour one account over the other. However, if viewing the group with ASD in isolation, a lack of correlation between social motivation and face recognition ability is inconsistent with the social motivation hypothesis. Alternatively, the absence of any correlation may be due to methodological differences between

different studies measuring different aspects of a core ability such as face perception vs. face memory, and AQ vs. SM (via MSCS). For the DP group, the narrow range of CFMT scores resulting from the inclusion criteria for that group could limit the ability to detect a relationship between face recognition and social motivation. Furthermore, social motivation can be expected to impact face ability only to the extent that it can serve as a proxy for face exposure, whereas the latter can only be truly established through empirical studies of the face-diet (Fausey, Jayaraman, & Smith, 2016; Jayaraman et al., 2015, 2017; Oruc, Shafai, Murthy, et al., 2019; Sugden et al., 2014; Sugden & Moulson, 2017). Future studies that assess daily visual exposure as well as social motivation can help close this gap.

After observing a 36% prevalence of severe face recognition impairment meeting the CFMT cut-off for developmental prosopagnosia in a sample of 80 of adults with ASD, Minio-Paluello et al. (2020) suggest that face recognition deficits in ASD may share the same etiology as DP. A shared etiology would support a perceptual/genetic origin for these deficits in ASD, providing an avenue for subtyping based on face recognition ability. In the present study we used two alternate methods to implement a provisional subgrouping, one based on CFMT (univariate) following Minio-Paluello et al. (2020), and the other adding on the context of social motivation (bivariate). Both methods resulted in similar proportions of ASD participants in the provisional DP-like subgroups: 36% (13/36) in the univariate approach and 39% (14/36) in the bivariate approach, consistent with Minio-Paluello et al. (2020).

To examine this *prosopagnosia subtype account* further, we compared face-recognition performance in our provisional ASD_{DP} and ASD_{nonDP} subgroups. Regardless of the classification methodology (univariate or bivariate), the ASD_{nonDP} subgroup consistently included participants with and without face recognition impairments, and importantly, on average, face recognition in the ASD_{nonDP} subgroup was significantly poorer than the Comparison group (Figures 2 and 4). This pattern of results is consistent with Barton et al. (2004) who studied face recognition, perception, and imagery in 24 adults with social developmental disorders, and found a

subcluster of 8 participants with normal face processing. Similar to our present findings, the remaining 16 participants in their study showed a range of deficits, some consistent with prosopagnosia in severity, and others with markedly milder deficits. Taken together, the empirical evidence suggests that a *prosopagnosia subtype account* cannot solely explain the spectrum of face deficits in ASD.

One possibility is that the ASD population contains two or more subgroups with distinct etiologies for face recognition challenges, one of which is prosopagnosic. On the other hand, simply meeting the CFMT cut-off for prosopagnosia does not necessitate a diagnosis of DP. Indeed, there are several arguments against this model. For example, Minio-Puello et al., (2020) found that face recognition ability in the prosopagnosic ASD subgroup was linked to performance in the Reading the Mind in the Eyes Test (RMET) (Baron-Cohen, Wheelwright, et al., 2001b), a task that requires participants to attribute the correct mental state of individuals from looking only at static images of their eyes. Yet, people with DP in the absence of autism do not have difficulties in the RMET task. (Duchaine et al., 2007; Duchaine, Parker, & Nakayama, 2003; Palermo et al., 2011).

Furthermore, like the RMET task, people with DP typically do not show deficits in expression perception (Duchaine et al., 2003; Humphreys, Avidan, & Behrmann, 2007; Palermo et al., 2011) or gaze perception (Duchaine, Jenkins, Germine, & Calder, 2009; Little, Palmer, & Susilo, 2022) when compared to controls. On the other hand, face expression perception deficits are well-documented in ASD, as well as atypical gaze perception (Leekam, Hunnisett, & Moore, 1998; Pantelis & Kennedy, 2017; Wallace, Coleman, Pascalis, & Bailey, 2006). Gaze perception atypicalities have been associated with identity recognition difficulties in children with ASD (Joseph, Ehrman, McNally, & Keehn, 2008) and expression perception challenges in ASD may be associated in severity with face identity perception deficits (Oruc et al., 2018). A model that suggests a shared etiology of identity recognition difficulties in ASD and DP, while ignoring expression and gaze perception deficits, which seem to be related in ASD, may not address the

full complexity of face processing issues in ASD. Instead, an experience-dependent model, such as the *social motivation hypothesis* of ASD (Chevallier et al., 2012; Dawson et al., 2005; Schultz, 2005) where face processing ability is conceptualized on a spectrum could provide a more parsimonious explanation for the face processing difficulties observed in autism.

Recently, Fry et al. (2022) investigated how autistic traits, based on AQ scores, impacts the neural and behavioural outcomes of DP in adulthood. Should the two disorders present themselves independently, the authors expected to observe similar behavioural profiles between those with high and low AQ scores. Conversely, if DPs with AQ scores characteristic of the broader autism phenotype (scores greater than or equal to 23 (Wheelwright, Auyeung, Allison, & Baron-Cohen, 2010)) present with a different pattern of face processing deficits, then the authors expected to find differences in behavioural performance across a battery of face related perception and memory tests. Overall, the authors demonstrated that individuals with DP and higher levels of co-occurring autism traits do not demonstrate a different behavioural profile of face processing ability than those with lower levels of autism traits. The lone exception to these findings was that those with higher levels of autism traits performed relatively poorer on the RMET task than the low AQ-DP group. The authors suggest support for a model where autism traits and DP occur independently but can be additive (Fry et al., 2022). These findings are consistent with the interpretation of our results that face recognition challenges in autism and DP may not share the same etiology, but the co-occurrence of ASD traits and face recognition challenges can lead to similar outcomes (i.e., decreased social interest, or challenges with emotion perception on the RMET task).

2.5 Conclusion

We tested a *prosopagnosia subtype account* of ASD by assessing face recognition ability and social motivation in ASD, DP, and a group of neurotypical controls. Such a model would provide a means of stratifying individuals with ASD into potentially meaningful subgroups,

based on those with and without face recognition difficulties. Our results, however, indicate that face recognition ability is graded in ASD, and that a *prosopagnosia subtype account* is not the sole explanation for face recognition challenges on the autism spectrum. Whether the ASD group was classified as having DP-like face recognition ability by traditional means of classifying DP (i.e., normalized face recognition scores equal to or less than -2) or via a bivariate classification model, our participants with ASD above the DP range of face recognition ability still, on average, underperformed with respect to the neurotypical comparison group. Thus, we conclude that face processing challenges in ASD and DP are unlikely to share the same etiology. Although our results do not support a *prosopagnosia subtype account* for ASD, the finding of prosopagnosia-like face recognition challenges in roughly 1/3 of adults with ASD is a consistent finding, highlighting the importance of considering face recognition ability in the context of the social challenges for autistic people. Conversely, our data also reveals the possible psychosocial impacts that a lifetime of face recognition challenges can have on social motivation for those with DP, informing opportunities for support for those with face blindness. Should face recognition ability in autism be best described by an experience-based model like the social motivation hypothesis, these results emphasize the potential utility of educational programs that facilitate exposure to faces for mitigating the compounding effects that poor face recognition may have on aspects of social competence.

Chapter 3 – The face diet of adults with autism spectrum disorder

3.1 Introduction

Autism spectrum disorder (ASD) is a developmental condition characterized by deficits of social communication and interaction, in addition to restricted and repetitive behaviours and interests (American Psychiatric Association, 2013). Individuals with autism experience challenges in face processing, including reduced performance in identity recognition and perception (Behrmann, Thomas, et al., 2006; Boucher & Lewis, 1992; Dwyer et al., 2019; Griffin et al., 2021; Hedley et al., 2011; Joseph & Tanaka, 2003; Minio-Paluello et al., 2020; Oruc et al., 2018; Simmons et al., 2009; Tang et al., 2015; Weigelt et al., 2012; Wolf et al., 2008), as well as expression recognition (Ashwin et al., 2006; Baron-Cohen, Wheelwright, Hill, Raste, & Plumb, 2001a; Harms et al., 2010; Loth et al., 2018; Oruc et al., 2018; Tanaka et al., 2012; Uljarevic & Hamilton, 2013; Wallace et al., 2008b). Recognizing and interpreting faces is critical for successful social interactions and the cortical processes involved in these abilities are argued to play a key role in social cognition (Adolphs, 2003). In the neurotypical population, reduced face memory ability has been associated with autism-like traits, specifically difficulties with social behaviour/interactions (Halliday et al., 2014; G. J. Lewis, Shakeshaft, & Plomin, 2018). The possibility of impaired face recognition abilities compounding existing impairments of social interaction and communication speaks to the importance of understanding the source of face recognition difficulties in ASD. This understanding can inform personalized interventions, improve face perception abilities, and in-turn improve the quality of life and functional independence of people with ASD.

Generally speaking, visuo-perceptual expertise is characterized by fast and accurate subordinate individuation of exemplars of a visual object category (Tanaka & Gauthier, 1997). In this regard, most adult observers are considered to be experts in face recognition (Carey, De Schonen, & Ellis, 1992; Diamond & Carey, 1986; Mondloch et al., 2006; Tanaka, 2001). For

example, upon running into a familiar face, one might automatically and effortlessly think “it’s Tom”, rather than “it’s a human face”. Face recognition expertise follows a protracted development, improving with age and experience (de Heering, Rossion, & Maurer, 2012; Germine et al., 2011). The development of expertise is accompanied by a processing style switch from one that focuses on object features (featural processing) to one that rapidly and efficiently processes the relationship between features (configural processing) (Mondloch et al., 2002). With enough training/experience, these specialized, efficient mechanisms can be recruited for classification (Gauthier & Tarr, 1997).

Perceptual accounts investigating the cause of reduced face recognition performance in ASD suggest these deficits occur fundamentally because of a visual bias towards local or featural information (Behrmann, Avidan, et al., 2006). Since face processing relies heavily on configural processing, this visual bias adversely impacts efficient face processing abilities in ASD. Conversely, experience-based accounts like the social motivation hypothesis posit that reduced social motivation in ASD leads to a lack of visual experience with faces, which over time leads to deficits in face perception (Chevallier et al., 2012; Schultz, 2005). Certainly, several instances of reduced or atypical social attention have been observed in autism. Reduced or atypical eye contact, for example, has been noted since the first observations of autism, and remains a characteristic of the autism phenotype according to the diagnostic and statistical manual of mental disorders, fifth edition (DSM-5); (Association, 2013; Kanner, 1943). Reduced social attention has been observed in lab-based and retroactive studies of home video footage of toddlers later diagnosed with ASD (Osterling & Dawson, 1994; Osterling et al., 2002), and lab-based eye-tracking studies reveal that when those with ASD are shown images of visual scenes, they tend to fixate preferentially on non-social aspects of the scene like objects or background, compared to faces (Fletcher-Watson et al., 2009; Riby & Hancock, 2008; S. Wang et al., 2015). Recently, Oruc et al. (2018) compared social motivation with facial identity and expression perception between a group of adults with ASD and a non-autistic comparison

group. In contrast to non-autistic adults, identity and expression perception abilities were both impaired and positively correlated with one another (r = .49) in the ASD group. The relationship between identity and expression perception in ASD suggests a common cause of these impairments. The authors suggested that front-end constraints on visual exposure to faces, possibly related to lower social motivation is an important contributing factor to these challenges. Indeed, social motivation was associated with compound face ability (an average of each individual's z-score of their respective performance in the identity and expression tasks), but only for those with low social motivation. In this case, self-reported social motivation scores were used as a proxy for social exposure. The idea that face processing abilities are most related to exposure when exposure is scarce, i.e., for individuals with low social motivation, is consistent with the social motivation hypothesis (Oruc et al., 2018). Lastly, the *eye avoidance hypothesis* suggests that the eye region of the face is emotionally charged, potentially causing immediate visceral responses mediated by increased skin conductance and amygdala activity (Tanaka & Sung, 2016). Thus, observations such as atypical eye contact, and decreased fixations towards faces in social scenes constitute a compensatory mechanism in ASD to reduce the discomfort or threat associated with looking at the eyes (Tanaka & Sung, 2016). Indeed, a relationship between the gaze direction and face memory has been demonstrated by Zaki and Johnson (2013), who showed reduced face recognition to faces with direct, but not averted gaze in ASD. These studies suggest that attention to faces is reduced and atypical in autism, but the question remains how these observations translate to the day-to-day visual experience of those on the autism spectrum.

Recently, Oruc et al. (2018) took a naturalistic observational approach to characterize the collection of faces encountered as part of one's day-to-day visual experience (termed the "face-diet") of neurotypical adults with an eye-wear embedded camera. The results of the study showed that familiar faces tended to be larger in the visual field of participants (median face width around 7.1 degrees visual angle), compared to unfamiliar faces (median face width

around 4.9 degrees visual angle), and were more likely to be seen in frontal or ¾ pose. Unfamiliar faces were more likely to be seen in ¾ or profile pose. The exposure statistics characterizing familiar face exposure are likely representative of viewing conditions typical of social interactions and are consistent with the literature describing ideal conditions for encoding faces with respect to pose (Troje & Bülthoff, 1996; Van der Linde & Watson, 2010a; L. Wang et al., 2007), and for efficient face recognition with respect to face size (N. Yang et al., 2014).

In the present study we examined the face-diet of adults with and without ASD. Participants were equipped with an eyewear-embedded camera, which recorded first-person perspective footage of a routine day. We determined exposure statistics for faces, including quantitative aspects of the face-diet such as overall exposure to faces, and qualitative aspects of the face diet, such as pose exposure patterns and viewing distance. We examine whether individuals with autism experience impoverished exposure to faces as part of their daily visual input to address the various accounts for face recognition deficits in ASD. We hypothesize that the face-diet of those with autism spectrum disorder will be reduced and atypical, meaning that our ASD group will see fewer faces, for shorter amounts of time, and those faces will not appear in the visual field in qualitatively similar patterns as our non-autistic control group.

3.2 Methods

3.2.1 Apparatus

First-person perspective footage was collected using a high-resolution 75° field-of-view eyewear-embedded camera, Pivothead Durango (http://www.pivothead.com/). The camera was set to timelapse mode to take 1 still image every 30 seconds at 3-megapixel resolution. Partway through data collection we acquired a second Pivothead Durango eyewear-embedded camera which produced images at a higher resolution (8-megapixel), but the same aspect ratio (4:3). Clear lenses were used so that the glasses could be worn in- or out-doors and the glasses were

connected to a pocket-sized external battery (Pivothead Power Pro Refuel 8000) which participants carried near or on their person.

3.2.2 Participants

First-person perspective footage of 17 adults with autism spectrum disorder (9 females; mean age = 27.9 +/- 11, range 18-51) were compared to that of 43 non-autistic controls (20 females; mean age = 30.0 +/- 8.1, range 18-54). An average of 5.02 hours of footage per participant was obtained from the ASD group, totalling 85.3 hours. An average of 6.47 hours of footage per participant was obtained from the control group, totalling 278.3 hours. Data from 30 non-autistic adults (14 females; mean age 31.9 +/- 8.4 years; range 20-54) previously published by Oruc, Shafai, Murthy, et al. (2019) was included in the current analysis.

3.2.3 Procedure

Participants were given the glasses and instructed to wear them during waking hours of one day. Participants were instructed to put on the glasses and turn on the camera upon waking in the morning and to go about their typical daily routine. At the end of the recording day, participants were given the option of connecting the glasses to their personal computer to review the footage. Participants could remove any images of a private nature (e.g., bathroom visits). Participants also filled out a post-participation questionnaire where they indicated their gender, age, ethnicity, occupation, whether recording was done on a workday or a non-workday, whether they removed or turned off the glasses for any period of time, and any additional comments they had. The protocol was approved by the review boards of the University of British Columbia, Simon Fraser University and Vancouver Hospital, and informed consent was obtained in accordance with the principles of the Declaration of Helsinki.

3.2.4 Data analysis

For a detailed account of the face detection and face annotation for pose, distance, and familiarity please refer to Oruc, Shafai, Murthy, et al. (2019). A brief, but thorough description of each has been provided here.

One-tailed non-parametric bootstrap tests with replacement and 100,000 repetitions was used for each exposure comparison. Wilcoxon rank-sum test was used for viewing distance comparisons.

3.2.4.1 Face detection

Participant footage was pre-processed with in-house MATLAB scripts, which automatically detected faces and placed them within bounding boxes. The automated detections were manually verified such that all faces had one and only one bounding box, and that non-face objects were not bounded. Face images appearing in media such as in print or on screen, as well as faces of children were not coded.

3.2.4.2 Face annotation

Pose (frontal, three-quarters, profile, other), and familiarity (familiar, unfamiliar, unsure) were manually annotated by two coders, each of whom independently annotated the entire footage. With respect to pose, a frontal pose was defined as both eyes visible and at least some portion of both ears visible; a three-quarter pose was defined as both eyes and one ear visible; and profile pose was defined as one eye and one ear visible only, based on the angle of the face. Features were considered “visible” if they would have been visible if not for another reason than the angle of the head.

All annotations are based on subjective judgements of the coders. Familiarity judgements are based on perceived context of interaction between the participant and the individual in the image. Images are coded in temporal order which helps indicate whether a face may or may not be familiar. In the initial Oruc, Shafai, Murthy, et al. (2019) face-diet study,

familiarity judgements were highly consistent between coders (97% inter-rater reliability), and highly accurate, as shown through a validation process with 4 participants. These 4 participants checked familiarity judgements across the entirety of each of their submitted footages, revealing a 98% correct familiarity judgement accuracy for the subjective judgements of the coders. Based on a set of transfer functions obtained through a face-size to distance calibration process from Oruc, Shafai, Murthy, et al. (2019), viewing distances were also estimated. First, coders drew a line segment between two pose-dependant anchor points on each face, in each image. For frontal and three-quarter faces, the anchor points were the two pupils. For profile faces the anchor points were the tip of the nose and the tragus of the ear. Then, one of six appropriate transfer functions (one for each pose-sex pair), were used to convert the line segment length to a physical distance from the face to the camera. Adult face sizes in degrees of visual angle were calculated directly from viewing distances based on a median face width of 12.8 cm for adult female faces and 14 cm for adult male faces (Poston, 2000).

3.2.4.3 Identity analysis

Following the face annotation process, images were subjected to a user-supervised, novel deep learning-based tool that quantifies the number of unique facial identities seen in a day. First, the Python-based program groups repeated faces that it deems to belong to the same identity (from the first set of face annotations). Faces are then manually adjusted (by two independent coders) so each unique identity is given a unique number within the footage set; if an identity was seen numerous times within footage, it was still only labelled as one unique identity. Each participant's footage was then quantified for the number of unique identities, percent exposure duration, pose, and viewing distance for familiar, unfamiliar, top-familiar, and top-unfamiliar faces. Top familiar faces were defined as the most frequently occurring face-identity in a participant’s footage. The top unfamiliar face was defined as the most frequently occurring unfamiliar face-identity in a participant’s footage.

3.3 Results

The following results are based on data weighted by the length of the footage provided by each subject, such that the final estimates are based proportionally on the total number of frames, to avoid overrepresentation of data from subjects who provided fewer frames.

3.3.1 Exposure duration

The ASD group spent 8.45 minutes per waking hour with at least one face in the visual field. This was significantly lower than the comparison group who were exposed to at least one face 12.21 minutes per waking hour ($p = .045$, $d = 2.26$). When split into familiar and unfamiliar faces, duration of exposure to familiar faces was significantly and substantially reduced in the ASD group ($M_{ASD} = 3.62$ min/hour, $M_{comp} = 8.44$ min/hour, $p < .001$, $d = 4.76$), whereas duration of exposure to unfamiliar faces did not differ significantly between the two groups ($M_{ASD} = 4.83$ min/hour, $M_{comp} = 3.77$ min/hour, $p = .85$). Figure 5A, 5B, and 5C show exposure durations to faces for those with and without ASD.

3.3.2 Number of unique identities

The ASD group viewed 17.21 unique identities per waking hour, which did not differ significantly from that of the Comparison group who viewed 13.49 unique identities ($p > .20$). Numerically, but not significantly, fewer familiar identities were observed for the ASD group ($M_{ASD} = 1.71$ unique identities per hour, $M_{comp} = 2.29$ unique identities per hour, $p = .16$, $d = 1.28$). Number of unique unfamiliar identities did not differ significantly between the two groups ($M_{\mathrm{ASD}} = 15.50$, $M_{comp} = 11.19$, $p = .38$, $d = 1.02$). Proportion of unique identities accounted for by familiar faces for the ASD group was 0.30, which was lower than in the Comparison group (0.40), though this difference did not reach significance ($p = .18$). Figure 5D and 5E show exposure frequencies to unique identities for those with and without ASD.

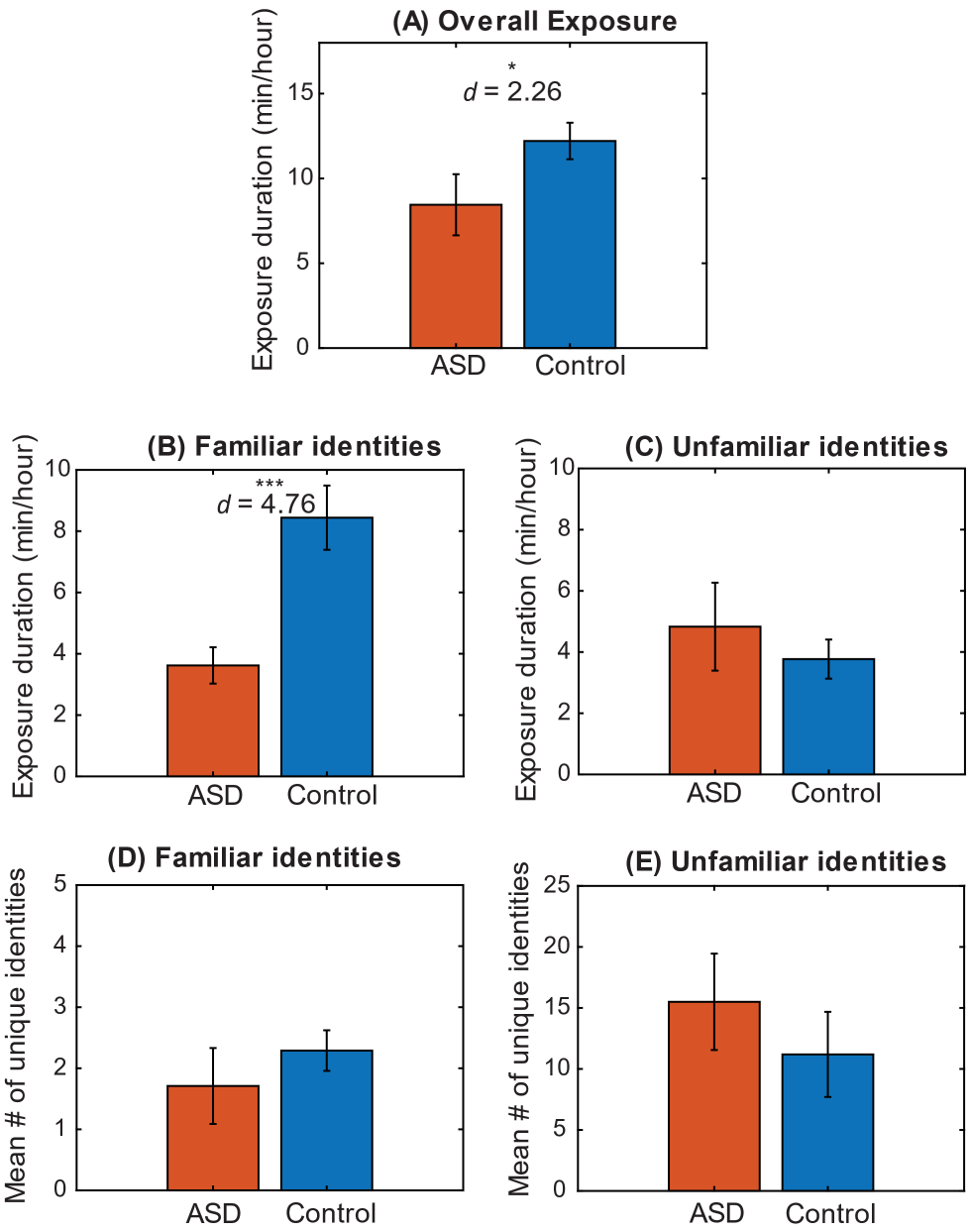


Figure 5. (A) Overall exposure duration (minutes per hour with a face in the visual field) for those with ASD (orange) and the comparison group (blue). (B) Exposure durations (min/hour) to familiar faces only (C) Exposure durations (min/hour) to unfamiliar faces only. (D) Mean number of unique identities encountered that were familiar. (E) Mean number of unique identities encountered that were unfamiliar. Error bars represent 68% confidence intervals. *p < .05, **p < .01, ***p < .001

3.3.3 Viewing distance

Median viewing distance for faces in ASD (*Mdn* = 299.54 cm) was significantly greater than the comparison group (*Mdn* = 154.10 cm, Wilcoxon Rank Sum Test, $p < .001$, $z = -20.51$). Familiar faces were viewed from significantly farther distances for those in the ASD group (*Mdn* = 229.77 cm) compared to the non-autistic comparison group (*Mdn* = 115.87 cm, Wilcoxon Rank Sum Test, $p < .001$, $z = -19.48$). Similarly, unfamiliar faces were also viewed from farther distances in ASD (Mdn_{ASD} = 522.90 cm, Mdn_{comp} = 200.31 cm, Wilcoxon Rank Sum Test, $p < .001$, $z = -15.94$). Figure 6A, 6B, and 6C show median viewing distances for those with and without ASD.

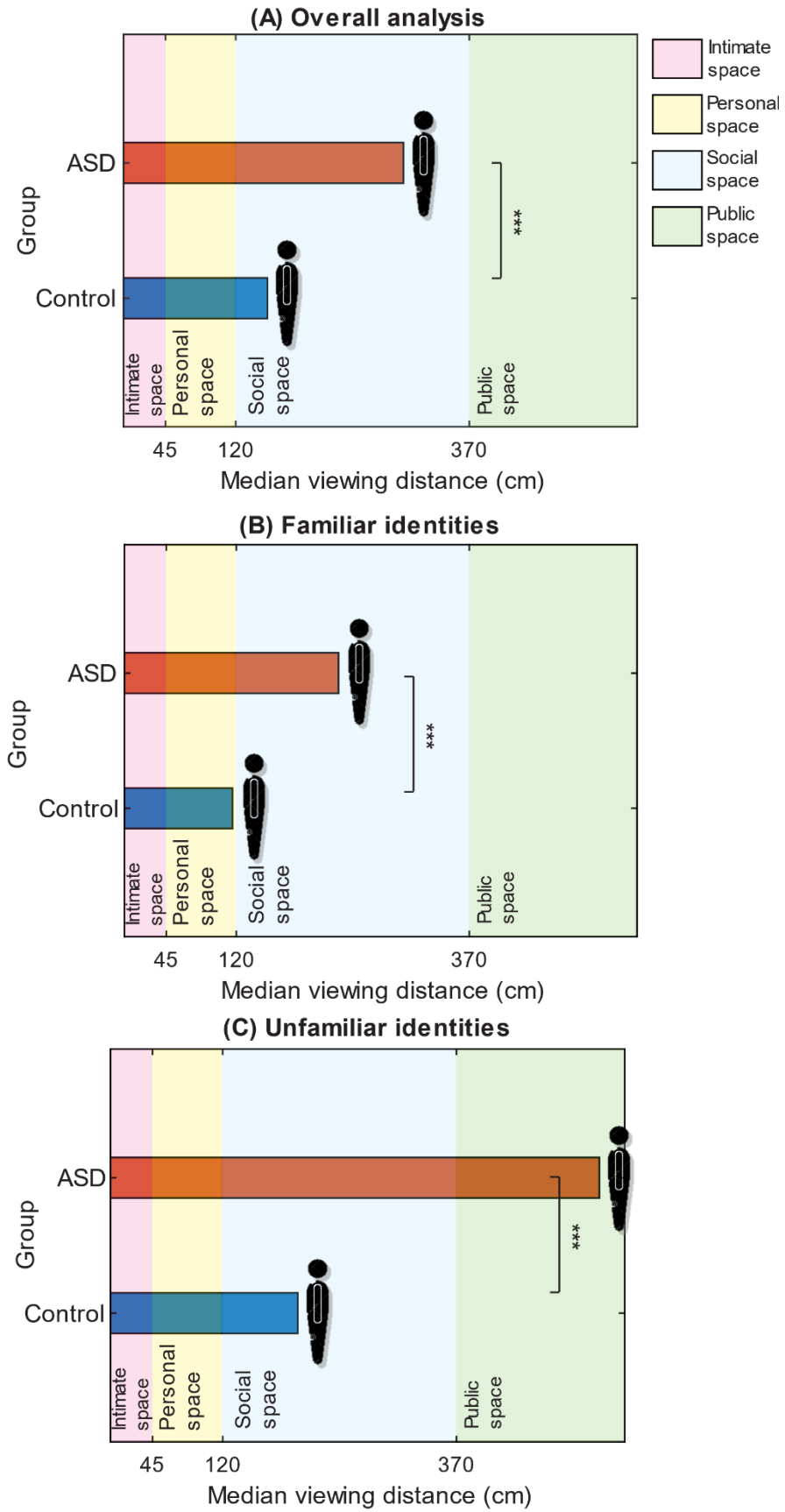


Figure 6. All figures are overlayed with a rough guide for interpersonal space as defined Edward T. Hall's study of proxemics (1966). Pink represents intimate space, yellow is personal space, blue is social space, and green represents public space. (A) Median viewing distance (cm) of all faces in the visual field during a routine day for those with ASD (orange) and the comparison group (blue). (B) Median viewing distance (cm) for only familiar identities. (C) Median viewing distance (cm) for only unfamiliar identities. Error bars represent 68% confidence intervals. ***$p < .001$.

3.3.4 Pose

Distribution of all face exposure across three categories of pose (frontal, three-quarters, profile) showed group differences. For the ASD group, 17.20% of all face exposure was in the frontal pose, which was lower than the 26.79% frontal exposure for the Comparison group indicating a trend (p = .052, d = 2.03). However, despite this trend, the difference did not reach statistical significance. In contrast, profile pose accounted for 36.67% of all face exposure in the ASD group, which was greater than profile exposure in the Comparison group (26.67%), however, this difference also did not reach significance, p = .06, d = 2.06). Three-quarter pose exposure was similar in both groups and was 44.11% and 43.01% for the ASD group and the Comparison group, respectively (p = .54). We also tested a frontal-profile contrast, which showed a highly significant frontal advantage for the Comparison group, compared to the ASD group (p < .001, d = 4.04).

For *familiar faces*, frontal exposure accounted for 18.58% in the ASD group, which was lower than the 29.86% frontal exposure for the Comparison group (p = .057, d = 2.03). Likewise, the 31.79% profile exposure in the ASD group was higher than the 21.59% profile exposure in the Comparison group, although this effect did not reach significance (p = .067, d = 1.96). Three-quarter pose exposure to familiar faces were similar for the two groups, 46.97% and 44.39% for the ASD and Comparison groups, respectively, and did not differ significantly (p = .61). We also tested a frontal-profile contrast, which showed a highly significant frontal advantage for the Comparison group, compared to the ASD group (p < .001, d = 4.13).

For *unfamiliar faces*, frontal exposure accounted for 8.28% in the ASD group, which was significantly lower than the 17.93% frontal exposure for the Comparison group (p = .003, d = 3.03). Profile pose exposure to unfamiliar faces was similar in the two groups, accounting for 40.15% and 41.32% in the ASD group and Comparison group, respectively (p = .45). Three quarter pose accounted for 50.48% of exposure to unfamiliar faces in the ASD group and 38.43% in the Comparisons group, and these did not differ significantly (p = .18). Distributions of

face exposures across three categories of pose are shown in Figure 7A, 7C, and 7E for both groups. Frontal-profile contrasts are shown in Figures 7B, 7D, and 7F.

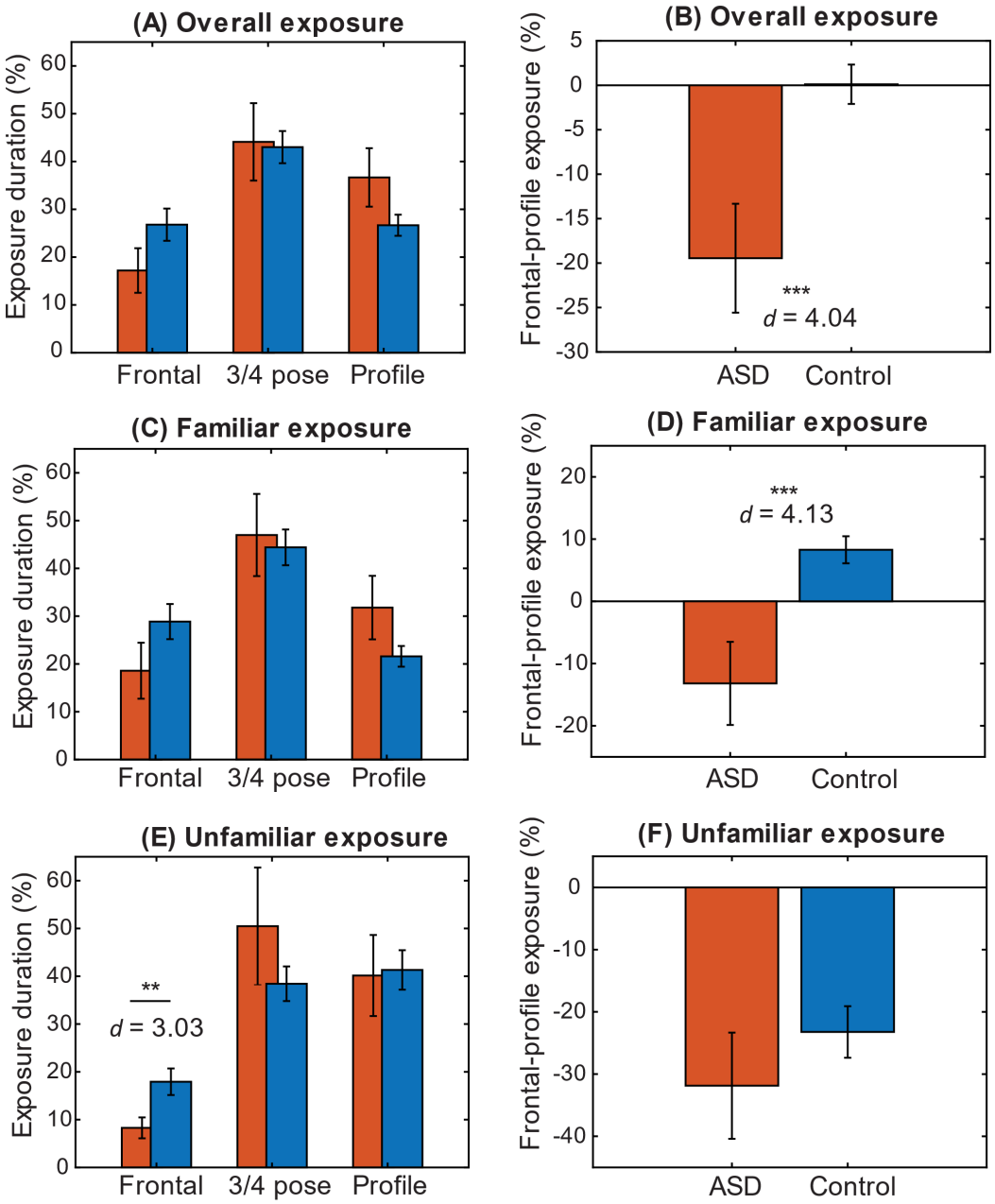


Figure 7. Pose exposure durations (%) to frontal, ¾, and profile faces for the group with ASD (orange) and the comparison group (blue). (A) Pose exposure duration patterns for all faces captured in the visual field of participants. (B) Frontal – profile contrasts for overall exposure (C) Pose exposure duration pattern for familiar identities only. (D) Frontal – profile contrasts for familiar face pose exposure. Percent

exposure contrasts below zero indicate higher proportions of profile than frontal faces. Percent exposure contrasts above zero indicate higher proportions of frontal than profile faces (E) Pose exposure duration patterns for unfamiliar faces only. (F) Frontal – profile contrasts for unfamiliar face pose exposure. Error bars represent 68% confidence intervals. $^{**}p < .01$, $^{***}p < .001$

3.3.5 Top familiar face

In the ASD group, the top familiar face (defined as the familiar face with the longest exposure within the footage) accounted for 1.08 minutes of exposure per waking hour, significantly lower than the 2.11 minutes of exposure per hour in the Comparison Group, (p = .004, d = 3.70). In the ASD group, the top familiar face was viewed in the frontal pose 24.79% of the time, which was not significantly different than the 34.26% frontal exposure in the Comparison group (p = .22, d = 0.99). In contrast, profile pose accounted for 30.98% of top familiar face exposure in the ASD group, greater than the 18.63% profile exposure in the Comparison group, indicating a trend (p = .051, d = 2.08). However, this difference did not reach significance. Three quarter pose exposure was similar in both groups with 44.22% and 45.84% in the ASD and Comparison groups, respectively (p = .43). We also tested a frontal-profile contrast, which showed a highly significant frontal advantage for the Comparison group, compared to the ASD group (p = .001, d = 3.67).

3.3.6 Top unfamiliar face

In both groups, the top unfamiliar face accounted for a similar duration, which was 0.14 and 0.09 minutes per waking hour for the ASD group and the Comparison Group, respectively, and did not differ significantly (p = .18). In the ASD group, the top unfamiliar face was viewed in the frontal pose 2.2% of the time, which is significantly lower than the 16.50% frontal exposure in the Comparison group (p < .001, d = 3.24). In contrast, profile pose accounted for 40.73% of top unfamiliar face exposure in the ASD group, similar to the 46.89% profile exposure in the Comparison group (p = .34, d = 0.50). Three quarter pose exposure was 55.06% in the ASD

group, which was not significantly different than the 36.61% exposure in the Comparison group (p = .12).

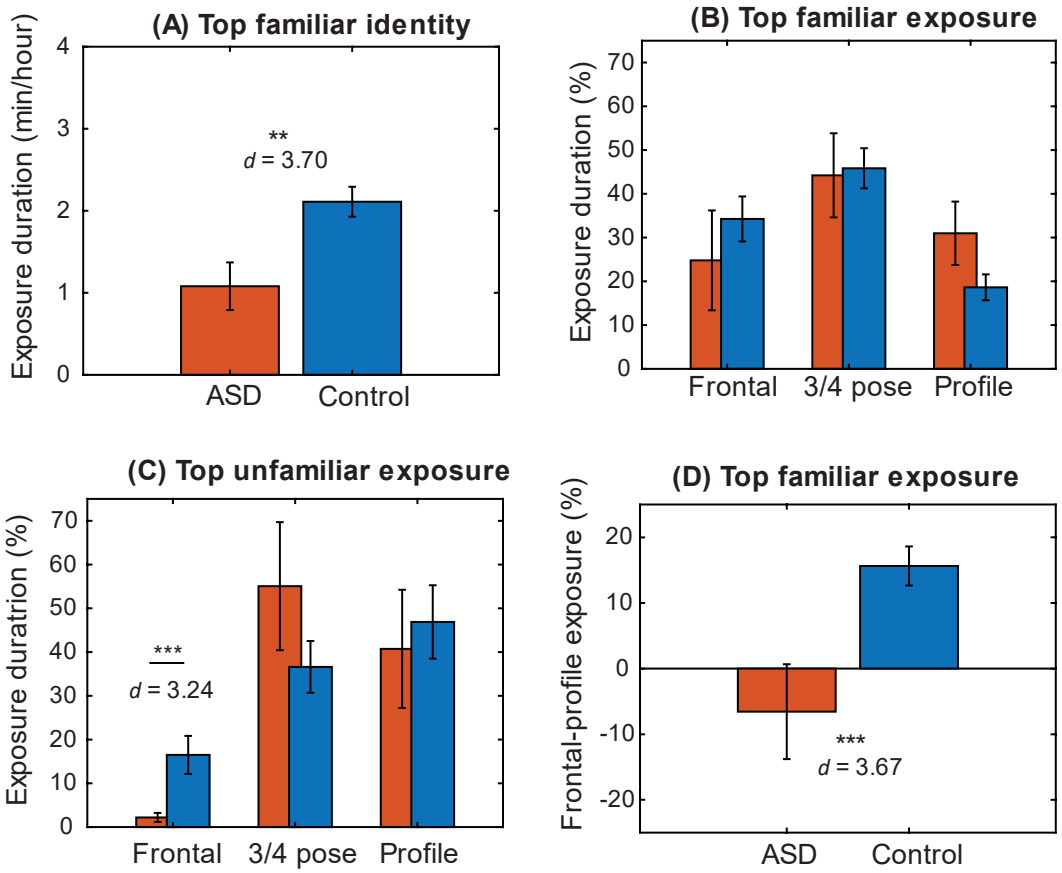


Figure 8. Face exposure statistics for the top familiar (most frequently occurring familiar face for each participant) and top unfamiliar (most frequently occurring unfamiliar face for each participant) faces. (A) Pose exposure durations (minutes per waking hour) to the top familiar identity for participants with ASD (in orange) and non autistic participants (in blue). (B) Pose exposure durations (%) to the most frequently occurring familiar faces for participants with ASD (in orange) and non-autistic participants (in blue). (C) Pose exposure durations (%) to the most frequently occurring unfamiliar faces for participants with ASD (in orange) and non-autistic participants (in blue). (D) Frontal-profile contrasts to top familiar faces for participants with ASD (in orange) and non-autistic controls (in blue). Percent exposure contrasts below zero indicate higher proportions of profile than frontal faces. Percent exposure contrasts above zero

indicate higher proportions of frontal than profile faces Error bars represent 68% confidence intervals. ***p* < .01, ****p* < .001.

3.4 Discussion

We compared the statistics of daily face exposure (i.e., face-diet) of 17 adults with ASD to that of 43 non-autistic controls. Oruc, Shafai, Murthy, et al. (2019)'s original investigation of the adult face diet with neurotypical observers suggests that expert face recognition processes are tuned to ecologically relevant viewing conditions, i.e., social interactions with familiar persons. The social motivation hypothesis posits that face processing challenges for those with ASD are related to reduced social attention due to low social motivation (Chevallier et al., 2012; Dawson et al., 2005; Schultz, 2005). Although investigations of retroactive home videos of children later diagnosed with ASD (Osterling & Dawson, 1994; Osterling et al., 2002), lab based investigations of social attention (Fletcher-Watson et al., 2009; Riby & Hancock, 2008, 2009; Swettenham et al., 1998; S. Wang et al., 2015), and studies using self-reported social motivation as a proxy for social attention (Oruc, Shafai, & Iarocci, 2019) suggest reduced social attention in ASD, it is unclear how these findings relate to the day-to-day visual experience of those on the autism spectrum. We predicted that in autism, a development disorder characterized by deficits of social communication and interaction, we would observe a reduced and atypical face diet. Reduced and atypical visual exposure to faces would confirm a core assumption of the social motivation hypothesis with an ecologically valid sampling of ASD visual experience.

3.4.1 Exposure

Our results revealed an overall reduced duration of exposure to faces as part of the daily visual input of those with autism spectrum disorder. Compared to the non-autistic control group, ASD participants spent almost 4 minutes less per hour with a face in the visual field. We investigated whether this reduction was due to reduced exposure to unfamiliar/stranger's faces

with whom our participants are less likely to socialize with or due to reduced exposure to familiar faces. As expert face processing is specifically crucial for ecologically relevant viewing conditions typical in social interaction with familiar persons, visual experience with familiar faces presumably plays a central role in the development of these processes. Our results show that the reduction in exposure to faces in ASD was fully accounted for by reduced exposure to familiar faces. A study of the infant face diet reveals that the first 3 months of visual exposure is dominated by a select few familiar faces (Jayaraman et al., 2015, 2017). This early 'dense' exposure is characterized by large faces, presenting with both eyes visible for nearly 15 minutes per waking hour, and is thought to be an especially important visual experience for developing neural architecture for expert face processing (de Heering & Maurer, 2014; Jayaraman et al., 2015, 2017). As the infant develops and becomes more mobile (between 11 and 24 months) this exposure reduces to 5 minutes per waking hour (Jayaraman et al., 2015, 2017). Our study indicates that when individuals are acting on their own volition in adulthood, non-autistic adults return to 'dense' exposure levels more consistent with early infanthood. Relatively high levels of exposure in early adulthood are consistent with observations that face recognition abilities peak after the age of 30 (Germine et al., 2011). In comparison, those with ASD remain at reduced exposure levels associated with later infanthood. Two retroactive observational studies of home videos from 1st birthday parties suggest that differences in social attention are apparent by 12 months for children with ASD (Osterling & Dawson, 1994; Osterling et al., 2002). Similarly, a study of social attention via analysis of laboratory recorded video found that those later diagnosed with autism spent less time looking at people, had shorter durations of looks at people, and were less likely to shift attention towards people than the comparison group at 20 months (Swettenham et al., 1998). Our investigation shows that patterns of reduced social attention continue into adulthood for those on the autism spectrum, providing compelling evidence that reduced experience with faces influences the development of expert face recognition processes in ASD.

Given that we did not observe statistical differences between the number of unique unfamiliar identities, or the time spent per hour with unfamiliar faces in the visual field, we can conclude that those aspects of the day where exposure to faces is likely, such as going for walks, taking public transit, or going to the store, are not fundamentally different between the two groups. These passing visual experiences, where faces are present and plentiful, but unlikely to be attended to or individuated, likely do not constitute an important experience for the protracted development of expert face processing. For example, neonatal nurses' ability to recognize newborn faces, a stimulus with which they have massive exposure to, but do not individuate, were found to be similar to adults rarely exposed to newborn faces (Yovel et al., 2012). To explore whether these results were because of the short durations of exposure to the newborns, or if newborn faces are more difficult to recognition generally, the authors of the study placed 20 university undergraduates into a newborn face training protocol focused on individuating (matching a name to a face) 12 newborn faces. Following 3 days of training (roughly the length of exposure of neonatal nurses to individual newborns), recognition of novel and trained newborn faces reached adult-level face recognition accuracies. Similarly, studies comparing individuation-based training protocols versus protocols involving identity-irrelevant categorization found greater improvements in face recognition of other-race faces following individuation (McGugin, Tanaka, Lebrecht, Tarr, & Gauthier, 2011; Tanaka & Pierce, 2009). These studies indicate that mere exposure is not sufficient for developing face expertise, and that some form of interest/motivation or task is necessary. These findings highlight the importance of familiar face exposure in the face-diet, the very exposure lacking for our group with ASD.

3.4.2 Size/Viewing distance

Our results show that regardless of familiarity, faces tend to be viewed from farther distances, and therefore, are smaller in the face diets of those with ASD. This effect was not

simply due to the increased proportion of unfamiliar exposures in ASD but was true for both familiar and unfamiliar faces. The median viewing distance for familiar faces in the visual fields of our comparison group was 115.87 cm, which translates to a median face-width of 6.62°. For our group with ASD, the median viewing distance of familiar faces was 229.77 cm, translating to a median face-width of 3.34° visual angle. For comparison, unfamiliar faces were roughly 3.83° for the control group, and 1.46° degrees for the group with ASD. All face-widths were estimated using the median viewing distance for that set of faces and a median-face width estimate for adult human faces of 13.4 cm from Poston (2000).

These results have important implications with respect to existing face recognition literature. In addition to larger faces being accepted as easier to recognize (Loftus & Harley, 2005), a recent study investigating face recognition efficiency as a function of face size found two distinct face recognition mechanisms varying across a 6° face width threshold. A more efficient expert mechanism is suggested for faces above 6° in size, perhaps configural processing, and less efficient process at 6° or less (N. Yang et al., 2014). In a related study, critical spatial frequencies for recognizing objects and faces across different sizes was investigated. Higher spatial frequencies carry more detailed information, while lower spatial frequencies carry coarser information. Objects and inverted faces demonstrated scale dependence, meaning that as the size of the stimulus increased, so did the critical spatial frequencies for recognizing those stimuli. Faces however, were scale invariant at sizes above 4.7°, meaning that critical spatial frequencies used for recognition did not continue to increase with size after this boundary (Oruç & Barton, 2010). In both cases, the authors suggest that specialized recognition processes are recruited for highly ecologically significant stimuli, i.e., upright faces viewed at distances typical of social interactions (Oruç & Barton, 2010; N. Yang et al., 2014). This conclusion is highly consistent with the characteristic viewing distances of faces for our controls. Overall, faces were 4.98° which makes faces greater than the 4.7° threshold with respect to scale invariance of the critical spatial frequencies used for detection. This would

allow potentially familiar faces to be recognized using ideal spatial frequencies for recognition of larger faces. In our non autistic cohort, familiar faces were typically viewed at 6.62°, utilizing the more efficient expert mechanism for faces greater than 6°. For our cohort with ASD however, familiar faces weren't viewed at distances characteristic of social interactions. The median face width for familiar faces in the ASD face diet (3.34°) is smaller than the 6° specialized face processing threshold suggested by N. Yang et al. (2014), and faces generally fell below the 4.7° boundary where critical spatial frequencies bands for face recognition stop increasing with face size, according to Oruc & Barton (2010). These results suggest that those with autism spectrum disorder are not seeing faces at sizes consistent with the development of expert face processing in the neurotypical population.

While perceptual accounts don't make any specific predictions regarding the visual experience of individual with autism, *local processing bias* accounts of reduced face recognition abilities in autism might argue that those with ASD are keeping faces at a distance where a local bias is most useful (just below the face size where higher spatial frequency information stops becoming as useful). Since faces are viewed at distances where more general object recognition processes are recruited, it makes sense that an object recognition processing style focused on features is used. Conversely, the *social motivation hypothesis* would suggest that those with ASD are less likely to engage in typical social interactions which would take them to closer distances to other people. Both of these assertions would assume that those with autism have a similar pattern of spatial frequency use across differently sized faces. Without holding this assumption, one might consider the types of compensation strategies that would arise for recognizing faces with a strategy focused on features. First, as a face moves further away, the human visual system loses the ability to resolve higher spatial frequencies. Thus, progressively lower spatial frequencies are lost to the observer at a rate inversely proportional to distance (Loftus & Harley, 2005). If those with ASD preferentially use higher spatial frequency information for identity recognition as suggested by Deruelle et al., (2004; 2008) in support of a local

processing bias, then one might expect that those with ASD would move closer to others to access more and more detail from their faces. On the other hand, more global characteristics of faces would shift into higher spatial frequencies at further distances, which could allow those with ASD to use preferred higher spatial frequency information to process global aspects of other faces. It seems then, that a locally biased processing style, and a supposed preference for higher spatial frequency visual information would be at odds in this scenario. The results here are consistent with the notion that those with ASD are keeping faces at distance where global/configural properties are shifted into higher spatial frequencies, promoting a more global processing style over a feature-based processing style.

3.4.3 Pose

The results from our comparison group were consistent with Oruc et al,. (2019), showing that faces are viewed most commonly in three-quarters pose in the adult face-diet of our neurotypical controls. This was also true for our group with autism. The second most viewed pose for our controls was frontal pose. In the group with autism, however, the second most viewed pose was profile. To again check whether this pattern was due to an increased proportion of exposure to unfamiliar faces we compared frontal-profile contrasts between our participants with ASD, and non-autistic controls for familiar/unfamiliar, and top-familiar/top unfamiliar faces. A substantial and significant frontal-profile contrast was observed in which those with ASD were more likely than non-autistic adults to view faces in profile compared to frontal for familiar and top familiar faces. Frontal-profile contrasts did not differ between groups for unfamiliar faces or the top unfamiliar face. A frontal pose advantage observed for familiar and top familiar faces for non-autistic adults suggests frontal and ¾ faces are the most commonly occurring poses during social interactions. In contrast, unfamiliar faces are more likely to be viewed in profile pose with frontal being the least likely. We argue that this represents a typical pose pattern of a non-social interaction. Regardless of familiarity, our group

with ASD was more likely to view faces in profile pose than frontal pose. Even the top familiar face, defined as the most frequently occurring face-identity, typically a family member, roommate, or close co-worker, was viewed with pose exposure patterns characteristic of non-social interactions for our group with ASD.

In the face recognition literature, several studies indicate a ‘three quarters advantage” for learning a face for future recognition across various poses (Krouse, 1981; O'Toole et al., 1998; Troje & Bülthoff, 1996), although some argue that full face (frontal pose) may be as advantageous as three quarters (Liu & Chaudhuri, 2002; Van der Linde & Watson, 2010a). The pattern of three quarter-frontal face exposure, signature of familiar face exposure for our controls, suggests that visual experience may contribute to the recognition performance reported in the behavioural studies listed above. The flip of this familiar face exposure pattern from three quarter-frontal to three quarter-profile in ASD suggests those on the autism spectrum are not viewing familiar faces in a fashion characteristic of a social interaction. This observation is consistent with the *social motivation hypothesis* for reduced face recognition performance observed in ASD. In a review by Weigelt et al. (2012), seven behavioural studies are outlined that found reduced face recognition memory in children, adolescents, and adults with ASD. All seven studies used experimental procedures including learning faces in three quarters or frontal view. A further 11 studies were outlined, all using standardized tests of face recognition memory including the Benton face recognition test (Benton & Van Allen, 1968), the Warrington test of face recognition (Warrington, 1984) the Weschler Memory Scale for faces (David Wechsler, 1997) and the Cambridge face memory test (Duchaine & Nakayama, 2006). Eight of the eleven studies reported reduced face recognition in autism. Importantly, all the above standardized tests use procedures including learning faces in frontal or three quarters view, but not profile. The pattern of exposure to familiar faces for our participants with autism suggests they may not be getting as much practice individuating the types of faces typically used as stimuli for tests of face recognition. Equivalent exposure to three quarters pose may limit the deleterious impact of

reduced exposure to frontal faces, providing a possible explanation for the moderate, but not severe deficits of face recognition often observed in autism (Barton et al., 2004; Griffin et al., 2021; Kamensek et al., 2023).

Pose exposure patterns in ASD, favouring profile over frontal poses during familiar exposures suggests viewing conditions that minimize the likelihood of making eye contact. This interpretation of the results would be consistent with the *eye avoidance hypothesis* which posits that individuals with ASD avoid the direct gaze of others to minimize negative arousal associated with making eye contact (Tanaka & Sung, 2016). Avoidance of the eyes has been suggested by lab-based eye tracking studies where individuals with autism demonstrate reduced fixations to the eyes, less time fixating on the eyes, and more time fixating on mouths and bodies compared to their non-autistic counterparts who show strong tendencies to fixate to, and remain fixated on the eyes of others (Dalton, Gernsbacher, et al., 2005; Jones et al., 2008; Klin et al., 2002).

The proportional increase in profile exposure in ASD indicates a rare situation where exposure to a certain type of face is increased in a population. The question remains however, whether these exposure patterns are also accompanied by increased attention to the face. The *eye avoidance hypothesis* would predict that profile faces would provide an avenue for interacting with faces that avoids negative arousal. The *social motivation hypothesis* might predict that these exposure patterns represent diminished social attention. Future assessments of pose dependent face recognition abilities can assess whether this unique exposure pattern is associated with enhancements in learning and recognizing faces in profile pose.

Whether observed deficits of face recognition in ASD are best explained by a difference in perceptual style, or because of atypical/reduced experience with faces remains to be seen. Here, a perceptual account would not necessarily be at odds with an experiential explanation for face deficits in ASD. As familiar faces are not as likely to be seen at far distances or in patterned poses associated with social interaction, this lack of experience may limit typical acquisition of

configural face processes, or the ability to apply those processes for efficient and accurate recognition. In this case however, the social interaction style in ASD would lead to a feature-focused perceptual style, rather than the other way around. Individual differences in social abilities, interest and experience could provide an explanation for findings of reduced face recognition abilities in some, but not all individuals with autism (Barton et al., 2004; Kamensek et al., 2023; Weigelt et al., 2012). One the other hand, potential differences in perceptual processing styles that lead to impairments in face recognition in ASD could deter those with these challenges from approaching social interactions. The important difference is that experiential accounts like the *social motivation hypothesis* specifically predict that visual experience with social stimuli is different for those on the autism spectrum. Here, we confirm that prediction with a cohort of adults with ASD. In either case, it should be noted that it is difficult to infer directionality, or a causal relationship between two factors based on association or correlation. Especially when those two factors seem to be co-related, as demonstrated by reduced social motivation in individuals who have had a lifetime of severe face recognition challenges as observed in development prosopagnosia. Future studies, assessing the face-diets of autistic and non-autistic individuals at different stages of development could help distinguish experiential and perceptual accounts. A reduced and atypical face-diet observed across the entire lifespan of an individual with ASD would be consistent with an experiential account for face recognition challenges in ASD. Conversely, a face-diet that becomes reduced and atypical over time, would suggest that perceptual aberrations that cause face recognition challenges and difficulties with social interactions lead to reduced visual exposure to social stimuli.

3.5 Conclusion

In the current study, we have characterized the exposure statistics of faces for adults with autism on a typical day. We have defined key aspects of the visual face-diet that are likely

to contribute to the protracted development of expert face processing, including overall exposure to, typical viewing distances (and therefore face size) for, and pose exposure patterns of familiar and unfamiliar faces. First, the face diet of adults with autism is quantitively reduced, which can be fully accounted for by reduced exposure durations for familiar faces, including the top familiar face. There was no difference between groups regarding unfamiliar face exposure durations. Qualitatively, faces presented in atypical pose exposure patterns and at farther viewing distances for those on the autism spectrum. Specifically, a profile-frontal pose bias was observed in ASD for familiar and top familiar faces, that differed from non-autistic controls, but not for unfamiliar or top unfamiliar faces. These exposure patterns, should they represent how our participants are interacting with faces, suggest that our participants with ASD are interacting with familiar faces in a way that is not typical of social interaction. While social situations characterised by familiar face exposure may tune visual expertise for faces in the general population, differential exposure patterns in ASD may contribute to the deficits of face recognition reported in the literature.

Chapter 4 – Pose-dependent face exposure and recognition in autism spectrum disorder

4.1 Introduction

Autism spectrum disorder is a neurodevelopmental condition characterized by impairments in social communication and interaction, as well as restricted and repetitive behaviours and interests (American Psychiatric Association, 2013). Suggested to contribute to the social and communication challenges core to autism are impaired face processing abilities, including trouble with identity recognition, (see Weigelt et al. (2012) for a review, and Griffin et al. (2021), for a meta-analysis) and expression recognition (see Harms et al. (2010) for a review; and Uljarevic et al. (2013) for a meta-analysis). A recent meta-analysis, including 119 studies of face recognition has shown that individuals with ASD tend to score, on average one standard deviation lower than their non-autistic counterparts (Griffin et al., 2021). These moderate impairments of face recognition have been shown to be associated with reduced social interaction in children (Corbett et al., 2014), and are predictive of autism severity later in adolescence (Eussen et al., 2015). On the other hand, better face recognition memory abilities are associated with increased cooperative play, better social skills, and fewer social difficulties (Corbett et al., 2014; Neuhaus et al., 2016). The entanglement of face recognition abilities and the social/communication challenges for individuals with ASD calls for a better understanding of the root causes of face recognition impairments in ASD.

Several hypotheses have been proposed to explain face recognition challenges in ASD. Generally, these hypotheses can be categorized as perceptual based explanations (nature) or experience-based explanations (nurture). The *social motivation hypothesis* is an experience-based hypothesis that posits that reduced attention to faces throughout development may lead to reduced face recognition abilities (Chevallier et al., 2012; Schultz, 2005). The *eye avoidance hypothesis* is another experience-based hypothesis, which suggests that gazing on eyes of

others can elicit quick, uncomfortable visceral responses, that have been observed through elevated skin conductance and increased amygdala response, which results in an “eye avoidance” compensatory strategy, potentially disrupting typical face processing (Tanaka & Sung, 2016). On the other hand, perceptual accounts suggest that impaired face perception is a primary deficit that stems from an anomalous visual processing style, rather than socio-cognitive factors. For example, *the local processing bias* hypothesis suggests that an inherent bias or preference for attending to individual features in ASD is costly to face perception, which involves the efficient binding of several features to a whole or global percept (Behrmann, Thomas, et al., 2006). Finally, the *prosopagnosia subtype hypothesis* observes an overrepresentation of clinical level deficits of face recognition in ASD, suggesting a shared etiology of face recognition difficulties with individuals with developmental prosopagnosia (Minio-Paluello et al., 2020). These hypotheses are not necessarily mutually exclusive and could all contribute at some level for a given individual with ASD. For example, variability in attention to faces throughout development moderated by reduced and heterogenous social interest or social comfortability in ASD could deter some individuals from reaching their potential face recognition ability. Underdeveloped face recognition abilities could mean that individuals on the autism spectrum apply more general feature-by-feature recognition strategies, instead of more expert, configural processing mechanisms (Carey et al., 1992; Carey & Diamond, 1994; Mondloch et al., 2006). Alternatively, inherent impairments of face recognition ability in some individuals with ASD (Minio-Paluello et al., 2020), combined with a locally biased perceptual style that is not conducive for efficient face recognition could compound existing social interaction and communication difficulties in ASD. Social frustration could reduce social interest and prevent sufficient experience with faces for the protracted development of recognition expertise. Given these possible alternative explanations, it is of particular interest to determine which might be occurring first. Are face recognition challenges in ASD perceptual in nature, or are they fundamentally shaped by the social-cognitive impacts of being on the autism spectrum?

The typical development of expert face recognition processes follows a protracted development, becoming tuned and specialized with visual experience (Mondloch et al., 2006; Tanaka & Gauthier, 1997). Kamensek et al., (2022) have recently described the daily visual exposure statistics for faces (termed the *face-diet*) of a group of adults with and without ASD. The face diet of those with ASD was found to be reduced and atypical, compared to that of non-autistic controls. Specifically, due to reduced familiar face exposure, significantly less time per hour was spent with a face in the visual field for those with ASD (8.45 minutes/hour in comparison to 12.21 min/hour for the control group). When faces were in the visual fields of the ASD participants, they tended to be further away from the viewer (i.e., smaller), and presented in an atypical pose exposure pattern.

A reduced and atypical face-diet as demonstrated through Kamensek et al., (2022)'s ASD cohort suggests that those on the autism spectrum may not be getting the necessary and sufficient experience for the protracted development of expert face processes. Strikingly, faces in the visual fields of those with ASD, tended to appear in patterns that favoured profile pose over frontal pose, regardless of the familiarity of the face. The original investigation of the neurotypical adult face-diet (n = 30) found that three-quarter and frontal pose faces were the most commonly occurring poses (in that order), with profile the least likely (Oruc, Shafai, Murthy, et al., 2019). These findings are consistent with behavioural studies (though not all, see Liu and Chaudhuri (2002)) observing a 'three-quarter pose advantage' for face recognition (O'Toole et al., 1998; Troje & Bülthoff, 1996), most evident during the encoding phase and when study and test faces differ in viewpoint (Troje & Bülthoff, 1996; Van der Linde & Watson, 2010b). Intermediate or equivalent performance with frontal faces has been observed and performance with profile faces tends to be comparatively poor (Krouse, 1981; Van der Linde & Watson, 2010b). However, if individuals with ASD get more experience with profile pose compared to frontal, would this potentially confer them with better recognition of the profile pose?

In the context of the eye avoidance hypothesis, a face in the profile pose is least likely to result in eye contact, providing comfortable viewing conditions to extract the necessary features for individuation and consequent social interactions with familiar faces. Indeed, a study of the impact of gaze direction on face recognition demonstrated that those with ASD do not derive a recognition advantage for direct gaze faces, compared to their non-autistic counterparts (Zaki & Johnson, 2013). Increased experience viewing familiar faces in the profile pose, as suggested by the proportional increase in profile pose exposure compared to frontal pose exposure in ASD reveals a population with a unique developmental visual history. Here, we investigate whether a visual exposure pattern favouring profile pose faces is associated with improved encoding and recognition of this stimulus type. We hypothesize that those on the autism spectrum have a profile pose recognition advantage, which will reveal itself through equivalent or better profile pose face recognition compared to frontal pose recognition. If so, this would be strong evidence for the assumptions underlying various social motivational hypotheses, that the anomalous experience of ASD subjects with faces is a contributing causal factor to their perceptual performance.

4.2 Methods

We examined face recognition ability in adults with ASD and a non-autistic comparison group using two methods of assessment. General face recognition abilities were assessed with the Cambridge Face Memory Test (CFMT), a validated tool for measuring face recognition (Duchaine & Nakayama, 2006). Pose dependent face recognition (PDFR) was assessed via a novel recognition paradigm modelled broadly after the CFMT, created in-house using Psychopy® (https://www.psychopy.org/). Participant IQ was estimated using full scale IQ 2 (FSIQ-2) composite scores from the Weschler Abbreviated Scale of Intelligence II (WASI-II)(D. Wechsler, 2011) which includes the vocabulary and matrix reasoning subsections.

4.2.1 Participants

Eighteen participants with ASD (8 females; age: M = 30.94, SD = 9.80), and 18 non-autistic adults (8 females; age: M = 27.50, SD = 6.10) took part in the study. Participants with ASD were all previously diagnosed by a clinician. Nine participants with ASD also participated in the face-diet study. The autism spectrum quotient (AQ) test (Baron-Cohen, Wheelwright, Skinner, et al., 2001), a fifty-item, self-administered questionnaire used to assess traits associated with the autism spectrum was completed by all participants. A score of 32 represents the cut-off for distinguishing individuals who have clinically significant levels of autistic traits (Baron-Cohen, Wheelwright, Skinner, et al., 2001). We used a cut-off score of 20 as exclusion criteria for comparison participants to maintain the greatest separation between adults with ASD and the adults in the comparison group, while still allowing for individuals who tend to have higher scores, such as those in mathematics or sciences (Baron-Cohen, Wheelwright, Skinner, et al., 2001). All participants had an estimated IQ greater than 75 based on the FSIQ-2 subsections of the WASI-II (M_{ASD} = 112, SD_{ASD} = 12.66; $M_{control}$ = 116.17, $SD_{control}$ = 8.10).

4.2.2 Apparatus

Participants in the ASD group and the comparison group completed the CFMT on a Dell laptop (model 3750) equipped with a 17-in. antiglare LED screen. Participants sat approximately 57 cm from the screen. The 50 item AQ were completed by all participants either online, or on paper. The PDFR task was run using PsychoPy® from an HP spectre laptop to a 23-inch, full high definition (1920 x 1080-pixel resolution) Dell flat panel monitor (model P2314H). Participants sat roughly 88 cm from the screen such that each test face presented subtended 6.8 degrees of visual angle.

4.2.3 Stimuli

The PDFR task stimuli were created using male and female faces from the Stirling face database (http://pics.stir.ac.uk/ESRC/index.htm). The task was split into two test conditions:

frontal and profile. First, faces are learned in one of the two poses. Faces in frontal are defined as having both eyes and both ears visible based on the angle of the face. Faces in profile are defined as having one eye and one ear visible based on the angle of the face. The learning phase for each test condition (frontal or profile) consists of faces presented across three unique illumination conditions with neutral expression. During the first test phase, faces are presented in the same pose as the learning phase, but with 3 novel image conditions: One novel image of each face (taken at a different time point) in matching illumination to one of the learning conditions, 1 novel illumination condition with neutral expression, and one happy expression condition. In the second test phase, regardless of the test condition (frontal or profile), faces are presented in three-quarter pose, defined as having both eyes and one ear is visible based on the angle of the face. Three-quarter faces were presented across three unique illumination conditions, two with faces presenting neutral expressions and one with faces presenting a happy expression. Faces were converted to grayscale and edited in Photoshop© (https://www.adobe.com/ca/products/photoshop.html) such that all obvious markings (jewelry, moles, freckles, facial hair, etc.) were removed. Faces in frontal pose were placed in an oval aperture to remove the hair line and lower part of the neck, then cropped along the cheeks of the face to remove the ear and any background from the image. Faces in three-quarter and profile pose were also placed in an oval aperture such that the hair line and ears were removed, and then cropped along the edges of the nose and cheeks to remove any background from the image. 6 male faces and 6 female faces were chosen as targets and 18 faces of each sex were chosen as distractors.

4.2.4 Procedure

Participants completed the CFMT and FSIQ-2 subsections of the WASI-II with the experimenter before completing the PDFR task. The PDFR task is composed of a frontal and a profile pose test condition each composed of 54 trials. Each condition is identical in procedure,

differing only by the pose that target identities are learned (frontal vs. profile) and recognized (same pose and 3/4 pose) in. Each condition is comprised of three phases: Learning (same images), recognition 1 (novel images in the same pose as learning), and recognition 2 (novel images in ¾ pose).

4.2.4.1 Learning - Phase 1 – Same images

In the learning phase, an on-screen prompt displayed on a grey screen instructs the participants to memorize the target face which appears for 1 second, 3 consecutive times (separated by a 500ms blank screen). Target faces are presented in either frontal or profile pose, across three unique illumination conditions, with a neutral expression. Then participants complete 3, 3-alternative forced-choice (3-AFC) trials, selecting the target face among two distractors. All target images in the test trials of phase 1 are identical to those studied. Distractor faces are presented in matching illumination and expression conditions as the target. During phase 1, 3 male targets and 3 female targets are learned. Distractor identities are randomly selected for each trial, without replacement, but all match the sex of the target.

4.2.4.2 Recognition – Phase 2 - Novel images

Prior to phase two, participants are shown a study screen for six seconds, including all learned target identities presented in two rows of three. Afterwards, 18 recognition trials, 3 trials per target identity are completed. All recognition trials include novel images of each target identity that were taken at either a different time, in a different illumination condition, or with a happy expression. Distractor identities were hand selected for each target to maximize difficulty and matched the image properties of the target (i.e., same illumination and expression). All participants completed the task with the same target – distractor combinations in phase 2 and phase 3. Trial order, however, was randomized for each participant in phase 2 and 3.

4.2.4.3 Recognition – Phase 3 – Novel images in ¾ pose.

Prior to phase 3, participants are asked to review the target identities one more time, with the same screen as presented before phase 2, for 6 seconds. Afterwards, 18 recognition trials, 3 trials per target identity were completed. All test faces were presented in three-quarter pose, in 3 unique illumination conditions (with respect to each other), two with neutral expressions and one with a happy expression. Again, distractor identities were hand selected for each target identity to maximize difficulty of the task and matched the illumination and expression of the target. Distractor identities appearing with a target in phase 2, were not repeated with the same target in phase 3. Trial order was randomized for each participant.

4.3 Results

4.3.1 CFMT

As a replication check, and confirmation of reduced face recognition abilities in ASD, we performed a two-sample t-test comparing upright face recognition scores on the CFMT between our group with ASD and the comparison group. This revealed a significant difference between groups ($t(34) = 2.49$, $p = .018$, $d = 0.83$) , with the comparison group ($M = 80.09\%$, $SD = 13.14$) scoring higher than the group with ASD ($M = 68.67\%$, $SD = 14.31\%$). These results are shown in Figure 9.

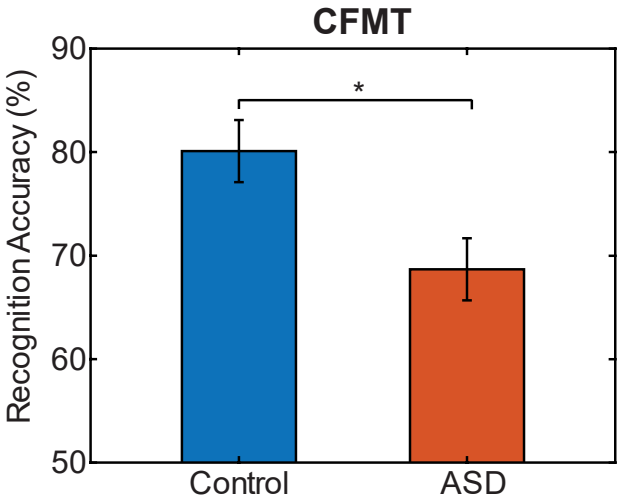


Figure 9. Face recognition accuracy scores (%) for the non-autistic comparison group (blue) and the group with ASD (orange) based on the upright CFMT. Error bars represent the standard error of the mean (SEM). *$p < .05$

4.3.2 PDFR test

To compare pose dependent face recognition in ASD to the non-autistic comparison group, we performed a repeated measures ANOVA with group (ASD vs, comparison) as the between-subjects factor and pose condition (frontal vs. profile) as the within-subjects factor. The analysis revealed a main effect of group ($F(1,34) = 18.05$, $p < .001$, $\eta^2 = 0.28$), with greater recognition accuracy for the comparison group ($M_{comparison} = 90.22\%$, $SD_{comparison} = 8.91\%$) than the group with ASD ($M_{asd} = 77.43\%$, $SD_{asd} = 14.70\%$), a main effect of test condition ($F(1,34) = 31.92$, $p < .001$, $\eta^2 = 0.21$), with greater accuracy for frontal recognition ($M_{frontal} = 89.20\%$, $SD_{frontal} = 10.83\%$) than profile recognition ($M_{profile} = 78.44\%$, $SD_{profile} = 14.24\%$), and a significant interaction between the two ($F(1,34) = 7.46$, $p = .01$, $\eta^2 = 0.06$).

Following the significant interaction between group (ASD vs. comparison) and pose condition (frontal vs. profile), post-hoc t-tests were conducted comparing face recognition accuracy across each testing condition for each group, and between groups at each testing condition. The results are summarized in Figure 10. Multiple comparisons were controlled using

Bonferroni correction. First, both groups performed significantly better in the frontal pose condition (M_{asd} 85.39%, SD_{asd} = 12.54%; $M_{comparison}$ 93.69%, $SD_{comparison}$ = 6.96%) than the profile pose condition (M_{asd} 69.44%, SD_{asd} = 12.37%; $M_{comparison}$ 87.80%, $SD_{comparison}$ = 9.85%; ASD p < .001, d = 1.68; comparison p = .017, d = .88). Second, the comparison group outperformed the group with ASD at both the frontal test condition (p = .033, d = .741) and the profile test condition (p < .001, d = 1.62). Contrary to our prediction, the interaction shows a greater decrement in the profile pose test condition in ASD, compared to the non-autistic control group.

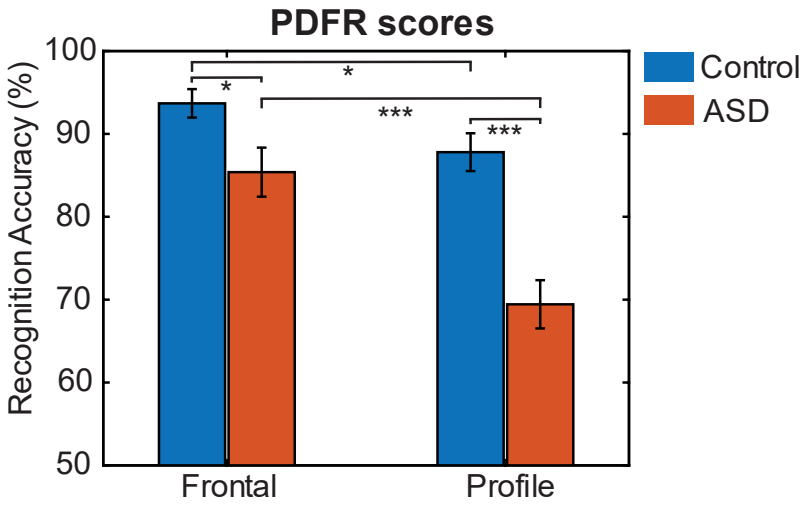


Figure 10. Face recognition accuracy (%) scores based on the frontal pose and profile pose conditions for the group with ASD (orange) and the comparison group (blue). Error bars represent the SEM. *p < .05, ***p < .001.

4.3.3 Correlations – PDFR and CFMT

Pearson correlation coefficients were calculated to assess the relationship between face recognition performance as assessed via the CFMT (Duchaine & Nakayama, 2006) and our in-house PDFR test. There was a strong positive correlation between upright face recognition (%) on the CFMT and the frontal face performance on the PDFR for those with ASD (r = 0.71, p < .001) and the comparison group (r = 0.60, p = .009). A strong positive correlation was also revealed between profile face performance on the PDFR and upright CFMT performance for the

comparison group, $r = 0.60$, $p = .008$. Profile pose performance was not significantly correlated with upright CFMT performance for the group with ASD, $r = 0.25$, $p = .325$. All correlations are shown in Figure 11.

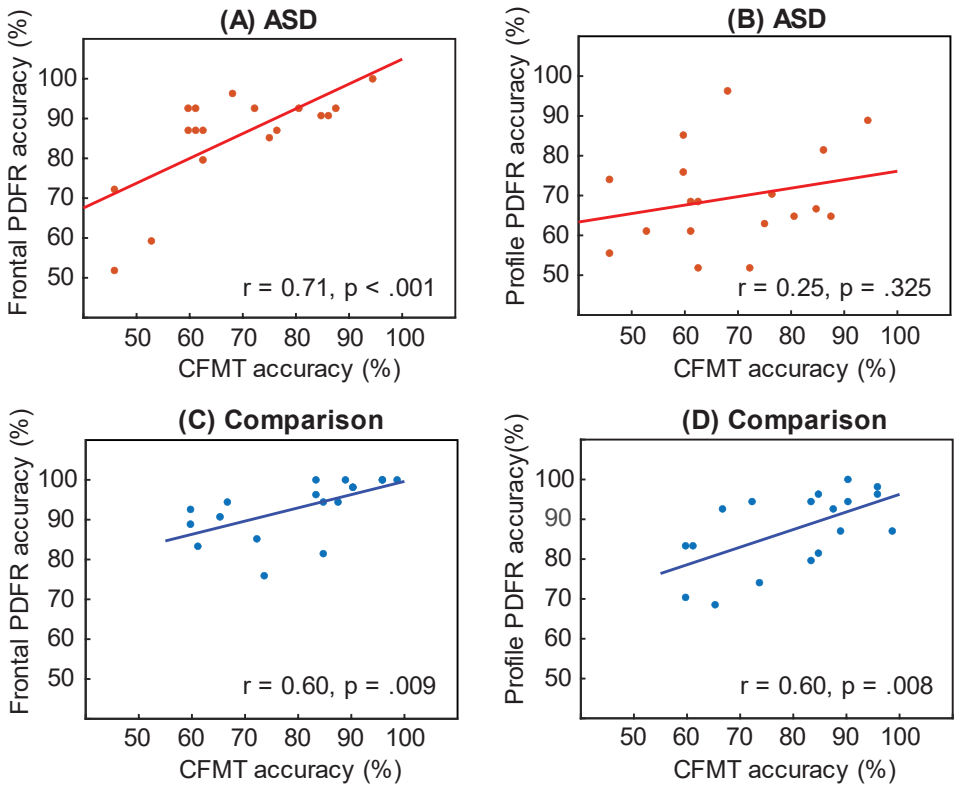


Figure 11. Scatter plots with best fit lines showing correlations between: (A) Frontal face recognition accuracy (%) based on the PDFR test and CFMT face recognition scores (%) for those with ASD. (B) Profile face recognition accuracy (%) based on the PDFR test and CFMT face recognition scores (%) for those with ASD. (C) Frontal face recognition accuracy (%) based on the PDFR test and CFMT face recognition scores (%) for the comparison group. (D) Profile face recognition accuracy (%) based on the PDFR test and CFMT face recognition scores (%) for the comparison group.

4.3.4 Viewpoint change transfer of learning

To assess recognition performance across each phase of testing for each pose condition in ASD and the non-autistic comparison group, we performed a repeated measures ANOVA with group (ASD vs. comparison) as the between-subjects factor and test phase (learning phase

vs. recognition phase 2 – novel images in the same pose vs. recognition phase 3 – novel images in three-quarter pose) as the within-subjects factor. For the frontal pose condition there was a main effect of group ($F(1,34) = 4.94$, $p = .033$, $\eta^2 = .08$), a main effect of phase ($F(2,68) = 25.21$, $p < .001$, $\eta^2 = .22$), and no significant interaction ($F(2,68) = 2.79$, $p = .068$). For the profile pose condition there was a main effect of group ($F(1,34) = 23.68$, $p < .001$, $\eta^2 = .30$), a main effect of test phase ($F(2,68) = 51.19$, $p < .001$, $\eta^2 = .37$), and a significant interaction between test phase and group ($F(2,68) = 7.14$, $p = .002$, $\eta^2 = .08$), due to a reduction in test performance across changes in pose, specific to the profile PDFR pose condition and the ASD group.

To examine cross-view point transfer of learning effects from encoding in the frontal and profile poses to recognition in the 3/4 pose, we conducted pair-wise t-tests comparing face recognition accuracy across each testing phase for each group. The results are summarized in Figure 12. Multiple comparisons were controlled using Bonferroni correction.

In the frontal PDFR pose condition, ASD performance in the learning phase ($M = 17.5$, $SD = .79$) was significantly higher than the recognition phase of faces in frontal pose (same-view) ($M = 14.83$, $SD = 2.87$) and the recognition phase of faces in the three-quarter pose (novel-view) ($M = 13.78$, $SD = 3.87$; both $p < .01$). Importantly, recognition performance did not differ significantly between the same-view and novel-view recognition phases.

Performance in the non-autistic comparison group was also significantly higher in the learning phase ($M = 17.94$, $SD = .24$) compared to the recognition phase of faces in frontal pose (same-view) ($M = 16.11$, $SD = 2.42$) and the recognition phase of faces in three-quarter pose (novel-view) ($M = 16.17$, $SD = 1.72$; $p < .05$, $p < .01$ respectively). Importantly, recognition performance did not differ significantly between the same-view and novel-view recognition phases.

In the profile PDFR pose condition, ASD performance in the learning phase ($M = 16.06$, $SD = 2.04$) was significantly higher than the recognition phase of faces in frontal pose (same-view) ($M = 11.67$, $SD = 2.83$) and the recognition phase of faces in three-quarter pose (novel-

view) (M = 9.78, SD = 3.75; both p < .001). Recognition performance was also significantly higher is the same-view recognition phase than the novel-view recognition phase in ASD (p = .03).

Recognition performance for the non-autistic comparison group was significantly higher in the learning phase (M = 17.39, SD = .92) compared to the recognition phase of faces in frontal pose (same-view) (M = 15.28, SD = 1.74) and the recognition phase of faces in three-quarter pose (novel-view) (M = 14.56, SD = 3.05; both p < .001). Recognition performance was not significantly different in the same-view vs. novel-view recognition phases for non-autistic controls (p = .396).

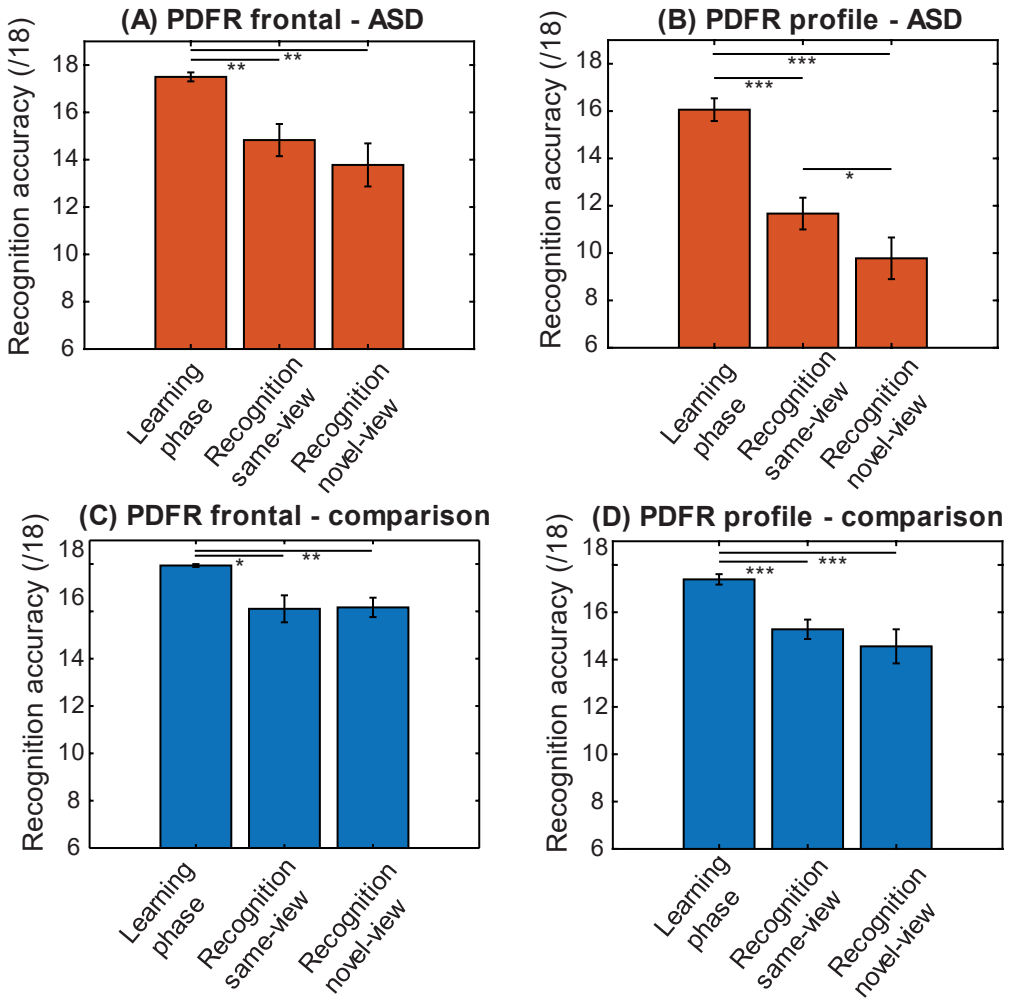


Figure 12. Recognition accuracy scores (/18) across each phase of the PDFR task in the (A) frontal pose condition for ASD, (B) profile pose condition for ASD, (C) frontal pose condition for the non-autistic comparison group, (D) profile pose condition for the non-autistic comparison group. Error bars represent the SEM. *$p < .05$, **$p < .001$ ***$p < .001$.

4.4 Discussion

Exposure statistics to faces in the daily lives of adults with autism spectrum disorder revealed an unusual pattern biased towards faces in profile pose. This pattern of exposure in ASD would be predicted by a preferred viewing strategy that avoids discomfort associated with direct eye contact during a social interaction (Tanaka & Sung, 2016). We hypothesized that more experience with the profile pose might confer people with ASD a recognition advantage in this pose. Our hypothesis, however, was not supported. Both groups demonstrated a frontal pose advantage for recognition, with disproportionally weaker profile pose recognition for our group with ASD.

Moderately impaired face recognition performance, as indicated by overall reduced performance on the PDFR tasks in ASD, adds to a robust literature indicating impaired face recognition in ASD when face memory is tested (Griffin et al., 2021; Webb et al., 2017; Weigelt et al., 2012). First, the observed reduction in CFMT performance in ASD closely replicates previous findings in the literature from those also using the CFMT (Dwyer et al., 2019; Hedley et al., 2011). Second, observed differences in overall PDFR performance are consistent with the general findings that face recognition tends to fall roughly 1 standard deviation below non-autistic performance.

Our results also indicated an overall encoding and recognition advantage for frontal faces compared to profile faces in both ASD and non-autistic controls. While a three quarter pose advantage for encoding faces has been reported in the literature (O'Toole et al., 1998; Troje & Bülthoff, 1996), a full-face, or frontal advantage has also been shown for familiar faces and when compared to profile faces (Bruce, Valentine, & Baddeley, 1987). Overall, our results

are consistent with the literature on pose dependent face recognition. An advantage for encoding and recognizing faces in frontal pose is also consistent with exposure patterns favouring frontal over profile pose faces in the face-diet of neurotypical adults (Oruc, Shafai, Murthy, et al., 2019).

With respect to the significant interaction between group and pose, indicating a disproportionate drop in performance for profile faces in ASD, one possibility is that this may reflect an underestimation of the difference between frontal and profile faces in typical subjects because of a ceiling effect for our comparison group in the frontal condition. Five out of 18 individuals in the comparison group scored 100% accuracy in the frontal condition, with an additional 8 subjects scoring above 90% accuracy. With this proportion of participants scoring at or near ceiling, we may be underestimating the true difference between frontal and profile performance in the comparison group. Regardless, both groups showed reduced performance with profile faces compared to frontal. A profile advantage in ASD would have revealed itself as an interaction where profile performance is better than, or comparable with frontal, however, this was not the case.

It is suggested that people with ASD perform worse at facial recognition tasks because of a local processing bias, or in other words, a greater reliance on featural information than gestalt or holistic information (Behrmann, Avidan, et al., 2006; Behrmann, Thomas, et al., 2006). One interpretation of our findings is that when featural information is reduced (half the face removed during profile face viewing), this adversely impacts those with ASD, resulting in the observed interaction between group and pose. On the other hand, the comparison group is also losing the same amount of featural information, as well as configural information with profile faces, argued to be especially important for typical expert face processing (Maurer et al., 2002; Mondloch et al., 2006; Tanaka & Farah, 1993). One might expect this double impact on face processing in the comparison group to result in reductions in performance no less than observed for the group with ASD. In a related study, Morin et al. (2015) assessed discrimination

thresholds for faces with a delayed match-to-sample test paradigm, with and without viewpoint changes between frontal and side-view, demonstrating that those with ASD had decreased performance in view-change conditions, but no differences between groups for same-view testing conditions. The authors suggest that the observed decrease in performance was due to decreased accessibility to local features across view changes.

Important differences in methodology limit the ability to make a direct comparison between studies. The faces used in the Morin et al. (2015) study were synthetic, identities were altered via geometric changes to face shape, and profile view faces were defined by a 20-degree rotation from front view (see Wilson, Loffler, & Wilkinson, (2002) for stimulus production methodology). Our results suggest that when images of real faces are used, with differing identities, and larger memory demands, differences in face recognition abilities in same-view conditions may be observed, as we did for frontal and profile faces. Faces rotated by 20 degrees would also be considered ¾ view, not profile or side-view with our definitions of profile. In a follow up to the Morin et al. (2015) study, Guy, Habak, Wilson, Mottron, and Bertone (2017) investigated the developmental trajectories of viewpoint dependent face discrimination abilities in individuals with and without ASD. The authors found that in both groups, discrimination thresholds decreased, and therefore, improved with age similarly between same-view and view-change testing conditions, and that both groups performed more poorly in view-change conditions. In contrast to the initial study, the developmental findings suggest similar patterns of face identification for autistic and non autistic individuals (Guy et al., 2017). These results, as well as results from other studies using a similar experimental paradigm showing reduced performance in view-change compared to same-view conditions for neurotypical adults (Habak, Wilkinson, & Wilson, 2008; H. R. Wilson et al., 2002) suggests that non-autistic adults rely on local informational cues to a similar degree as those with ASD.

In the current study, we showed that when faces are encoded in frontal pose, there is not a recognition performance difference between same-view and novel-view test conditions. In

other words, learning of faces in frontal pose transferred to recognition of three-quarter faces for ASD and for non-autistic controls. Using Morin et al. (2015)'s reasoning, these results suggest that with images of real faces, decreased access to local features is not a limiting factor to recognition performance across view changes from frontal to three-quarter pose in ASD. These results are also consistent with the notion that autistic and non autistic individuals share the same patterns of face identification across view-point changes (Guy et al., 2017), at least for faces learned in frontal pose. For faces encoded in profile pose, however, ASD recognition performance was worse in the three-quarter pose (view-change) recognition condition than the profile pose (same-view) condition. There was no significant difference between same-view and novel-view conditions in the non-autistic comparison group. Our results showing no differences between same-view and view-change recognition performance in frontal or profile test conditions for the non-autistic comparison group is not consistent with the findings of Guy et al. (2017); Habak et al. (2008) or H. R. Wilson et al. (2002) who found poorer discrimination thresholds across view-change conditions for non-autistic individuals. These differences could be due to the methodological differences discussed with respect to synthetic vs. real face stimuli, or differences in outcome measures (discrimination thresholds vs. recognition memory). Overall, these results suggest that those with ASD are less able to recognize faces across viewpoint changes that are learned in profile pose. A perceptual bias account arguing for a feature-based visual processing style in ASD might argue that this processing style is able to overcome viewpoint changes from frontal to three quarter but struggles with more challenging viewing conditions when featural information is removed for profile faces.

Alternatively, the increased proportion of familiar faces in profile pose observed in the face diet of adults with ASD may not indicate a viewing preference for social interactions. Instead, it may indicate that a social interaction may not be occurring or may be occurring without attention towards the face. Kamensek et al.'s (2022) comparison of the face-diet between those with ASD and a comparison group revealed that familiar faces were more likely

to be in frontal pose than profile pose for controls, which was assumed to be a signature of a social interaction. The flipped pattern observed in ASD (i.e., proportionally greater profile pose familiar faces vs. frontal pose familiar faces) may not be indicating an atypical social interaction face-viewing preference, rather it may indicate a lack of social engagement. The notion that attention is not being allocated to faces in the visual field would be consistent with experiential accounts suggesting that decreased social interest may lead to decreased social attention and decreased cortical specialization for faces (Grelotti et al., 2002). Eye tracking studies have shown reduced attention to social elements of a visual scene (Fletcher-Watson et al., 2009) including biased attention to objects and backgrounds over faces (Riby & Hancock, 2008; S. Wang et al., 2015). A retroactive study of home video tapes of children later diagnosed with ASD suggest reduced attention to faces can be observed as early as 1 year (Osterling & Dawson, 1994). One limitation of defining a face diet via a head-mounted camera, that allows for the least interference with the participants day-to-day routine, is that eye movements and attentional data is unavailable, and therefore can only be inferred. The data here, however, suggest that an increased proportion of profile faces in the face diet of those with ASD does not translate to better performance with this stimulus type in a recognition task, and therefore, may signal a lack of social attention to people in the visual field.

A closer look at the pose exposure patterns reported by Kamensek et al. (2022) reveals that despite proportionally greater exposure to faces in profile pose in the ASD face-diet, reduced overall exposure durations to faces may limit the potential for this exposure pattern to influence face recognition development and ability. It was estimated that familiar faces of others were in the visual fields of those with ASD for 3.62 minutes per waking hour, and that 31.79% of those faces were in profile pose (Kamensek et al. 2022). This equates to roughly 1.15 minutes/hour of potentially meaningful exposure to faces in profile pose. In contrast, profile pose exposure accounted for 21.59% of the 8.44 minutes/hour of familiar face exposure in the comparison group, equating to 1.73 minutes/hour exposure to profile pose faces. Therefore, the

comparison group has more minutes of potentially meaningful exposure, despite proportional decreases in profile exposure. This limited exposure in ASD may not be sufficient for the typical protracted development of expert face recognition processes, or a profile recognition advantage.

Oruc, Shafai, Murthy, et al. (2019)'s initial investigation of the adult face diet revealed a median face size of 6 degrees face width, with familiar faces more likely to appear larger than 6 degrees, and unfamiliar faces more likely to appear smaller than 6 degrees. These observations are related to results from N. Yang et al. (2014), whose study of face recognition processing efficiency found that faces above 6 degrees face width employed an efficient expert mechanism, whereas smaller faces were associated with a less efficient processing mechanism. These examples demonstrate that expert face processing mechanisms may be specifically tuned to viewing conditions associated with social interactions with familiar persons (Oruc, Shafai, Murthy, et al., 2019). Faces tended to be smaller in the ASD face-diet, with overall median viewing distances nearing 3 meters, double that of the non-autistic control group. Perhaps faces are not entering viewing distances conducive to the development of expert face recognition. Future work, assessing face recognition processing efficiency as a function of size in ASD could elucidate whether face processing efficiency is related to face size similarly between those with and without ASD.

To assess the relationship between performance on our in-house PDFR task and the CFMT we calculated correlations between the two. The CFMT is a validated measure of face recognition shown to be sensitive and specific to a wide range of upright face recognition ability (Duchaine & Nakayama, 2006; Germine et al., 2011; Wilmer, Germine, Chabris, Chatterjee, Williams, Loken, et al., 2010), is the gold standard for diagnosing prosopagnosia (Bowles et al., 2009), and has been adjusted for testing face recognition in children (Croydon et al., 2014; Dalrymple, Gomez, & Duchaine, 2012), and other race faces such as Chinese Malaysian faces (Kho, Leong, Keeble, Wong, & Estudillo, 2023). The test introduces the target identities with three study images presented in 1/3 right profile (right ¾ pose with our definition), frontal pose,

and 1/3 left profile (left ¾ pose), and then presents test images in a variety of pose and lighting. Convergent validity with our frontal PDFR test would help to demonstrate the validity of our test and would be expressed by a strong positive correlation between the frontal PDFR and upright CFMT. Strong positive correlations between performance on the frontal version of the PDFR and the upright CFMT test for controls and those with ASD supports the notion that the two tests are tapping into similar processes and helps to validate our procedure. Interestingly, profile PDFR performance also strongly correlated with CFMT performance for controls, but not for those with ASD. This post-hoc analysis reveals that profile pose recognition may also be tapping into similar processes as those utilized for the CFMT for the comparison group, however profile pose recognition in ASD was only weakly correlated with CFMT performance, and this correlation was non-significant. We speculate that recognition performance for profile faces in ASD may not share similar face specific processes utilized for encoding frontal and ¾ pose faces in the CFMT. To further validate the test, one would need to show divergent validity with a test of non-face object recognition, which would be expressed by a weak correlation. This however, was not the intent of this project. Future work could compare frontal and profile pose recognition with a test of non-face object recognition to confirm divergent validity for the PDFR and investigate whether profile face recognition in ASD is tapping into more general, object recognition processes.

4.5 Conclusion

An altered visual experience weighted away from frontal and favouring profile faces in ASD prompted us to test the hypothesis that those on the autism spectrum may have encoding and recognition advantages for faces in profile pose. Our hypothesis was not supported as our group with ASD demonstrated a disproportionate drop in profile recognition performance compared to our neurotypical comparison group. We add to a robust and growing literature showing reduced face recognition performance in ASD and demonstrate that those with and

without ASD have superior frontal face encoding and recognition when compared to profile face encoding and recognition. We show that the unique visual experience observed in the adults ASD face-diet does not translate to a unique pattern of recognition ability, a result that is inconsistent with experiential accounts for face recognition ability on the autism spectrum. However, exposure does not necessarily equate to meaningful experience. Given that for our comparison group, increased proportions of profile pose exposure in the adult face diet was related to unfamiliar exposure, i.e., non-social experiences, it may be the case that those with ASD are not socially engaging with familiar faces, and therefore, are not gaining visual experience with profile pose faces. On the other hand, reduced profile pose recognition is consistent with perceptual accounts, given the disproportionate drop in recognition performance in ASD when facial features are removed for profile faces. Difficulties recognizing faces across viewpoint changes is also consistent with a *local processing bias* account, however, we only observed this effect for faces learned in profile pose in ASD. Therefore, partial support is given to a perceptual account, but is difficult to rule out potential experiential explanations for face recognition challenges in ASD.

Chapter 5 – Conclusions

Although the presence of face recognition challenges for those with ASD has become well established, the underlying cause for these challenges remains unknown. Several theories have been proposed to underly these issues, which fall generally under two categories, nature arguments and nurture arguments. Nature arguments in general, claim that face recognition impairments in ASD are perceptual/genetic in nature. Some claim that impairments may share the same etiology as those with developmental prosopagnosia, a condition characterized by severe impairments of face recognition (Minio-Paluello et al., 2020). If so, face recognition ability would allow researchers to stratify individuals on the autism spectrum into meaningful subgroups, one group characterized by deficits of face recognition, and another without. A subtype of autism characterized by severe impairments of face recognition could target research at common genetic pathways leadings to this behavioural phenotype in individuals with ASD and DP. Additionally, it would allow clinicians to target interventions focussed on perceptual strategies for processing faces at specific individuals on the autism spectrum and allow a better understanding of social interaction impairment for each subtype. Others claim that the primary cause of face recognition impairments on those on the autism spectrum is a perceptual style biased towards features, which prevents or interrupts efficient, expert configural processing of perceptually homogeneous stimuli like faces (Behrmann, Avidan, et al., 2006; Scherf et al., 2008). A pervasive attention to detail, if present in autism would also aim intervention strategies at developing perceptual strategies for efficient face processing. Nurture arguments, in short, suggest that individuals on the autism spectrum may not reach expert levels of face processing ability primarily because of an atypical development with respect to experience with faces. The *social motivation hypothesis* claims that faces do not hold the same attentional valence to those with ASD compared to those without, which leads to reduced attention to faces, which overtime has impacts on the typical protracted development of face

recognition ability (Chevallier et al., 2012; Grelotti et al., 2002; Schultz, 2005). Finally, the *eye avoidance hypothesis* suggests that the eyes hold negative valence to those with autism, which leads to intentional avoidance of eyes and faces, and compensatory face recognition processes focused on the bottom half of the face. It is unlikely that each of the theories is mutually exclusive, as evidence has been provided for each. However, which theory best accounts for the primary cause of face recognition challenges remains to be resolved. In this thesis we aimed to assess the validity of the core claims of nature and nurture theories of face recognition impairment in ASD. We assessed whether distinct subclusters of individuals with ASD can be delineated by face recognition ability, and whether social motivation can influence the characterization of sub-groups. We observed the daily visual exposure to faces for autistic and non autistic adults to assess the claim that those with ASD have atypical and/or reduced experience with faces, core assumptions of the social motivation and eye-avoidance hypotheses. Finally, we assessed whether observable patterns of exposure to faces, specifically to profile and frontal pose faces in ASD is associated with differentiated face recognition abilities.

5.1 – Do those with ASD and DP share the same etiology for face recognition difficulties?

In Chapter 2, we assessed the claim that those on the autism spectrum are stratified into distinct subtypes based on face recognition abilities (Minio-Paluello et al., 2020). A subtype of ASD defined by severe impairments of face recognition would be consistent with the literature, where on average, those with ASD have been shown to have moderate impairments of face recognition ability (Barton et al., 2004; Griffin et al., 2021). Those with prosopagnosia-level challenges would average out the scores of those with typical face recognition ability, and sampling variability across studies could contribute to the heterogeneity of findings in the literature (Griffin et al., 2021; Weigelt et al., 2012). The underlying assumption of a distinct

prosopagnosic subtype of autism is that those belonging to the subtype would have severe impairments of face recognition, and those not belonging to the subtype should have typical face recognition abilities. Using two separate strategies for classifying those with ASD into a DP-like and non-DP subtype, we found that both methods of classification revealed a non-DP group in ASD who also demonstrated moderate impairments in face recognition compared to non-autistic, non-DP controls. First, we used the cut-off point for DP diagnosis on the CFMT (2 standard deviations below population mean) to classify those with ASD into a DP subtype. For non-DP classified individuals with autism (ASD_{nonDP}) we still observed reduced face recognition ability compared to controls with an effect size of 0.51. Second, we used a bivariate classification method, with CFMT performance and social motivation scores on the MSCS as the variables of choice. Overall, social cognition has been shown to be typical for those with DP (Duchaine, Murray, et al., 2009), however, thematic assessments of interviews with DP individuals have suggested negative psychosocial impacts of face-blindness, including fear of, discomfort in, and avoidance of social situations (Dalrymple et al., 2014; Yardley et al., 2008). We chose social motivation as the second variable for our study due to its proposed core relationship to face recognition ability in ASD, and its potential but unexplored relationship to face recognition challenges in DP. A correlation between face recognition ability and social motivation in both the DP and ASD group would provide evidence inconsistent with the social motivation hypothesis, as it would suggest that face recognition challenges that are perceptual in nature (in DP) lead to reduced levels of social motivation. A correlation exclusive to the ASD group, however, would indicate that perceptual aberrations do not lead to reduced social motivation (in DP), and provide support for the *social motivation hypothesis.* We did not find a correlation between social motivation and face recognition for either group, which is inconsistent with the *social motivation hypothesis* for ASD, but also does not provide evidence for a perceptual account.

The non-DP group within our ASD cohort delineated by the bivariate classification model also demonstrated moderate face recognition impairments (*d* = 0.54). Consistently reduced face recognition abilities in our ASD_{nonDP} groups defined by two alternative methods suggest that a shared etiology of face recognition difficulties between DP and ASD cannot fully explain face recognition challenges on the autism spectrum. The distribution of face recognition ability in our ASD group is continuous and graded, ranging from severe impairment to typical performance, with many demonstrating moderate difficulties. Consistent with Minio-Paluello et al. (2020) though, roughly 1/3 of our participants with ASD (36.1%) had DP-like severity of face recognition impairment, regardless of classification method. The question becomes: what is the best explanation for this increased prevalence of 'face-blindness' in ASD? We suggest that an experiential account, where reduced and atypical exposure to faces through development, likely influenced by reduced social motivation is the most parsimonious explanation for the overall moderate reductions and graded range of ability in ASD. However, we cannot rule out perceptual accounts, given the observed reduced social motivation in DP, and lack of correlation between social motivation and face recognition ability observed in ASD.

A notable difference between the two classification models were differences in social motivation scores across groups. First, those with DP had significantly reduced social motivation compared to our neurotypical comparison group, with scores equivalent to those with ASD. Reduced social motivation levels in DP measured with a validated assessment tool confirms the findings of Yardley et al. (2008) and Dalrymple et al. (2014) where reduced social motivation was suggested through interviews. Our results indicate that even in the absence of social cognitive impairments associated with autism, reduced face recognition abilities can lead to reductions in social motivation, consistent with a perceptual account for face recognition challenges in ASD. When social motivation was included in our bivariate classification model, the ASD_{DP} group had significantly lower social motivation scores than both the DP and ASD_{nonDP} groups. Those with DP had similar social motivation to the ASD_{nonDP} group. This analysis

reveals that those with ASD characterized by especially poor face recognition are also characterized by especially reduced social motivation. These findings reflect an important relationship between face recognition and social motivation, wherein challenges in one aspect of social cognition can potentially lead to compounding reductions in the other, leading to a downward spiral in ability.

Recently, Burns, Gaunt, Kidane, Hunter, and Pulford (2022) have demonstrated the impact that subthreshold (not meeting the CFMT criteria for a classical diagnosis of DP) deficits of face recognition can have on the neurotypical population. In their study, they recruited individuals (*n* = 62) who believed they had prosopagnosia, i.e., a lifelong impairment of face recognition with no obvious historical reason for it being acquired. Virtually all individuals met the threshold for prosopagnosia based on PI20 scores, which indicate subjective levels of face recognition impairments (P. Shah et al., 2015), but 56% of individuals did not meet criteria on the CFMT. The 56% of excluded DP cases demonstrated face recognition memory and perception challenges that were roughly 1 standard deviation lower than neurotypical norms. These findings demonstrate that face recognition abilities do not have to be severe to result in the subjective experience of high levels of prosopagnosia symptomology (Burns et al., 2022). The authors suggest that the -2 SD on the CFMT may, therefore, represent the center of the distribution of face recognition ability in DP with roughly half of individuals demonstrating objectively severe face recognition impairment (major group), and half demonstrating mild impairments. Unlike those with prosopagnosia and those in the neurotypical population (Gray, Bird, & Cook, 2017; Livingston & Shah, 2018; P. Shah et al., 2015), self-reported prosopagnosia traits does not predict objective face memory performance in ASD (Minio-Paluello et al., 2020). Importantly, PI20 scores did not predict membership in the prosopagosic subtype for Minio-Paluello et al. (2020)'s ASD participants. This is an important difference between those with DP and those with face recognition challenges on the autism spectrum. Those with ASD do not seem to have the same subjective awareness of their face recognition abilities, which might

suggest that their abilities, or lack there of, are of less concern. This interpretation would be consistent with general reductions in social motivation in ASD. In contrast, those with major and mild DP according to Burns et al.'s conceptualization are particularly aware and bothered by their inability to recognize faces. This would suggest that face recognition challenges are core to reduced social motivation we observe in DP and social motivation is more likely to be core to the face recognition challenges we observe in ASD. In addition, where -2SD on the CFMT would represent the center of the distribution for those with DP (in Burns et al.'s DP concept), only 1/3 of individuals with ASD fall below -2SD on the CFMT (Minio-Paluello et al., 2020), suggesting that even in this conceptualization of DP, those with ASD belong to an independent and less impaired distribution of face recognition performance.

Nevertheless, it is still difficult to ascertain whether especially reduced social motivation is caused by inherent face recognition challenges in the ASD_{DP} group, or whether especially low social motivation is causing especially severe face recognition challenges. However, the fact that our ASD_{nonDP} group also had moderately reduced face recognition performance suggests a continuous graded distribution of face recognition ability in ASD. We propose that the most parsimonious explanation for an overrepresentation of DP-like face recognition challenges in ASD is therefore a leftward shift of the ASD distribution of face recognition ability caused by the detrimental impact of reduced social motivation on the typical protracted development of expert face recognition processes. This would result in moderate impairments for most, typical performance for some and a higher-than-expected prevalence of severe deficits overall. The distribution of face recognition ability presented in Chapter 2, Figure 1 is consistent with this prediction.

Our interpretation is consistent with a report from Halliday et al. (2014) who demonstrated that an individual's degree of autistic traits (as assessed by the AQ), can be predicted by performance on an identity recognition test in the typically developed population. The authors suggest a dynamic and mutually reinforcing relationship between impaired face

perception and core ASD traits wherein primary deficits of social interaction are compounded by impaired face recognition. In the current study, while we do not observe a direct correlation between social motivation and face recognition in ASD, we do see that the group of individuals with ASD characterized by more severe challenges of face recognition also have the lowest social motivation. Together these findings suggest that interventions focussed on face training and creating reward systems emphasizing the importance of faces can be effective in reducing social interaction impairments both for those with ASD and the broader autism phenotype, which in turn may improve social motivation, reversing the mutually reinforcing relationship between face recognition ability and ASD traits (Halliday et al., 2014; Tanaka et al., 2010).

5.2 – Do those with ASD experience atypical exposure to faces as part of their daily visual input?

A core assumption of the social motivation hypothesis is that social attention is reduced and/or atypical in ASD. Social motivation reflects one's propensity for social interaction, and therefore, low social motivation may lead to reduced social attention and experience with faces. Social motivation scores in ASD typically fall 2 standard deviations below their non-autistic counterparts (Trevisan et al., 2018; Yager & Iarocci, 2013). Concurrently, those with ASD tend to demonstrate select impairments of various aspects of face perception, including impairments of identity processing (Boucher & Lewis, 1992; Dwyer et al., 2019; Oruc et al., 2018; Simmons et al., 2009) and expression processing (Baron-Cohen, Wheelwright, et al., 2001a; Harms et al., 2010; Oruc et al., 2018; Uljarevic et al., 2013; Wallace et al., 2008b). Although two phenomena cooccurring does not necessarily mean they are related, should low social motivation impact attention to faces, one might not expect the same degree of fine tuning of the visual perceptual system for those with low social motivation. The social motivation hypothesis proposes that core deficits in social motivation in ASD lead to reduced attention to faces through development, which leads to reduction in face processing ability (Chevallier et al., 2012; Dawson et al., 2005;

Schultz, 2005). Atypical and reduced attention to faces in ASD has been shown in several paradigms using measures of eye tracking (Fletcher-Watson et al., 2009; Riby & Hancock, 2008; Sasson et al., 2007; C. E. Wilson et al., 2010), as well naturalistic observations of home videos of children later diagnosed with ASD (Osterling & Dawson, 1994; Osterling et al., 2002). In addition, for those with ASD and low social motivation, associations between face processing abilities and social motivation have been demonstrated (Oruc et al., 2018). Yet, it is unknown whether lab-based eye tracking studies reflect the day-to-day lives of those with autism, or whether reduced social attention in early childhood persists into adulthood. Using a naturalistic observation approach, we collected the daily face-diets of adults with and without ASD to address these questions, and importantly, define visual exposure statistics to faces including viewing distance, pose, exposure duration, and familiarity. Our lab's previous investigation with neurotypical adults reveals that, like infants in their first 3 months, daily visual exposure to faces is dense, and rich with large, familiar faces, where both eyes are visible (Jayaraman et al., 2015, 2017; Oruc, Shafai, Murthy, et al., 2019). Consistencies between the visual exposure statistics of the adult face diet and classic behavioural phenomena like the other race effect, three-quarter pose advantage and size expertise strongly suggest that face recognition abilities are tuned for social interactions with familiar faces. The adult face-diet of individuals with autism was both quantitatively reduced and qualitatively atypical in comparison to non-autistic controls. Quantitatively, we observed a near 4-minute reduction in exposure to faces per hour compared to controls. This reduction was completely explained by reduced exposure to familiar faces. Exposure durations for familiar faces in ASD was roughly 3 minutes per hour, which is like the reduction observed in infants from 3 months to 18 months of age (familiar face exposure reductions from roughly 14 min/hour to 5 min/hour) (Jayaraman et al., 2017). Our findings suggest that during neurotypical development individuals return to a dense level of exposure to faces, perhaps by choice, or because of their environment (related to factors such as attending school, or work, etc.). However, in ASD, individuals do not return to dense levels of exposure,

which again could be a result of purposeful behaviour avoiding social interaction, or a result of their environments (although only 4 of 17 individuals with ASD indicated they were unemployed). Unfamiliar face exposure levels (both exposure frequency, and exposure duration) was similar between groups, suggesting that both groups are going about their daily lives similarly, e.g., walking to the store, taking public transit, leaving the home, etc. For infants, reductions in face-specific exposure were not accompanied by reductions in body specific exposure, providing support for the *face-input hypothesis* which predicts reductions in faces, but not people in visual fields of infants during development (Jayaraman et al., 2017). Exposure in infants is constrained by the environment and largely dependent on the presence of caregivers. In ASD, when these constraints are removed in adulthood, we observe an extension of the *face-input hypothesis*, but with one caveat: the faces we see a reduction in are exclusively familiar faces with whom individuals are most likely to engage socially with.

Our qualitative assessment of the ASD face diet suggested individuals on the autism spectrum are avoiding typical viewing conditions associated familiar interactions. Signatures of unfamiliar face exposure in our non-autistic control group mirrored familiar face exposure patterns in ASD. Particularly, decreased exposure to frontal faces and increased viewing distances of faces. In other words, our participants with ASD were treating familiar persons, visually speaking, like strangers.

Our investigation of the adult face-diet in ASD is consistent with a key prediction of the *social motivation hypothesis*, that exposure to faces is reduced and atypical in ASD. For non-autistic adults, face exposure statistics are consistent with behavioural investigations showing fine tuning of face related perceptual processes, such as the other race effect (Meissner & Brigham, 2001; Michel, Rossion, et al., 2006; Mousavi & Oruc, 2020; Sangrigoli & De Schonen, 2004), ¾ pose recognition advantage (Bruce et al., 1987; Krouse, 1981), and size-related expertise (Oruç & Barton, 2010; N. Yang et al., 2014). Dense exposure in early adulthood is also consistent with observations of late maturation of face recognition memory abilities

(Germine et al., 2011). In ASD, reduced and atypical exposure to familiar faces suggests that those on the autism spectrum are not getting the necessary and sufficient experience for the protracted development of expert face processes. Depending on the individual, this experience could result in delays for the obtainment of behavioural signatures of perceptual expertise for faces or could simply result in quantitative reductions in face-specific recognition ability. It should be noted that the results here do not refute perceptual accounts like the *local-processing bias*, or *prosopagnosia subtype* account, although these hypotheses do not make direct predictions regarding the visual experience of those with ASD.

Our investigation of pose exposure in ASD is also consistent with the central tenant of the *eye avoidance hypothesis* (Tanaka & Sung, 2016). Pose exposure patterns with decreased frontal-pose faces, regardless of familiarity, demonstrate that those with ASD may be avoiding faces that could make direct eye contact (Dalton, Gernsbacher, et al., 2005; Tottenham et al., 2014). Taken together, we propose that experience with faces is the central limiting factor for the heterogeneity of, and face recognition challenges observed in ASD. Importantly, and regardless of interpretation, we observed reduced and atypical exposure patterns to faces in ASD, particular for familiar identities. Reduced and atypical exposure to familiar identities with whom face processing mechanisms seem to be tuned for in the non-autistic population, strongly suggest that experiential factors unique to those with autism are primarily linked to face recognition challenges on the autism spectrum. Given the success of face expertise training for those on the autism spectrum (Damiano, 2011; Faja et al., 2012; Hopkins et al., 2011; Tanaka et al., 2010), and the trainability of configural processing with non-social objects like greebles or houses (Damiano, 2011; Faja et al., 2009), it is unlikely that an inability to make fine grained discriminations of perceptually homogeneous stimuli is the core explanation for face recognition challenges. This is not to refute the claim that those on the autism spectrum may have these challenges, or that they are related to a local perceptual bias (Behrmann, Avidan, et al., 2006; Behrmann, Thomas, et al., 2006; Scherf et al., 2008). Rather, these challenges in making fine

grained discrimination of faces result from lack of motivated practice, possibly caused by effortful or unconscious avoidance of faces.

5.3 – Are patterns of face recognition abilities consistent with patterns of pose exposure in the ASD face diet?

The ASD face-diet revealed quantitative and qualitative differences in exposure statistics to faces, which are likely to be related to face recognition challenges on the autism spectrum. In our analysis of pose exposure, we observed reductions in exposure to frontal pose faces for unfamiliar, and importantly, familiar faces. Even the most frequently occurring familiar face was more likely characterized by three-quarter and profile pose, rather than frontal and three-quarter pose, the pattern observed in the non-autistic group. The results suggest those with ASD may be purposefully avoiding faces in full frontal orientation. People with ASD tend to avoid making eye contact with others (American Psychiatric Association, 2013; Kliemann, Dziobek, Hatri, Steimke, & Heekeren, 2010), with subjective reports revealing discomfort with direct eye gaze (Tanaka & Sung, 2016), and objective fMRI or skin conductive response reports revealing high emotional arousal in response to direct eye gaze (Dalton, Gernsbacher, et al. (2005), Kylliainen and Hietanen (2006), although see Clin and Kissine (2023) for a recent hypo-arousal account). Our naturalistic observation study provides behavioural evidence consistent with the avoidance of eye contact. As a product of reduced frontal face exposure, our participants had higher proportions of ¾ and profile face exposure, potentially indicating a unique developmental visual history. We specifically tested whether this unique visual history was associated with improvements in profile face recognition compared to frontal face recognition. We hypothesized that those with ASD would show equivalent or superior face recognition ability for profile faces, compared to frontal faces.

First, we replicated finding of an overall reduction in face recognition performance in ASD, by about 1 SD (Griffin et al 2020), both in our in-house PDFR test, and on the CFMT.

Secondly, in accordance with the literature on pose, we showed overall better recognition of frontal face compared to profile faces. Lastly, both conditions of our test (profile and frontal) showed good convergent validity with CFMT performance in our non-autistic control group via strong correlations between frontal-CFMT and profile-CFMT performance. These results suggest that face specific mechanisms assessed by the CFMT, were similarly being assessed by our PDFR test. To further validate the PDFR test, future projects could assess discriminant validity by testing for non-correlations with object or pattern recognition performance.

Our hypothesis with respect to pose dependent face recognition performance, however, was not supported. Our participants with ASD demonstrated marked impairments in profile pose recognition. Our comparison group scored on average 0.88 standard deviations lower in our profile pose recognition task compared to frontal. Reductions in profile pose recognition in ASD was nearly double (d = 1.68). In addition, for the comparison group, both frontal and profile pose recognition ability was strongly correlated with CFMT performance, suggesting face specific mechanisms are being applied to both conditions. In ASD, frontal pose recognition performance, but not profile pose recognition was strongly correlated with CFMT performance. These results suggest that recognition processing mechanisms leading to successful frontal PDFR and CFMT performance are not leading to success in profile face recognition in ASD.

Profile faces contain about half the feature information of frontal faces. If those with ASD are reliant on local features for recognition (Behrmann, Thomas, et al., 2006; Jemel et al., 2006; Lahaie et al., 2006) removing half could have a detrimental impact on recognition performance, resulting in the observed difference between frontal and profile face recognition in ASD. Alternatively, those with ASD have been shown to be less likely to attend to core ‘important’ features of faces (Pelphrey et al., 2002), which could lead to attending non-diagnostic features of our profile face stimuli like the edges of the oval aperture behind the cheek. Both of these interpretations would be consistent with our findings. Our non-autistic control group, however, also experienced the same level of feature reduction for profile faces and had less configural

information to work with. Given that a local bias view would predict superior processing of face parts in ASD (Jemel et al., 2006), one might expect that when face recognition in constrained to a more feature-based recognition style (for profile faces configural relationships between the eyes are not available, width of the mouth with relation to the nose or eyes is removed, etc.) we would not expect to observe a disproportionate drop in performance for profile face recognition in ASD compared to controls.

Our hypothesis was driven by an assumption that reduced exposure to frontal faces in ASD might indicate attention is preferentially being allocated to profile faces. This atypical developmental visual history could lead to strengths in processing these types of faces. Given our findings, however, it is possible that increased proportions of profile faces are a product of avoiding faces in frontal pose. Patterns of pose exposure in ASD, even for the most frequently occurring familiar faces show reduced frontal faces, a pattern more consistent with unfamiliar face exposure for non-autistic controls. We interpret this unfamiliar exposure pattern in controls to be a signature of a non-social interaction, and absence of social engagement. Decreased frontal pose exposure in ASD may also be a signature of social dis-engagement, suggesting attention is not being allocated to profile faces. In an investigation of face recognition of neo-natal nurses who are constantly exposed to newborn faces, Yovel et al. (2012) demonstrated that this passive exposure does not lead to enhanced recognition of newborns. Only after a face training paradigm involving individuating newborn faces, did recognition performance improve (Yovel et al., 2012). It is possible that patterns of decreased frontal face exposure in ASD signal a more passive visual experience with faces, where focused individuation is less likely to occur. As a result, profile pose recognition is not enhanced. Even if attention was being preferentially allocated to profile faces, reduced overall exposure durations may not allow this experience to lead to behavioural improvements in face recognition. This interpretation of our results would be consistent with experiential accounts like the social motivation hypothesis, where reduced attention for faces leads to poor performance in face processing. Frontal faces, being easier to

recognize than profile faces, and the prototypical face of early visual developmental (Jayaraman et al., 2015, 2017) are thus also easier to process for adults with ASD. Profile faces, a biproduct of visual experience likely influenced by avoiding social faces in frontal pose are not, therefore, better recognized by those on the autism spectrum, rather, recognition for these faces is poor.

5.4 – Implications

The development of face recognition follows a protracted development and is a core component of social cognition (Adolphs, 2001, 2009). Individuals with ASD demonstrate challenges with face processing which is proposed to be tightly related to the social difficulties in ASD (Pelphrey, Adolphs, & Morris, 2004; Schultz, 2005; Schultz et al., 2000). Genetic investigations of face recognition abilities in the neurotypical population suggest that an individuals' maximum potential level of achieved performance with respect to face recognition is largely genetically determined and that experience could modulate the time course of development (Wilmer, Germine, Chabris, Chatterjee, Williams, Loken, et al., 2010; Wilmer, Germine, Chabris, Chatterjee, Williams, Nakayama, et al., 2010; Zhu et al., 2010). Behavioural investigations of signatures of expert face recognition processes demonstrate heterogeneity on the autism spectrum, however, several studies indicate that those with ASD are able to utilize holistic or configural strategies for processing faces (Gauthier et al., 2009; Hedley et al., 2015; Teunisse & de Gelder, 2003; Weigelt et al., 2012), although these abilities may develop atypically, or more slowly (Gauthier et al., 2009; Joseph & Tanaka, 2003; López et al., 2004; Ventura et al., 2018). Our quantitative analysis of face recognition memory in ASD reveals high variability of ability on the autism spectrum, but on average, moderate reductions in face recognition performance, with the greatest reductions observed in individuals with especially low social motivation. The ASD face diet suggests that reduced and atypical exposure to faces likely impacts the time course of face recognition development. We posit that the observed distribution of face recognition ability in ASD does not represent the potential final level of

performance. Rather, the distribution represents individuals in various stages of expert face recognition development, which has been modulated by reduced experience with faces in typical viewing conditions characteristic of social interactions with familiar persons. It may not be the appropriate reaction to these findings to suggest that all individuals on the autism spectrum need to be subject to neurotypical cultural expectations and standards for social interaction, in order to 'properly' develop face recognition expertise. Self-reported social motivation in adults with ASD reveal overall reduced social motivation, suggesting that those on the autism spectrum may not be as interested in typical social contact. However, many individuals report social motivation levels in the neurotypical range. These findings reinforce the importance of an individual-centered approach to addressing social-cognitive challenges for those with ASD.

Although those with ASD seem to be less aware of the face recognition abilities and the impact that reduced abilities might be having (Faja et al., 2012; Minio-Paluello et al., 2020), improving face recognition abilities could improve the functional independence of those on the autism spectrum. Improving face recognition ability could be most beneficial for those with ASD during transitions through especially difficult phases of development like puberty and adolescence (Kelly, O'Malley, & Antonijevic, 2018; Mandy et al., 2022; Rimmington, 2019). It is evident that subthreshold challenges with face recognition in DP can have considerable subjective impact on individuals with these challenges with respect to DP symptomology (Burns et al., 2022). More severe challenges of face recognition can also have considerable impacts on social motivation, as evident in this thesis. The removal of the potential barrier that poor face recognition ability can have on a successful social interaction could therefore have positive impacts on those with ASD.

The major implication of our findings is therefore, the utility of face recognition training paradigms that can assist individuals develop face recognition processes in the potential absence of sufficient experience with faces. Three notable randomized control trials have suggested the success of face perceptual training in ASD (Gev, Rosenan, & Golan, 2017;

Hopkins et al., 2011; Tanaka et al., 2010). With the goal of reinforcing attention to the eyes, improving expression and identity recognition, and promoting holistic processing of faces, Tanaka et al. (2010) developed a set of 7 easy to play computer games. Over 4 months children who demonstrated impaired performance on the Let's Face It! Skills Battery (Wolf et al., 2008), completed 20 hours of game play, at a pace of 100 minutes of game play per week. Children could upload scores anonymously online to see how they fared against peers and were given tokens as compensation for good work. The children in the treatment group showed reliable gains in holistic processing of the eyes, as shown through performance in the Parts/Whole face task and demonstrated improvements in mouth and eye feature discriminations. Children did not show improvements in recognition memory, identity recognition, or expression recognition. Improvements in feature discriminations of the mouth and eyes were interpreted as support for a bias towards an analytical (or feature based) processing style in ASD (Behrmann, Thomas, et al., 2006). However, improvements in holistic processing of the eyes demonstrated that training and practice could redirect attention to the eyes and improve the ability to integrate that information with the rest of the face (Tanaka et al., 2010). The investigation demonstrates promising effects of training and practice presented in a child-friendly context, but perhaps 20 hours is not enough practice to improve identity/expression recognition and memory. A year later, Hopkins et al. (2011) published a separate report, detailing the effects of another computer based social skills training program for children with ASD. The structured computer-based environment uses a realistic avatar assistant to guide children through a set of games involving following eye gaze of others (promoting attention to the eyes), completing face puzzles (that promote holistic processing) and matching, and manipulating face expressions (promotes attention to the eyes to recognize expressions). The treatment group, separated into low and high functioning cohorts (LFA and HFA; with and without intellectual disability) demonstrated better basic emotion recognition (LFA and HFA), better face recognition based on the Benton face recognition test (only HFA), fewer negative social interactions following training (LFA), and

improved social skills including more positive interactions with others (HFA). Parents reported improvement in social skills, and anecdotal evidence was provided suggesting overt enjoyment of the training program. Worried that computer based programs may be limited by motivation challenges in children with ASD, Gev et al. (2017) assessed the utility of an animated series called 'The Transporters' in teaching emotion recognition skills in children aged 4-7. The intervention consists of 10-minute-long episodes, watched every day for 8 weeks, featuring emotional faces grafted onto rail based locomotive characters whose adventures are meant to teach children about face expressions, their meanings, and consequences. Without parental support, children demonstrated significant improvements in emotion recognition skills which generalized beyond the teachable material and lasted 3 months post treatment (Gev et al., 2017). Importantly, children seemed to enjoy watching the episodes, which for some even became an intense area of interest (Gev et al., 2017). Together, these studies demonstrate the effectiveness of face training programs for children in promoting more efficient face processing strategies (holistic processing of the eyes), and mitigating some social difficulties, but further development is warranted. Improving face recognition memory seems to be more challenging than improving expression recognition, as gains were only observed in higher functioning individuals by Hopkins et al. (2011) and expression recognition improvements were more consistently observed across studies and functioning ability (Gev et al., 2017; Golan et al., 2010; Hopkins et al., 2011). Each approach differs in the extent to which the active involvement of the individual is required (i.e., watching a show vs playing a game) and the amount of direction is provided (self-directed game play vs an avatar assistant). Perhaps combing these approaches can maximize outcomes.

Although we propose experiential accounts positing that reduced and atypical experience with faces is core to observed face recognition challenges in ASD as the most parsimonious explanation, similarities between ASD and DP should be considered in the context of face training. Although impairments of holistic processing are less frequently

observed in ASD (Tanaka & Sung, 2016; Weigelt et al., 2012), these challenges are suggested by some to be fundamental to DP (Avidan, Tanzer, & Behrmann, 2011; Cohan, DeGutis, Mercado, Wilmer, & Nakayama, 2012; DeGutis, Cohan, Mercado, Wilmer, & Nakayama, 2012). Some research groups have proposed that these difficulties are specific to the eye region in DP (Cohan et al., 2012; DeGutis et al., 2012), as they have been shown to be in ASD (Joseph & Tanaka, 2003), while others note substantial heterogeneity in the literature (Corrow, Dalrymple, & Barton, 2016). Training paradigms targeting the development of holistic processing by having individuals sort and categorize faces based on configural changes to the eyes and mouth have led to improvements in holistic processing, decreased reaction times, improvements for frontal face discrimination, and more face-specific electrophysiological/neurological responses in DP (DeGutis, Bentin, Robertson, & D'Esposito, 2007; Degutis, Cohan, & Nakayama, 2014). However, training effects have been shown to fade with time, so continued practice is needed to maintain gains (DeGutis et al., 2007), and improvements do not seem to generalize across viewpoints (Degutis et al., 2014). Another perceptual training paradigm (11 weeks long, roughly 30 minutes a day), involving making face discriminations across changes in expression, identity and viewpoint have shown more lasting improvements of perceptual sensitivity and have even led to minor improvements in face recognition memory in adults (Corrow et al., 2019). Lastly, A randomized control trial (30 minutes per day for 10 days) involving adults with DP and a modified game of “Guess Who” where faces differ in their second order relations between features lead to a 7.5% increase in performance on the CFMT (Bate, Dalrymple, & Bennetts, 2022). A follow up with 5 children demonstrated more heterogenous results, with improvements for some, but not others (Bate et al., 2022). It is clear that training paradigms can lead to improvements in face-specific processing in DP, like ASD, which opens an avenue to further test the shared etiology hypothesis. If face recognition challenges share a common etiology in DP and some individuals with ASD, then it could be presumed that they would respond similarly to intervention. Future research in developing face training paradigms, if feasible, should include

cohorts of individuals with ASD and DP to investigate the similarities and differences in response to different interventions.

The fact that 1/3 of ASD individuals are effectively ‘face-blind’ calls for further investigation of this phenomena, and education of clinicians and educators alike. In speaking with an elementary school teacher who supports children with developmental disorders, they were surprised to hear such a statistic. They mentioned how impactful it could be to make minor adjustments to the classroom to assist students who might be having trouble differentiating their peers and teachers. I propose that child-tailored, computer games with guided instruction, virtual (and anonymous) leaderboards and prizes (like the programs currently being developed for ASD and DP children) could be an impactful addition to the elementary school classroom. Without stigmatizing children with face recognition challenges, all children could complete these training programs as a fun activity to simultaneously teach social cognitive skills and computer literacy. Given that success has been shown in training programs designed for individuals with DP, where face recognition challenges are perceptual in nature, these training programs could be helpful regardless of whether face recognition challenges are primarily related to experience or perceptual differences in ASD. Leaderboards accessible to teachers and parents could indicate children who might be struggling with various aspects of face processing, and if appropriate, could educate individuals who are less aware of their challenges. Positive outcomes could be experienced by children with ASD, children on the lower end of the typical distribution of face processing abilities, and children with DP.

Social motivation, as assessed by the MSCS, was not associated with face recognition ability (Chapter 2) in ASD. However, those individuals with ASD who had the poorest face recognition (were classified as ASD_{DP} by our bivariate classification method) also had the lowest social motivation scores (lower than the ASD_{nonDP} and DP groups). This observation is consistent with findings from Oruc et al. (2018) who demonstrated an association between face processing ability and social motivation, but only for those with low social motivation. It could be

that accuracy measures like the CFMT are not as sensitive as robust psychophysical assessments of contrast detection thresholds, and therefore, are less likely to reveal correlations. Nevertheless, in support of the *social motivation hypothesis*, these results show that face recognition abilities are most associated with social motivation, for individuals with lower social motivation scores. Therefore, clinicians could use low social motivation scores on the MSCS as an indicator for individuals at risk of having or developing more severe deficits of face recognition.

5.5 – Strengths and limitations

This thesis used multiple modes of assessment to gain a holistic picture of the relationship between social motivation, visual experience, and face recognition in autism spectrum disorder. All adults with ASD and non-autistic controls recruited in our studies are well characterized with validated assessments of IQ (WASI-II, D. Wechsler (2011)), autistic-like characteristics (AQ, Baron-Cohen, Wheelwright, Skinner, et al. (2001)), and social competence (MSCS, Trevisan et al. (2018)). All participants with ASD were diagnosed by a clinician according to the guidelines of the DSM-5. Further, 26 participants with ASD in Chapter 2, 5 from chapter 3, and 7 from chapter are further characterized with ADOS scores. In addition to including DP participants in an investigation of claims that those with ASD may share the same etiology of face recognition impairments, all participants with DP had diagnosis confirmed by current standards of severe impairment on the CFMT and a famous face test, and PI-20 scores greater than 64 (Barton & Corrow, 2016; Susilo & Duchaine, 2013). Lastly all DP and control participants met a stringent AQ requirement of scores less than or equal to 20, ensuring a good separation of autistic-like traits from our group with ASD. Lastly, face recognition was assessed with the current gold standard for testing face specific recognition processes with the CFMT (Duchaine & Nakayama, 2006), and our in-house pose dependent face recognition task showed good convergent validity with the CFMT.

In addition to using current gold standard, well-validated assessments, our study employed a relatively new method of collecting first-person visual experience with a non-obtrusive eyewear-embedded camera where participants can go about their daily routines (Oruc, Shafai, Murthy, et al., 2019). From these data we could determine ecologically valid visual exposure statistics for faces using in-house software written in MATLAB and Python, hand-coded and checked by 2 investigators per data set. A total of 33,396 hand-coded frames were used to characterize the face-diet of non-autistic controls, and 10,236 hand coded frames were used to characterize the face-diet of those on the autism spectrum.

The face-diet of our participants was collected with a front facing eyewear embedded camera, and therefore information about gaze location is unavailable to infer attention allocation. Although we cannot guarantee the location of attention, we are confident with the validity of our methods as several studies utilizing head mounted cameras in concert with eye trackers show a central bias of gaze in free world viewing (Aslin, 2008; Bambach, Crandall, & Yu, 2013; Foulsham, Walker, & Kingstone, 2011; Li, Fathi, & Rehg). Maintaining eccentric gaze is difficult and uncomfortable, so eyes tend to be centrally positioned (orbital reserve), and when gaze does shift, head and eye movements are tightly coupled, typically aligning within 500ms (Pereira, Smith, & Yu, 2014; Tseng, Carmi, Cameron, Munoz, & Itti, 2009; Yoshida & Smith, 2008).

A limitation of our face-diet study was a small sample size for our ASD cohort (n = 17). Although historically this sample size is more on the medium size for studies in including participants with ASD, especially given the highly involved nature of our experiment, it would have been ideal to recruit more participants. Unfortunately, due to technical issues with the equipment, and the COVID-19 pandemic, in-person research was suspended. Now, it may be the case that the healthy adult face-diet needs to be recharacterized post pandemic. Depending on where you lived, pandemic restrictions included reducing your social circles to 1 or 2 households, social distancing to 6 feet, and mask wearing, could redefine a typical adult face-

diet. Nonetheless, a larger sample size would have given us more power to detect more subtle differences in exposure and allowed for a more precise estimate of daily face-exposure statistics for those with ASD.

5.6 – Future directions

In investigations involving special populations, assumptions are often made based on highly controlled, lab-based assessments. For example, eye-tracking and face recognition tests often use static, black and white images of faces (Duchaine & Nakayama, 2006; Guy et al., 2017; Lahaie et al., 2006; McPartland et al., 2010; Morin et al., 2015; Pelphrey et al., 2002; Sterling et al., 2008). While these methods allow researchers to control for important confounds, some ecological validity is unavoidably lost. The use of non-obtrusive wearables allows researchers to sample behaviour with a method that is highly ecologically valid. As face recognition ability follows a protracted development, a natural next step would be to investigate the face diets of adolescents and children with ASD. Children and adolescent with ASD may have higher levels of exposure from being in school, but how early are the adult signatures of the ASD face-diet observable? As the face-diet becomes better characterized, perhaps there are visual exposure signatures that can reliably predict group membership on the autism spectrum. Sampling the visual experience of individuals before and after face training could assess whether improvement in social cognition is related to increases in social exposure.

As technology advances, researchers can track eye movements while simultaneously collecting visual exposure statistics to confirm exactly where attention is being allocated during daily life. This type of technology has been used to track eye gaze and skin conductance responses during an in highly controlled face-to-face paradigm to assess responses to direct or averted eye contact of an experimenter (Clin & Kissine, 2023). Clin and Kissine (2023) found that in contrast to eye tracking studies where participants look at screens, individuals with ASD (n = 40) did not differ from controls (n = 40) in eye behaviours or skin conductance during direct

eye gaze, however, non-autistic subjects were bothered by averted gaze of the experimenter during a word definition task. This technology, however, is not at a place where participants can go about a natural routine day without any expectations or task demands associated with a lab. When the individual with autism has full autonomy, with a minimally obtrusive wearable camera/eye tracker, researchers can collect a highly ecologically valid sampling of visual attention. In combination with other wearables, like fit-bits or smart watches, researchers can simultaneously track indicators of stress such as heart rate, respiration rate, or electrodermal activity (skin and sweat response) to monitor the relationship between visual exposure and stress within the individual. Further, this type of investigation can help define atypical social approach core to ASD (American Psychiatric Association, 2013). This type of knowledge can direct interventions at highly specific behaviour, with the goal of easing social interactions for individuals with these challenges.

Our investigation of social motivation in individuals with DP revealed ASD-like reductions in social interest. Do these reductions lead to a reduced or atypical face-diet? Using methods of collecting daily visual exposure statistics we could ask: How does face blindness in the absence of social impairment impact daily visual exposure statistics for faces. Because expression perception is largely unaffected in DP (Duchaine et al., 2003; Humphreys, Avidan, et al., 2007; Lee, Duchaine, Wilson, & Nakayama, 2010; Palermo et al., 2011), although not always (Biotti & Cook, 2016; Tsantani, Gray, & Cook, 2022), one might predict that despite impairments in identity recognition, quantitative and qualitative exposure to faces may be largely typical. However, the reduced social motivation levels observed in this dissertation suggest that exposure could also be reduced, as it is in ASD. A neurotypical face-diet in DP could also elucidate important differences between the relationship between visual experience and face recognition ability between those with DP and ASD. Severe face recognition deficits despite typical visual experience in DP, and moderate face processing impairments with reduced and atypical visual experience in autism would suggest separate etiology for face recognition

challenges in each condition. Finally, understanding the social impacts of a lifetime of face recognition challenges can help determine the specific needs or accommodations appropriate for those with these impairments.

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