Holistic Face Processing in Children and Adults Along the Autism Spectrum as Measured by the Complete Composite Face Test.

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Abstract

The current study aimed to investigate the development of holistic face processing in individuals with and without Autism Spectrum Disorder (ASD). To date, the literature is unclear as to whether there are impairments in the way that individuals with ASD process faces holistically and whether any differences are qualitative or quantitative. Holistic processing was assessed by the Complete Composite Face Task (CCFT), the best known experimental paradigm for assessment of holistic processing, in both children and adults with ASD and compared their performance to age-matched control groups of children and adults. The results reveal that holistic processing is evident in adults with ASD but not in children with ASD. In contrast, typically developing children show evidence of holistic processing that remains qualitatively unchanged through to adulthood, only improving quantitatively. This pattern suggests that there is a developmental delay in holistic processing in ASD relative to typically developing individuals, where holistic processing is evident in typically developing children but not in children with ASD. Additionally, holistic processing of a larger magnitude in adults with ASD relative to control adults suggests that while holistic processing is present in ASD by adulthood, it is possible that the type of holistic processing that emerges in ASD is qualitatively different than that in typically developing individuals, as indicated by atypical performance in misaligned trials.

Chapter 1: Introduction

Much of the information that human beings require to engage in typical social interaction is derived from visual properties of the human face. Human beings are remarkably adept at processing facial emotion, gaze direction, and remembering and differentiating the multitude of faces encountered over the course of daily life. The specialized visual systems that we have evolved help us to process the visual information contained within a face with a high degree of efficiency and precision in order to determine the appropriate social reaction. These visual systems are different from those visual processes that are engaged when processing non-face objects. However, there are several groups of individuals with mental disorders whose ability to engage in appropriate social interactions is impaired. Among them are those with Autism Spectrum Disorder (ASD), a complex neurodevelopmental disorder affecting an estimated 1% of the population (*Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition, or DSM-5)* that is defined by, among other characteristics, deficits in social communication and social interaction. The *DSM-5* also describes restricted, repetitive patterns of behavior in ASD in addition to a preference for sameness and rigidity in their thought patterns, stereotypical repetitive body movements, and hypo- or hypersensitivity to sensory input that are manifested early in development and cause significant impairment in daily functioning. These individuals often demonstrate deficits in nonverbal communicative behaviours used for social interaction, ranging from abnormalities in eye contact and body language to a lack of facial expressions and nonverbal communication. They often have deficits in understanding social relationships, may have trouble adjusting behaviour to suit different various context, and demonstrate a lack of interest in their peers. Because of the importance of visual analysis and the processing of facial information in typical social interactions, such as recognizing emotion in others, determining gaze direction in order to engage in shared attention and to gauge another's interest in the topic at hand, and many other examples, much research has investigated whether the visual face processing mechanisms in individuals with ASD differ significantly from individuals without the disorder and if deficits exist, at what age they become apparent. The current study aims to investigate the course of development of a particular aspect of visual face processing, holistic processing, in individuals with and without ASD.

Configural Processing in Typically Developing Individuals

In order to understand face processing impairments in ASD, it is important to understand visual face processing in typically developing individuals. The cognitive mechanisms involved in the processing of faces are distinct from ones involved in the processing of non-face objects. Specifically, the type of processing that makes us so adept at processing faces is called configural processing, while the processing that is involved with non-face objects is called featural or part-based processing. Importantly, in typically developing individuals, faces that are presented with their features in a different configuration than the typical upright, eyes-over-nose-over-mouth within an oval outline are processed as objects rather than as faces and involve featural processing. Thus, configural processing is engaged only for very specific visual stimuli.

Configural processing for faces was first demonstrated by what is called the inversion effect (Yin, 1969). The effect was shown with a recognition memory task in which faces and non-face objects (e.g. houses) were presented for encoding and tested for recognition both in the upright orientation and in the inverted orientation. Memory performance was much better for upright than inverted faces but there was no such difference between upright or inverted houses. This inversion effect with faces is accepted as evidence that we have selectively adapted our visual processing to the orientation that we typically see faces in our environment. On the basis of these results, Yin speculated the existence of some process unique to upright faces that has since been termed configural processing. The idea is that inverting a face disrupts configural processing and causes us to resort to visually processing a face in the same way that we would process any other visual object: on a feature-by-feature basis. Other methods of disrupting configural processing include the application of spatial frequency filtering to face images (Cheung, Richler, Palmeri, & Gauthier, 2008) as well as misaligning the top and bottom of a face, which is the method used in the current study.

Configural processing has been separated into three subtypes: first order, second order, and holistic processing (Maurer, LeGrand, & Mondloch, 2002). First order configural processing refers to our high sensitivity in detecting the unique spatial orientation of the features of a human face: eyes located above the nose above the mouth, which means that typically developing individuals are able to pick out face-like formations much more readily than other visual patterns (Moskovitch, Winocur, & Behrmann, 1997). Second order configural processing refers to the ability to differentiate among the slightest variations in spatial relationship between facial features, like the distance between the eyes or the distance between the mouth and the bottom of the nose. For instance, individuals are easily able to differentiate between two versions of the same upright face that differ only in the distance between the eyes, but find it very difficult to detect this same difference when the two faces are inverted, which disrupts configural processing (Maurer et al. 2002). Finally, a third type of configural processing, and the focus for the current study, is holistic processing, which refers to a face being processed as a Gestalt-like whole entity that is more than a sum of its parts, so to speak. When upright faces are processed, the internal features are so strongly perceptually integrated that it becomes difficult to parse the face into isolated features, at least when only briefly exposed to the face, such that feature-by-feature comparisons are prevented (Hole, 1994). Farah, Wilson, Drain, and Tanaka (1998) suggest that face representations (memories) are perceived as single entities, and as such, individual face features such as eyes, nose, and mouth are not encoded or represented.

Debate exists as to whether there are *any* configural processes that are innate and devoted only to faces or whether configural processing develops with expertise in any given category of visual objects (see McKone & Robbins and Gauthier & Bukach, both 2007). There is evidence that both 2^{nd} order processing and holistic processing can be applied to non-face objects under certain contexts or experimental circumstances, which suggests that the process is not unique to only faces and supports the expertise model of face processing. Matheson and McMullen (2012) have shown that when faces are presented within a block of trials that also contains house images, 2^{nd} order configural processing will be applied to houses. When blocks of trials included only houses, without the presentation of faces, 2^{nd} order configural processing is not evident and houses are processed solely on a featural basis. This demonstrates that 2^{nd} order configural processing can be applied to non-face objects in certain contexts. Similarly, Richler, Bukach, and Gauthier (2009) have shown that holistic processing can be induced when processing exemplars of a novel artificial category of visual objects by the context of the experiment. Thus, neither holistic nor 2^{nd} order configural processing appear to be exclusive to the processing of faces.

Since neither 2^{nd} order or holistic processing appear to be exclusively applied to the processing of faces, and the current study seeks to investigate the visual processes that are most closely linked to social skills, other potential relationships between types of configural processing and social skills were considered. Richler, Cheung, and Gauthier (2011) have shown that holistic processing is predictive of face recognition memory, a highly socially relevant ability. Based on this evidence and the lack of demonstration that 2^{nd} order configural processing can predict facial recognition, holistic face processing was selected as the subtype of configural processing that is most likely to be related to social functioning and, therefore, the subject of the current study.

The Measurement of Holistic Processing

Two experimental tasks have been commonly used to measure the holistic processing of faces in visual cognition research: the part-whole paradigm (Tanaka and Farah, 1993) and the composite face task (Young, Hellawell, & Hay 1987), with the latter being recognized as the most valid measure. In the part-whole paradigm, typically developing children and adults are better at recognizing face parts (e.g., nose, mouth, eyes) when they are studied and tested in the context of an upright, whole face than when studied as a whole but tested in isolation (a *whole-advantage*). Importantly, this whole-advantage disappears when faces are presented in an inverted orientation because inversion disrupts holistic configural processing. This is interpreted as evidence of involvement of holistic configural processing in task performance of upright faces.

There are several lines of evidence that suggest that results derived from the part-whole task should be interpreted with caution. First, the whole advantage has been demonstrated with non-face object categories (Gauthier & Tarr, 1997; Tanaka, Giles, Szechter, Lantz, Stone, Franks, et al., 1996). Second, while experts perform better than novices in terms of other measures of holistic and configural processing of non-face object categories, the whole advantage is comparable in novices and experts (Gauthier & Tarr, 1997; Gauthier & Tarr, 2002; Gauthier, Williams, Tarr, & Tanaka, 1998). Third, evidence from Leder and Carbon (2005) shows that the whole advantage depends on participants originally studying whole faces; when they originally study only parts of faces, recognition of parts is superior. This suggests that the whole advantage reflects a more general encoding-specificity principle, whereby items are better recognized in the context in which they were studied (i.e., in the context of a whole face) than in different contexts (as isolated parts) (Tulving & Thomson, 1973). The results generated from part-whole tasks might be more loaded on memory ability than perceptual processes. Therefore, studies that used the part-whole task as a measure of holistic processing to investigate holistic processing are problematic because results may better reflect more domain-general principles of encoding-specificity.

By comparison, the Composite Face Task (Young et al., 1987) is thought to be a better measure of holistic processing (Gauthier, Klaiman, & Schultz, 2009). The paradigm involves studying face stimuli (Study faces) that are composed of top and bottom face halves from different unfamiliar face identities. Subsequently, a Test face is presented that is also a composite of tops and bottoms derived from different face identities. Participants are required to indicate via key press whether the Test face has the same *top* half as the Study face stimuli, regardless of whether the *bottom* half is the same or different from the Study face. For a more detailed description of the Composite Face Task paradigm, please refer to Appendix A. Several variations on this task exist in the literature, but the best version to date is the *Complete* Composite Face Task (CCFT), which was used in the current study. For a detailed discussion on the benefits of the CCFT versus other partial versions of the Composite Face Task, see Cheung et al. (2008).

The illusion of the composite face can be detected even when viewing two faces simultaneously (see Figure 1), thus, this measure of holistic processing is not as dependent on memory ability as the part-whole task and is therefore tapping into perception and holistic processing in a purer sense. The validity of the Composite Face Task for testing holistic processing is also supported by a study by Gauthier and Tarr (2002) who found correlations between brain activity in areas known to respond specifically to faces and holistic processing as measured by the Composite Face Task.

The Development of Face Processing in Typically Developing Individuals

These experimental paradigms, among others, have been used extensively to determine the typical pattern of development of configural processing. Broadly speaking, data from face inversion, 2^{nd} order relational, and part-whole tasks have shown that typically developing children demonstrate evidence of configural face processing mechanisms (first order, 2^{nd} order, and holistic) by 8-10 years old at the latest (McKone & Robbins, 2007) while rudimentary versions of these mechanisms are present at a much earlier age, even from birth, depending on the measures used. It has been proposed that the neural substrate predisposed for configural processing is present at birth and becomes more efficient with more experience and exposure to faces (de Haan, Pascalis, & Johnson, 2002).

When addressing the development of holistic processing specifically, the Composite Face Task has demonstrated evidence of holistic processing for faces (and not in non-face objects like cars) in typically developing children as young as 3.5 years of age (Cassia, Piccozi, Keufner, Bricolo, & Turati, 2009).

Face Processing in ASD

While much research has been devoted to face processing in typically developing individuals, less is known about the face processing abilities of children and adults with ASD. Given the social deficits in ASD, it is natural to question whether face processing abilities are different in this population. Generally, some of the research on face processing in ASD suggests impairments in face processing, while still others refute these claims. When adults with ASD were shown faces, they demonstrated reduced activation compared to typically developing controls in the Fusiform Face Area (FFA), an area of the brain known to typically show increased activation in response to faces (Pierce, Muller, Ambrose, Allen, & Courshenes, 2001) and increased activation in other areas of the brain that are typically devoted to object processing and visual searching (Hubl, Bolte, Feineis-Matthews, Lanfermann, Federspiel, Strik, et al., 2003). This suggests that individuals with ASD are processing faces like non-face objects. Still other studies have found conflicting evidence, where no abnormalities have been found in face-related brain activity in children with ASD (Apicella, Sicca, Frederico, Campatelli, & Muratori, 2012). Activity in cortical areas known to be related to face processing typically increases between adolescence and adulthood as memory for faces improves, but there is evidence that in ASD this activation decreases and occurs in a slightly different area of the brain during this period of development (Scherf, Luna, Minshew & Behrmann, 2010). Additionally, there has been evidence to suggest that the cortical thinning in the temporal lobes that typically occurs in young adolescents does not occur in adolescents with ASD (Raznahan, 2009) and results in a thicker cortex in adults with ASD, which could also contribute to differences in face processing related to these brain areas. Despite evidence that there are cortical abnormalities in individuals with ASD, a behavioural link to this cortical abnormality is still subject to investigation. However, the above-mentioned evidence supports the need for further investigation into face processing in ASD.

When focusing on configural processing, Rose, Lincoln, Lai, Searcy, & Bellugi (2007) have demonstrated an atypical inversion effect in adults with ASD compared to a typically developing control group. Some studies have even found a reversed inversion effect in adults with ASD; in other words, they were better at recognizing inverted faces than upright faces (Hole, 1994). Based on data derived from the CCFT, Richler, Bukach, and Gauthier (2009) suggested that adults with ASD process faces like typically developing individuals process other non-face objects. There is also contrasting evidence to suggest that abnormal visual processing of configural information is a global deficit in adults with ASD and not specific to face processing (Behrmann, Thomas, and Humphreys, 2006). A review of behavioural studies suggests that the differences in face processing in ASD are centered around the overall ability level, or performance, on face processing tasks, where participants appear to do worse on behavioural face processing tasks than typically developing individuals (Weigelt, Koldewyn, & Kanwisher, 2012). However, the mechanisms by which they perform these tasks appear to be intact. In other words, they perform tasks in the same *way* as typically developing individuals (qualitatively similar) but do more poorly on them (quantitatively different). Generally, then, further investigation needed to determine whether there are qualitative or quantitative differences in face processing in ASD.

Possible Models of the Development of Holistic Processing in ASD

When it comes to *holistic* processing in ASD, specifically, the picture is no less murky, with some studies showing atypical holistic processing (Joseph & Tanaka, 2003; Tuenisse & de Gelder, 2003; O'Hearn, Tanaka, Lynn, Fedor, Minshew, & Luna, 2014) while others show no impairments in holistic processing (Gauthier et al., 2009; Nishimura, Rutherford, & Maurer, 2008). Thus, the current study sought to compare holistic processing in children and adults with ASD with typically developing children and adults in order to provide a compelling demonstration of the course of development of holistic processing in ASD. If there is evidence from the current study that there is impairment in holistic processing in ASD, there are several possibilities of how it might differ from typically developing individuals across the lifespan.

Several models are described below along with related supporting evidence from previous studies.

First, the differences in ASD could be qualitative or they could be quantitative. That is, they might demonstrate completely different patterns of performance, indicative that they are completing the CCFT in a non-holistic way, i.e. they are *qualitatively* different. One possible qualitatively different type of processing on the CCFT would be that individuals with ASD might process faces as if they were non-face objects in a featural or part-based manner. Or, they might possess underdeveloped versions of typical holistic face processing mechanisms but demonstrate similar patterns of performance on well-known holistic processing tasks such as the CCFT, i.e. they are *quantitatively* different. This would be consistent with the conclusions drawn by Weigelt et al. 2012) that the differences in face processing in ASD are largely quantitative.

In support of a qualitatively different face processing in individuals with ASD, Gauthier et al. (2009) found evidence of holistic processing in adolescents with ASD that they described as being qualitatively different than the automatic holistic processing found in typically developing individuals. They showed that in adolescents with ASD, interference from an incongruent half was evident in the misaligned condition, suggesting that holistic processing was occurring even when faces were misaligned. The authors speculate that this type of holistic processing is more susceptible to interference from context and more similar to how novices process visual objects than how experts process visual objects, but this is still subject to future research. In other words, individuals with ASD process faces the way that typically developing individuals process non-face objects for which they have no expertise (Richler, Bukach, & Gauthier, 2009). This study, however, did not include an adult group of participants that might shed light as to whether these atypical patterns become more typical by adulthood or whether holistic processing remains qualitatively different in ASD. The explanation for their findings was largely speculative, by their own admission. It is also unclear whether what they are calling qualitative differences are actually due to an immature mechanism for holistic processing that is more susceptible to that found in typically developing adults due to less experience with faces. Thus, their data could actually reflect a quantitative difference.

Alternatively, if there are quantitative differences in individuals with ASD, these differences could take several forms. We propose that the most likely patterns of development, based on the literature to date, are as follows: A Lifelong Impairment model, a Developmental Plateau model, or a Developmental Delay model. Individuals with ASD might demonstrate a Lifelong Impairment in holistic processing, where they demonstrate significantly less interference from the bottom half of a face than would typically individuals in both childhood and adulthood. Although there are no studies prior to the current study to investigate holistic processing in both children and adults with ASD, Teunisse and de Gelder (2008) tested adolescents and found atypical holistic processing. If this atypical processing were to be replicated in an older population in the current study, this could support the lifetime impairment model of holistic processing in ASD. Importantly, Teunisse and de Gelder (2009) used a 'partial' version of the Composite Face Task, which uses an alignment effect as a measure of holistic processing. It is unclear whether other measures that could have been obtained by using the complete version of the task (the CCFT) would have revealed evidence of holistic processing in this sample of ASD participants. Therefore, this study does not lend strong support to any one of the proposed models of development.

Our data could also support a Developmental Plateau model where holistic processing in ASD might be on par with controls in childhood, but by adulthood they might no longer be processing holistically to the same degree. This model is based on work by O'Hearn, Schroer, Minshew, & Luna (2010), who found behavioural evidence that is consistent with atypical maturation of face processing in late adolescence in individuals with ASD. Before this late phase of development, the children with ASD in their study performed much like typical children as measured by a standard test of face memory, the Cambridge Face Memory task (Duchaine & Nakayama, 2006). A 'developmental plateau' in holistic processing has also been supported by O'Hearn, Tanaka, Lynn, Fedor, Minshew, and Luna (2014) where ASD children performed much like typically developing children on the part-whole task (Tanaka & Farah, 1993) and an immediate memory task, but in late adolescence, holistic processing is lesser in ASD than in typically developing individuals. Thus, they demonstrated that holistic deficits in ASD as assessed with the part-whole task are more profound in adulthood than in adolescence: A developmental plateau. One important note of caution about this study is the use of the part-whole task to measure holistic processing, which has limitations that were discussed above.

Alternatively, the ASD participants in the currents study might demonstrate a Developmental Delay in holistic processing, where the interference in performance from the bottom half of a face within the CCFT is not as strong as in typically developing individuals in childhood, but by adulthood, holistic effects would be equivalent to typically developing individuals. Previous studies have shown impairments in holistic processing in children with ASD but none have included both a child and adult group to determine whether those deficits are maintained in adulthood. Joseph and Tanaka's (2003) results are partially in accordance with this model, in that they found that children with ASD, unlike typically developing children, showed whole advantages and inversion effects in the part-whole task (Tanaka & Farah, 1993) only when making recognition judgments based on the mouth, but not the eyes or nose, revealing atypical face processing. However, other studies have failed to replicate one of these findings, finding a normal face inversion effect with eyes and nose processing, when controlling for floor (Teunisse and de Gelder, 2003). Nishimura, Rutherford, and Maurer (2008) demonstrated that there were no differences between adults with ASD and control adults in terms of both holistic and 2nd order configural processing. This, in combination with the results from Joseph and Tanaka (2003), support the model of a developmental delay, where holistic processing is impaired in childhood and normal in adulthood. Of course, a more compelling argument would come from one study that finds that same pattern using the same methodology, as would be possible from the results of the current study. Additionally, Nishimura et al. (2008) also used a 'partial' version of the CCFT that contains a confound between alignment and congruency, which blurs the interpretation of results. Basically, all trials where the correct response was 'same' (i.e. the tops were identical) were incongruent, and all 'different' trials were congruent (see Figure 2). This meant it was not possible to directly compare the aligned/congruent with aligned/incongruent conditions, which is the condition in which holistic processing is most evident. Thus, the impact of congruency, which provides insight as to whether individuals are able to selectively ignore the top half of a face or whether holistic processing causes a gluing of the top and bottom together, is not obtainable from the partial design of the CCFT. For a detailed discussion of the confounds within the partial CCFT, see Gauthier and Bukach (2007). For this reason, the current study employed the complete version of the CCFT.

Current Study

To the best of our knowledge, this is the first study of holistic processing to include both child and adult ASD groups and comparison control groups for each. This allows direct comparison among the four groups in order to examine whether differences in development of holistic processing are evident between ASD and control groups. Additionally, this is the first study to do so using the best measure known to date to tap most directly into holistic processing, the CCFT. This ensures that the effects observed are related to holistic processing, most specific to faces and relevant to social functioning, rather than domain general principles of visual processing.

Chapter 2: Method

Participants

19 children with ASD, 16 control children, 14 adults with ASD, and 64 control adults completed the CCFT. Of those, 3 children with ASD and 1 control adult were excluded from data analyses due to below-chance performance (50%). In order to facilitate statistical analyses by having equal *n*'s in each group, 14 participants for each group were selected so that the child ASD and child control groups were age-matched as closely as possible and that the adult ASD and adult control groups age-matched as closely as possible. The resulting child ASD group had a mean age of 14.0 years with a standard deviation of 2.9 years (93% male). The child control group had a mean age of 12.4 years with a standard deviation of 2.2 years (86% male). The ASD adult group had a mean age of 32.6 years with a standard deviation of 11.7 years (71% males) and the control adult group had a mean age of 23.8 years with a standard deviation of 4.1 years (36 % males). All participants were of Caucasian descent.

The severity of social impairment was assessed with the Social Responsiveness Scale (*SRS*; Constantino & Gruber, 2005), which yielded an average SRS t-score of 70.0 (*sd*=15.6) for the child ASD group and 71.0 (*sd*=10.9) for the adult ASD group. These scores both reflect moderate levels of impairment, which indicates deficiencies in reciprocal social behaviour that lead to substantial interference in everyday social situations (Constantino & Gruber, 2005). The average *SRS* score for the child control group was 43.5 (*sd*=4.6) and for the adult control group was 50.5 (*sd*=5.1) both of which fall within normal limits. *SRS* data was not obtained for four of the adult control participants.

IQ was assessed with the *Weschler Abbreviated Scale of Intelligence* (*WASI, 1st edition*). The mean Full-Scale IQ (4-factor) for the child ASD group, child control, adult ASD, and adult control groups was 107.3 (*sd*=13.8), 107.5 (*sd*=6.4), 119.1 (*sd*=8.1), 113.9 (*sd*=11.5), respectively. Demographics for all four groups are summarized in Table 1.

For participants with ASD be included in the current study, the assessment procedures for the original diagnosis of ASD had to include either the ADOS (Autism Diagnostic Observation Schedule) or ADI-R (Autism Diagnostic Interview-Revised). Due to the high level of comorbidity with other mental health disorders, participants were not excluded if they disclosed common comorbid diagnoses such as depression or anxiety.

Procedure

This study received ethics clearance from the Izaak Walton Killam Hospital for Children's Research Ethics Board, Dalhousie University Social Sciences and Humanities Research Ethics Board, and Mount Saint Vincent University's Research Ethics Board. Participants were recruited via Dr. Shannon Johnson's participant database, all of whom had previously agreed to be invited to participate in research, and through posters displayed at Dalhousie University, the Izaak Walton Killam Hospital for Children, or Autism Nova Scotia.

Participants were tested in the Clinical and Cognitive Neuropsychology laboratory in Dalhousie University's Life Sciences Centre. All adult participants were asked to sign a written consent form prior to testing. For each child participant, a parent or guardian was asked to sign a written consent form. As well, each child participant provided verbal assent at the beginning of the session after being informed of the nature of the tasks. A research assistant provided information about the tasks and study so that consent was informed and addressed any questions or concerns raised by participants.

Participants completed the CCFT as well as a number of other tasks involving face processing with different face stimuli and object categorization that were not analyzed as part of the current study. Adult participants and parents of child participants completed the *SRS* as well as a general demographic questionnaire. If the participant had not completed an intelligence test within the last two years prior to testing, the *Weschler Abbreviated Scale of Intelligence* (*WASI, 1st edition*) was administered. The duration of the testing session ranged from 1.5 to 3.5 hours with participants being given frequent breaks and snacks, as required. All participants were compensated with five dollars for each half hour of participation.

Stimuli

The CCFT was presented on a 15" MacBook Pro using MatLab 2012 experimental software. The face stimuli consisted of greyscale computer-generated Caucasian, young, adult male faces with neutral expressions and without hair (bald; see Figure 3 for examples). The images were presented in black and white and were 400 pixels by 400 pixels in size. The face stimuli for this task were composed of the top half of one face and the bottom half of another face, with the top and bottom halves separated by a thick black line to clearly define the boundaries of the top and bottom halves of the faces.

The top and bottom halves were either aligned horizontally to create an intact face, or the top and bottom halves were misaligned along the horizontal plane (see Figure 3 for examples). The Study and Test faces always had the same alignment: Either both aligned or both misaligned. Each Test face had one of the following four relationships to the Study face: 1) The top and bottom were *both* the same as the Study face (Same, Congruent), 2) the top was the same as the Study face but the bottom was different from the Study face (Same, Incongruent), 3) the top and bottom were both different from the Study face (Different, Congruent), or 4) the top was different but the bottom the same as the Study face (Different, Incongruent). Further, each of these four different types of trials had tops and bottoms that were either aligned or misaligned (see Figure 2), resulting in a total of eight different conditions in a 2 (Same, Different) x 2 (Congruent, Incongruent) x 2 (Aligned, Misaligned) repeated-measures design. Equal numbers of each condition were presented for a total number of 64 trials/condition. The order of trial types was randomized across all variables.

There were 8 practice trials so that participants had a chance to get used to the pace and to ensure that they understood task instructions. The examiner observed the participant and was available for questions during those practice trials to ensure that the correct response keys were pressed and to answer any questions about task demands. Upon completion of the practice trials, the examiner provided a brief reminder about the instructions orally and the participant was instructed to begin when he or she was ready. The CCFT consisted of 512 trials resulting in an average task duration of twenty minutes. Participants were notified of the duration of the task before they began.

To begin each trial, a centrally presented fixation cross appeared on a computer screen for 1 second. Then, a Study face was presented centrally for 0.5 second for the participant to study, followed immediately by a 0.3 second visual mask composed of black and white visual static. A Test face was then presented for 5 seconds and the participant was asked to attend to only the top half of the face (the eyes, eyebrows, forehead), and determine whether the top half of the Test face matched the top half of the Study face. Participants were asked to press one of two computer keys (S for same, D for different) to indicate their decision.

Analysis

In order to address the question of which of the groups of participants demonstrated typical patterns of holistic processing, Analysis of Variance (ANOVAs) analyses and correlation analyses were completed. A 3-way mixed Analysis of Variance (ANOVA) was completed with

Alignment (aligned, misaligned) and Congruency (congruent, incongruent) as within-subjects variables and Group (Adults with ASD, Children with ASD, Control Children, and Control Adults) as the between-subjects variable. D-prime (d') was the dependent variable, which is a measure of sensitivity derived from Signal Detection Theory that measures how accurate a participant was at responding 'same' when the tops of the faces were actually the same ("hits" in signal detection terminology) but also incorporates the frequency with which the participants responded 'same' when, in fact, the tops of the faces were different ("false alarms" in signal detection terminology). This d' score reflects whether a participant is truly able to detect a 'same' trial or if he or she is merely responding 'same' for every trial. If a participant were to respond with a high hit rate and also a high false alarm rate, it would yield a low d-prime score, reflecting poor ability to differentiate from trials where the tops were actually the same from the trials where the tops were actually different.

The typical pattern of performance in individuals who are processing faces holistically is that performance is impaired (i.e. d' will be reduced) in incongruent trials relative to congruent trials. This results in a relatively large difference between congruent and incongruent trials due to interference from the bottom half of the face. In other words, it is easier to differentiate between Same and Different trials when face tops and bottoms are congruent than when they are incongruent. This is demonstrated by a significant main effect of congruency in the ANOVA.

Moreover, the impairment due to interference from an incongruent bottom half is greater when faces are aligned because the meaningful configuration of the face (tops and bottoms aligned and presented in an upright orientation, the way we typically encounter faces in our environment) triggers holistic processing, relative to when the tops and bottoms are misaligned. This is revealed by a significant interaction between alignment and congruency in the ANOVA, where there is less difference between congruent and incongruent trials in the misaligned orientation, where there should be a release from interference.

In the 3-way ANOVA, then, it was expected that there would be a significant 2-way interaction between Congruency and Group. The difference in congruency effects between groups might be non-significant, indicating no impairment in ASD, or the differences might fit any of the previously-described models of atypical development of holistic processing in ASD: The Lifelong Impairment model, the Developmental Plateau model, or the Developmental Delay model. If the course of development in holistic processing follows the Lifelong Impairment model, there would be a significant Congruency by Group interaction when comparing children with ASD to control children, indicating that there is a bigger congruency effect in control children (i.e. the difference between congruent and incongruent trials would be greater). We would also expect to find a significantly larger congruency effect in control adults as compared to adults with ASD, indicating that holistic processing continues to be impaired in ASD in adulthood relative to control adults.

Alternatively, if the Developmental Plateau model of holistic processing in ASD were to hold true, we would expect to find that children with ASD are performing similarly to control children, as would be indicated by a lack of Congruency by Group interaction between those two groups. This would indicate that the interference from the bottom half had equal impact on both children with ASD and control children. However, according to this model, we would expect that control adults have continued to become more holistic where adults with ASD have slowed in development of holistic processing, resulting in a significantly larger congruency effect in control adults compared to adults with ASD.

Finally, if the Developmental Delay model should hold true, we would expect that we would find a significantly larger congruency effect in adults with ASD compared to children with ASD. We would also expect to find that there is a significant difference in the congruency effects between children with ASD and control children, as we would expect to find that the control children demonstrated more impairment from incongruent faces than would children with ASD. We would also expect that there would be no difference in holistic processing between adults with ASD and control adults.

As mentioned, correlation analyses were also completed to investigate the size of the congruency effect as a function of the age (in months) of the participants. To accomplish this, a single value was calculated for each participant that represented the magnitude of the Congruency effect (difference between d' for congruent trials and d' for incongruent trials, collapsed over Alignment). This value was used because Congruency effects have been deemed the best measure of holistic processing within the CCFT whereas Alignment effects were not included in this analysis because they are not necessary for verifying holistic processing (Cheung et al., 2008). The more a participant processes faces holistically, the larger the difference between congruent and incongruent conditions, yielding a larger value for the calculated Congruency variable. When comparing this calculated value with age, the resulting correlation reflects whether the bias to process faces holistically increases with age. Two separate correlations were completed: One with all of the ASD participants (children and adults) grouped together, and another with the control adults and children grouped together. A positive correlation will reflect that there is increasing holistic processing with age, whereas a negative correlation will indicate that holistic processing decreases with age. No correlation is thought to indicate that there is no developmental change occurring in holistic processing across the age range of participants in this study.

In order to compare the magnitude of the two correlations (ASD and control), a Fisher's *r* to *z* transformation (Hays, 1981) was applied to each correlation. Using these z-scores, a test statistic (reported as an absolute value) was calculated and was compared to the *z* distribution cut-off point for a 0.05 Type-I error rate (+/- 1.96) in order to determine whether correlations were statistically different from one another (Hays, 1981).

Chapter 3: Results

The current study investigated holistic processing of faces in ASD and in control participants as measured by the Compete Composite Face Task paradigm (CCFT). To this end, two types of analyses of d-prime (sensitivity) were performed: a 2 (Alignment) x 2 (Congruency) x 4 (Group) mixed-design Analysis of Variance (ANOVA) with group as the only between-subjects factor and correlation analyses that assessed the degree of holistic processing as a function of age separately in the ASD group and then in the control group. An alpha level of 0.05 was used for all statistical tests.

Comparison of CCFT Performance Across Groups

The ANOVA revealed a significant main effect of Group, $F(3, 52)=780.95$, $p<0.001$, indicating that sensitivity differed across the groups. *Post hoc* tests revealed that the sensitivity of the adult ASD group was significantly higher than the child ASD group, $t(26)=3.43$, $p=0.003$. The control adult group performed better than the child control group, $t(26)=3.74$, $p=0.001$. The two adult groups (ASD and control) were not significantly different from each other, $t(26)=0.72$, $p=0.19$. Similarly, the two child groups (ASD and control) were not significantly different from each other, $t(26)=0.06$, $p=0.126$ (see Figure 4a).

Additionally, as typically found in the CCFT, there was a significant main effect of Alignment, $F(1, 52)=4.41$, $p=0.041$, where performance was better in the misaligned than the aligned condition (Figure 4b). As expected, there was a significant main effect of Congruency, $F(1, 52)=33.80$, $p<0.001$, where performance was better for congruent than incongruent trials (Figure 4c). There was also an expected significant interaction of Alignment and Congruency, $F(1, 52)=33.94$, $p<0.001$ (Figure 4d). *Post hoc* tests revealed that this interaction took the expected shape, where the congruent and incongruent conditions were significantly different in the aligned condition, $t(110)=3.76$, $p<0.001$, but were not different in the misaligned condition, suggesting that, overall, participants experienced interference from an incongruent bottom half of a face when face parts were aligned, but when face parts were misaligned, there was a release from interference, resulting in similar performance in the congruent and incongruent conditions. There was also a significant difference between the incongruent aligned and incongruent misaligned conditions, $t(110)=2.69$, $p=0.008$, showing that there was a release from interference when incongruent face parts were misaligned. As expected, there was no difference between the aligned congruent and misaligned congruent because the congruent bottom half does not interfere with performance in the aligned condition, therefore misaligning the face parts will not cause any release from interference that was not there in the first place.

Importantly, there was a significant interaction of Group and Congruency, $F(3,52)=4.45$, $p=0.007$, indicating that Congruency impacted performance differently amongst the four groups (see Figure 5). *Post hoc* tests revealed that the adult ASD group showed a significantly larger Congruency effect than the child ASD group, $t(26)=3.82$, $p=0.001$, indicating that the adult ASD group was demonstrating more holistic processing than the child ASD group (see Figure 6). Additionally, and unexpectedly, there was a trend for the ASD adult group to exhibit a larger effect of Congruency than the adult control group, $t(26)=1.99$, $p=0.058$, suggesting they might be more impacted by Congruency, and therefore demonstrating more holistic processing, than typical adults. The *post hoc* t-tests revealed no differences in the size of the Congruency effect between control children and control adults, $t(26)=0.32$, $p=0.755$ and between the control children and children with ASD, $t(26)=1.24$, $p=0.227$.

Finally, there was no significant interaction of Alignment and Group, $F(3, 52)=0.47$, $p=0.708$, and there was no significant 3-way interaction between Alignment, Congruency, and

Group, $F(3, 52)=1.05$, $p=380$. It is possible that the lack of 3-way interaction was due to a lack of statistical power in our analysis.

Individual Group ANOVAs

For each of the four groups of participants, a 2-way ANOVA of Alignment (2) by Congruency (2) was completed to investigate the unexpected trend that the effect of Congruency effect was larger for the adult ASD group than for the control adult group. Similarly, further investigation into the child ASD and control child groups was warranted since the Lifelong Impairment and Developmental Delay models of the development of holistic processing predicted a difference in performance between the two child groups, which was not evident in the Congruency by Group *post hoc* analyses. The results of these ANOVAs are presented in Figure 7.

Control Children. There was a significant effect of Congruency in the child control group, $F(1, 13)=4.78$, $p=0.048$, where performance was better in the congruent than incongruent condition, suggesting that the child control group demonstrated holistic processing. The main effect of Alignment that is often found in the composite fact task was not significant. As expected, the interaction between Congruency and Alignment was significant, $F(1, 13)=7.06$, $p=0.02$, where there was more interference from incongruent bottom halves (i.e., a bigger difference between congruent and incongruent conditions) in the aligned condition than in the misaligned condition.

Control Adults. There was a significant main effect of Congruency, $F(1, 13)=7.50$, $p=0.017$, where performance was better in the congruent than incongruent condition, which suggests holistic processing. There was also a significant interaction between Alignment and Congruency, $F(1,13)=19.93$, $p=0.001$, where the congruency effect was larger in the aligned than misaligned condition. There was no significant main effect of Alignment.

ASD Adults. There was a significant main effect of Congruency, $F(1,13)=30.34$, $p<0.001$, where performance was better in the congruent condition than in the incongruent condition, suggesting evidence of holistic processing in adults with ASD. There was also a significant interaction between Alignment and Congruency, $F(1,13)=5.50$, $p=0.036$ where the impact of Congruency was greater in the aligned condition than misaligned condition. There was no significant main effect of Alignment.

ASD Children. Importantly, the children with ASD *did not* demonstrate holistic processing, as evidenced by a non-significant main effect of Congruency, $F(1, 13)=0.69$, $p=0.42$. They demonstrated an unexpected significant crossover interaction between alignment and congruency, $F(1, 13)=11.32$, $p=0.005$, where in the aligned condition, participants performed better on congruent than incongruent trials, but in the misaligned condition they performed better on incongruent trials than congruent trials. Like the other groups, there was no significant main effect of Alignment.

Summary of ANOVAs. The most important finding from these analyses is that Congruency varied by Group. Further investigation revealed that the Congruency effect was larger in the adult ASD group than in the child ASD group and marginally larger than in the control adult group. Additionally, the child ASD group did not demonstrate evidence of holistic processing in terms of the congruency effect, whereas the control child group did. Together, these findings are most consistent with the developmental delay model of the development of holistic processing in ASD. This suggests that holistic processing has developed sufficiently to impact performance on the CCFT in the control children, but that the development of holistic processing is delayed in the child ASD group. However, the marginally larger Congruency effect in the adult ASD group than in the control adult group cannot be explained by this mode, as discussed below.

Correlation Between Age and Degree of Holistic Processing

The ANOVA results suggest that there is development in holistic processing within the range of ages tested in the current study in the ASD group but not within the typically developing sample of participants. In order to further test this idea, and in order to work around the dilemma of arbitrarily choosing cut off ages for group membership, the child and adult ASD participants were grouped together (n=28) and the child and adult control participants (n=28) were grouped together and two separate correlation analyses were completed.

Consistent with the developmental delay model of the development of holistic processing in ASD, there was a significant positive correlation (r=0.45, p=0.008) between Age (in months) and the size of the Congruency effect (reflective of the degree of holistic processing) in the ASD group, where the degree of holistic processing was shown to increase with age (see Figure 7). By contrast, there was no significant correlation between Age and the measure of holistic processing in the control sample, r=-0.02, p=0.459 (Figure 8), which is consistent with the expectation that even the youngest control participants would process holistically to a similar degree as adults. However, when these two correlations were compared using Fischer's r–to–z transformation, the difference did not reach significance (*test statistic*=1.64, which did not reach the criterion of 1.96).

In order to address the concern that the age range of the control group is more restricted than in the ASD group (which lessens the likelihood of obtaining a significant correlation), the correlation analyses was repeated after excluding the oldest five ASD participants so that the age range in the ASD group was more similar to the age range in the control group (ASD: 9-33 years, M=18.3; control: 8-34 years, M=18.1). This revealed a stronger correlation for the ASD group, r=0.73, p<0.001. When compared using Fischer's r-to-z transformation, these two correlations were found to be significantly different from one another, *test statistic*$=2.84>1.96$, which is indicative of a difference between the development of holistic processing in ASD and typically developing participants.

Chapter 4: Discussion

The current study investigated whether the holistic face processing as assessed by the CCFT is intact in individuals with ASD aged 9 to 58 years relative to age-matched controls. The first was an ANOVA with Congruency and Alignment as within-subjects variables, Group as a between-subjects variable, and d-prime as the dependent variable. Subsequently, correlations were used to assess the degree to which there was a relationship between the magnitude of holistic face processing and the age of an individual. Separate correlations were performed on data from control participants and participants with ASD.

The ANOVA revealed that the two adult groups (ASD and control) performed better on the CCFT than the two child groups, who did not differ from each other. The performance of the ASD and control adult groups did not differ from each other either. The ANOVA also showed a significant main effect of Congruency, which indicated that when all groups were collapsed together, participants demonstrated holistic processing. As expected, there was also a significant interaction of Alignment and Congruency where sensitivity was more impaired by incongruent face bottoms in the aligned condition than in the misaligned condition due to release from interference when holistic processing was disrupted in the misaligned condition.

Importantly, there was a significant interaction between Congruency and Group. Because congruency effects are the hallmark of holistic processing within the CCFT (Gauthier et al., 2009) and the focus of this research is on how ASD affects holistic processing, this group interaction was further investigated with *post hoc* tests that compared the magnitude of congruency effect (the difference between congruent and incongruent trials irrespective of alignment) between groups. *Post hoc* tests revealed that there was no difference in the size of the Congruency effect between control children and control adults, as expected. In contrast, the

Congruency effect in the adult ASD group was larger than in the child ASD group. The child ASD group was the only group of the four to show *no* significant main effect of Congruency (when data from each group was analyzed separately). Therefore, the child ASD group did not process faces holistically in the CCFT, but the adult ASD group did. Interestingly, the ASD adult group also demonstrated a trend towards a larger effect of Congruency than the adult control group, which was not predicted *a priori* by any of the models of the development of holistic face processing in ASD. Interpretation of this effect is discussed below.

When comparing the child ASD and child control groups, the *post hoc* t-tests revealed no differences in the strength of the Congruency effect between these two groups. However, when looking at the pattern of performance in each individual group, the children with ASD did not demonstrate any evidence of holistic processing, as defined by a congruency effect, whereas the control children did show a significant effect of congruency, suggesting that the two groups are qualitatively different. It is likely that this difference was not significant due to limitations in statistical power. However, in summary, three groups demonstrated a congruency effect that is indicative of holistic processing, (control children, control adults, and adults with ASD), whereas the child ASD group did not.

With respect to the correlation analyses, in the ASD sample, there was a correlation between the value calculated to represent the magnitude of holistic processing and age indicating greater holistic processing in those participants that were older. By contrast, there was no significant correlation between age and magnitude of holistic processing in the control sample. These two correlations were shown to be statistically different, suggesting that the course of development of holistic processing in control participants and ASD participants is different. The results of the ANOVA analyses are consistent with the results of these correlation analyses. For the typical groups, the ANOVA results showed no difference between adult and child holistic processing. Similarly, the correlation analyses for the control participants showed no relationship between holistic processing and age. These results are similar to many studies that indicate that holistic face processing is present from a very early age, as described below.

In terms of findings with respect to the control participants, the results of the current study reveal a lack of qualitative difference between control children and control adults and are consistent with previous studies of holistic processing using the CCFT. Patterns of performance were found in the ANOVA analysis in the current study that are thought to indicate holistic processing, that is, a main effect of congruency that is impacted by alignment (Gauthier et al., 2009; Cheung et al. 2008) in both the typical child and adult groups. This is consistent with the results of the correlation analysis that indicate no relationship between age and holistic processing in our control sample. This is also supported by evidence that shows reliable holistic processing as young as 3.5 years of age in typically developing children using the composite face task (de Heering, Houthuys, & Rossion, 2007; Cassia et al. 2009).

Since the conclusions drawn about holistic processing in ASD in other studies are mixed, it is not surprising that our results are consistent with some prior research and inconsistent with others. It is also difficult to compare results of the different studies in the area because they investigate different age groups and employ different methodologies.

Our results with respect to the ASD groups are partly consistent with what was reported by Gauthier et al. (2009) and the similarities are critical to the interpretation of the results of the current study. The ASD group in the Gauthier et al. (2009) study and the adult ASD group in the current study demonstrate similar interesting patterns of performance on the CCFT. In addition to the fact that in both studies these groups demonstrated Congruency effects indicative of holistic processing, another interesting similarity was in the interaction between alignment and congruency. Although it is thought that Alignment is not a necessary manipulation to provide evidence of holistic processing within the CCFT (Cheung et al., 2009), the interaction between Alignment and Congruency provides insight as to why the Congruency effect was larger in the adult ASD group than in the adult control group in the current study.

The two studies revealed similar patterns, where there is impairment in the incongruent condition relative to the congruent condition when faces were misaligned, while typically interference from an incongruent bottom half is released when misalignment disrupts holistic processing. In other words, misalignment causes face parts to be treated as non-face objects rather than faces, where part-based or featural processing allows easy perceptual isolation of the top half of the face, leading to better performance on the CCFT in the incongruent condition. Thus, the bottom half should not interfere with performance for all misaligned trials, which usually renders performance to be roughly equal between congruent and incongruent trials in the misaligned condition. However, in the Gauthier et al. (2009) study and the adult ASD group in the current study, it appears that holistic processing *is* engaged when faces are misaligned as evident in the maintenance of poorer performance for incongruent trials than congruent trials when faces are misaligned. In a sense, this can be thought to reflect hyper-holistic processing in ASD, or holistic processing that is extended to other circumstances than an intact (aligned) face. The impairment due to incongruency (i.e., the difference between congruent and incongruent trials) in the misaligned condition does not reach statistical significance in the current study, but since the trend is in the same direction as what was reported in Gauthier et al. (2009), it is worth serious consideration. Additionally, although the difference between congruent misaligned and incongruent misaligned conditions is not significant, when this difference is added to difference between congruent aligned and incongruent aligned conditions when collapsing over Alignment, the overall difference between congruent and incongruent conditions becomes significantly larger in the adult ASD group than the control adult group. Thus, this similarity to the Gauthier et al. (2009) study helps to explain the otherwise mysterious larger Congruency effect in the ASD adult group than the control adult group in the current study.

The authors of that study (Gauthier et al., 2009) put forth an interesting theory of *why* this pattern has emerged in their ASD group: essentially, they proposed that while adults with ASD are capable of processing faces holistically, they remain less expert than typically developing individuals. If the holistic processing of adults with ASD is less automatic, then it follows that it is therefore more susceptible to the context in which faces are presented. The authors suggest that the context of misaligned faces intermixed with aligned faces at the study phase of the CCFT *primes* the ASD participants to process all faces (whether aligned or misaligned) holistically even when parts are misaligned. They described this as a *contextual* type of holistic processing that is qualitatively different from the *automatic* holistic processing of faces observed in typically developing individuals (present in both aligned and misaligned conditions). It is thought, therefore, that automatic holistic processing is so deeply engrained in typically developing individuals that it is not as susceptible to context, which is why it is typically applied only to aligned faces within the CCFT. It is possible then, that as holistic processing develops in ASD (later than in typically developing individuals), it becomes more and more automatic/exclusive to faces and less susceptible to context. Therefore, as the individuals with ASD age, they become less and less likely to be swayed by the context of misaligned faces at the study phase and therefore less likely to process misaligned faces holistically. This could account for why the Congruency by Alignment interaction did not reach significance in Gauthier et al.'s

(2009) adolescent ASD group but reached significance in our adult ASD group, and why the difference between misaligned congruent and incongruent conditions was significant in the Gauthier et al. (2009) study but was smaller and did not reach significance in the current study. In other words, older ASD participants, who are more experienced with faces exhibit diminished susceptibility to context-sensitive holistic processing.

Evidence for this type of contextual holistic processing has been demonstrated in typically developing individuals who are *novices* at processing categories of non-face objects within the CCFT (Richler, Bukach, & Gauthier, 2009). At the study phase of the CCFT, when participants ‘select’ what visual processing strategy to employ, if the order of misaligned and aligned presentations are randomized, a Congruency effect has been observed even in the misaligned condition. When the order of the aligned and misaligned trials at the Study phase are blocked, this effect is not observed, likely because there is less cost to efficiency of performance to switch processing strategies every block of trials than to have to switch between holistic and featural processing for every trial as would be required when trial types are randomized. Thus, it appears that adults with ASD might be processing faces much in the way that typically developing individuals process novel objects, which is consistent with the idea, broadly speaking, that individuals with ASD do not preferentially attend to faces in the way that typically developing individuals do and, therefore, acquire less expertise over time. Similar contextual effects have been observed in other configural processes, such as 2nd order configural processing with houses, when house and face trials are randomized (Matheson & McMullen, 2012).

Therefore, we propose that, while typical children process holistically much like typical adults, children with ASD do not demonstrate holistic processing; therefore, a developmental delay exists in holistic processing ability. It is most likely that prior to having enough expertise with faces to develop holistic processing, children with ASD process faces in a part-based manner, similar to the way typically developing individuals process non-face objects. Holistic processing appears to develop later in ASD, as evidenced by a Congruency effect in our adult ASD group. However, as discussed above, it appears that holistic processing remains qualitatively different in adulthood in ASD, where perhaps insufficient experience with faces has led to an underdeveloped *automatic* holistic processing. As such, the holistic processing that develops late in ASD appears to involve processing faces more like typical individuals process objects (non-face visual stimuli) as *novices*, in that they are much more susceptible to the influence of the context in which face parts are presented than are typical individuals. Altogether, this interpretation does not fit cleanly with any of the predicted models of the development of holistic processing in ASD that were proposed *a priori*, but fits best with a combination of developmental delay and qualitative difference models.

Broadly speaking, the adult ASD data might fit with the cognitive inflexibility attributed to ASD, where the holistic type of visual processing gets applied to all visual stimuli within the task that the individual is completing. It can also fit with the experience-based models of the development of face processing ability. Although by the time individuals with ASD reach adulthood, they have enough experience with faces to be able to process holistically, they are not likely to catch up in face processing experience to typically developing individuals, therefore the typically developing individuals will remain more expert and more automatic in their holistic processing. This could allow for the larger contribution of the contextual type of holistic processing proposed to be involved in the processing of misaligned faces in the CCFT. Clarification is necessary as to whether both automatic and contextual holistic processing co-exist in typically developing individuals, but are engaged to different degrees depending on the level of expertise with a given category of visual objects. Likewise, it is possible that both types can possibly exist within individuals with ASD but that the relative lack of facial expertise results in a larger contribution of the contextual type of holistic processing that emerges in the CCFT, resulting in the extension of holistic processing to misaligned faces. It is also possible that the neural substrate necessary for *automatic* holistic processing is absent from birth in ASD. The notion of a qualitatively different type of holistic processing is a new one and must be investigated further in future research.

There remain parts of the results of the current study that are discrepant from what was reported by Gauthier et al. (2009) in that they found evidence of holistic processing in younger ASD participants. The main effect of Congruency that was found in the adolescent ASD group in the Gauthier et al. (2009) study was found in the current study in adults with ASD but *not* in child ASD group. The adolescent group in that study was most comparable to the child ASD group in the current study (current study: *M*=14.0 years, *sd*= 2.9 years, Gauthier et al: *M*= 12.8 years, *sd*= 2.9 years). This suggests that the children with ASD in our sample were not processing the faces in the CCFT holistically, while the participants in Gauthier et al.'s (2009) ASD group showed evidence of processing holistically by virtue of the presence of a congruency effect. It is unclear why Gauthier et al. (2009) might have found evidence of holistic processing in their young ASD sample where we did not. One possible explanation is that their ASD group was qualitatively different than our group, which would not be surprising given the high degree of variation in the level of functioning in these individuals. Intelligence is often used to describe groups of ASD participants and is measured by Full Scale (overall) Intelligence Quotient (FSIQ). The ASD participants in Gauthier et al.'s study had average intelligence (*M*=93.1, *sd*=20.0), as did the children in the ASD group in the current study (M=104.8, sd=12.8), therefore it is difficult to attribute any differences in performance to overall cognitive functioning or that the participants in either group had difficult understanding the instructions for the CCFT.

We also investigated whether the groups might have differed on measures that assess other functional impairments that are more social in nature, which might logically impact their performance on face-related tasks. One score that was available for the participants in the current study was the Social Responsiveness Scale (SRS) total score, which reflects overall functioning in social reciprocal behavior and can be thought of as a gauge of the severity of ASD social symptoms. The average score on this measure for the child ASD participants in the current study was 71.3, which is 2 standard deviations above the average and falls in the Moderate range of impairment, indicative of substantial interference with everyday social interaction. Among the participants in the current study, this score ranged from 45 (within normal limits) to 90 (severe impairment), with a group standard deviation of 13.5 points. The most comparable social skills measure available from the Gauthier et al. study was the Autism Diagnostic Observation Schedule (ADOS; Lord, Rutter, & Dilavore, 1999) social algorithm score that the authors reported to be in the Moderate level of symptomology on average. Although there is no way to directly compare SRS from the current study to ADOS social algorithm scores in Gauthier et al.'s study, both groups appear to have social symptomology that is moderately impaired and, thus, are similar along the dimension of social impairment. However, it is unlikely that differences in social responsiveness are related to performance on the CCFT because we performed an analysis with our data that compared SRS to a measure of holism (difference in d' between congruent and incongruent aligned trials) and there was no significant relationship between the two variables (r=0.20, p=0.164), suggesting that even if the social skills measures of Gauthier et al.'s group were significantly different, it is not likely that the differences in performance on the CCFT can be attributed to differences in social symptom severity between the two groups.

The most likely explanation for the evidence of holistic processing in children with ASD is that Gauthier et al. allowed 3 seconds for the adolescents to examine the Study face, whereas in the current study, all participants, regardless of age, were allowed only 0.5 seconds. It is possible that if the children in our study had been allowed more time to study the faces, they would have demonstrated evidence of holistic processing. This suggests that there could be mechanisms in place that allow holistic processing at the age tested in the current study but that were not tapped into because of methodology. However, the children with ASD remain less able to process holistically than typically developing control children who had the same short duration of time to examine the study faces and whose performance did demonstrate the effects of holistic processing. Therefore, our overall conclusion of a developmental delay remains valid.

The current study has improved on the methodology of Teunisse and de Gelder (2008) by eliminating the confound between Congruency and Alignment in the partial version of the Composite Face Task (see Gauthier et al., 2009, for a detailed explanation of the advantages of using the CCFT versus the partial Composite Face Task) and obtaining a better measure of holistic processing in the congruency effect. When doing this, the results were not consistent with Teunisse and de Gelder (2008), who showed that individuals with ASD in late adolescence/early adulthood (16-24 years; average 19 years, 5 months, most comparable to our ASD adult group), did not show a “composite effect” (as defined by an alignment effect using the partial version of the CCFT) and interpreted this as evidence that adolescents with ASD did not process faces in a holistic fashion. However, the current study found that adults with ASD do, in fact, show evidence of holistic processing in terms of a congruency effect. If Teunisse and de Gelder (2003) had utilized the CCFT rather than the partial design, it is possible that they might have found a congruency effect even with the absence of an alignment effect, which would be consistent with intact holistic processing. This would be consistent with what was found in the current study when analyzing the performance of each group in insolation in separate ANOVAs; no significant alignment effects were found in any individual group despite evidence of holistic processing in terms of the congruency effect, which is likely related to the reduced statistical power when analyzing only one group of participants and thus including less data. Gauthier et al. (2009) also failed to find main effects of alignment, and Cheung et al. (2008) also suggest that alignment is not a necessary manipulation within the CCFT to demonstrate holistic processing. Additionally, it is difficult to compare the current study to that of Teunisse and de Gelder (2008) because the ages of their participants (16-14 years) fell in between the ages of our child and adult ASD groups. It is possible that if we had used the same age range as they did to define our groups, we may have found that adolescents had not yet developed sufficient holistic processing to demonstrate a significant effect of Congruency.

The results of the current study do not support the idea of a developmental plateau in holistic processing in ASD as proposed by O'Hearn et al. (2010, 2014). This model proposes that the development of holistic processing in children with ASD is on par with typically developing children until late adolescence when development slows in ASD but continues to develop in typical individuals, leading to significant impairment in ASD relative to typical individuals by adulthood. Our data are inconsistent with this model because the ASD adults are at least equally as holistic (and trending towards being more holistic) than control adults. The results of the current study suggest, instead, that holistic processing develops at a slower rate than in typically developing individuals but eventually reaches typical levels by adulthood. As described above, the part-whole task that was used in the O'Hearn et al. (2014) study on which they based their idea of a developmental plateau, is more accurately described as a measure of domain-general configural face processing mechanisms and results obtained with this task may not necessarily hold true of holistic processing. Additionally, it is possible that the age range of their participants did not capture individuals with ASD who have reached full development of their holistic processing abilities. The individuals in our adult ASD group extended to 58 years old, with an average age of 32.6 years (*sd*=11.7 years), which allows for the inclusion of quite mature participants who are likely to have reached the point in development where their holistic processing has reached full maturity. By contrast, the participants in O' Hearn et al.'s (2014) study only included individuals up to 35 years old. While limitations on our statistical analyses do not allow us to speculate about the age when holistic processing attains full development, there is evidence that face recognition abilities in ASD continue to develop up until just past thirty years old (Germine, Duchaine, & Nakayama, 2011). Although O'Hearn et al. do not report the average age of the participants, it is likely that a large portion of their adult group are younger than this age, suggesting that their face processing abilities might have yet to fully mature. Thus, when looking at mostly adults under the age of thirty, it appears that holistic processing does not reach the levels seen in control adults, but it could be that holistic processing only reaches full maturity in ASD beyond the age captured in their study.

The developmental delay of holistic processing in ASD (that may ultimately be of a different nature than automatic holistic processing found in typical individuals) suggested by the results of the current study is consistent with experience-based theories of the development of face processing (Gauthier & Bukach, 2007) whereby faces are not 'special' in that we are biologically predisposed to visually process them in a special way (holistically), but that holistic processing is how we process exemplars within a category of which we have become experts. Since typically developing individuals rely on information contained within the upright human face for social functioning, they become experts at an early age. Therefore, since it is well known that individuals with ASD do not extract the same information from faces and do not spend as much time looking at faces, it therefore makes sense that they take longer to accumulate the experience required to become an expert face processor and process faces holistically. Furthermore, if the theory put forth by Gauthier et al. (2009) was shown to be true, it might be that they never acquire such expertise and that automatic holistic processing of faces is therefore never free of contextual interference like it is in typically developing individuals.

Limitations & future research

There are several limitations of the current study that should be kept in mind when interpreting our results. Firstly, there were a limited number of participants in each of the four age groups and further research should expand the number of participants in each group. Additionally, the inclusion of younger participants would allow better assessment of the developmental trajectory of holistic processing in ASD.

Additionally, the average age of the two adult groups differed, where the average age for the ASD individuals was around ten years older than the control adults. This was due to the methods of recruiting participants, where most of the control adults were young undergraduates who were completing the study for course credit. Future studies should include older control participants to better compare them to the ASD group. However, it is not expected, based on existing literature, that the holistic processing in typically developing individuals would change past childhood, therefore, it is not expected to have significantly impacted the conclusions drawn from the data collected.

An extension of the current study with more participants in the child group might help to pinpoint at what age children with ASD begin to demonstrate significant congruency effects that indicate intact holistic processing. It is possible that the children within the age range tested are beginning to process faces holistically but are not yet doing so to such a degree that it significantly impairs their ability to ignore the bottom half of faces in the CCFT. It is likely that the age range of our child ASD sample is too wide to pinpoint an age where changes in holistic processing occurs, with the younger children in the group not yet processing holistically but the older group showing an inclination to do so. In order to look for evidence that supports this idea, we subdivided the child ASD group into two groups of n=7 with the youngest in one group and the older in another group, and performed alignment x congruency ANOVAs for each group. Although this analysis lacked statistical power, there was an indication that this might be true and might warrant further investigation: the youngest ASD child subgroup (M=11.71 years, sd=1.98 years) showed no trend towards a main effect of congruency, whereas the older ASD child subgroup (M=16.29 years, sd=1.25 years) showed a trend that approached significance, $F(1,6)=4.492$, $p=0.078$, indicating that there was more detrimental impact on their performance when the bottom halves of the face were incongruent. With more children at each age, we can subdivide the child group into smaller age brackets and determine at what point there is a clear pattern of holistic processing and how many years behind typically developing children this might occur, which can help inform intervention for the development of face processing expertise. Similarly, the correlation analysis that we completed might illustrate a particular curve more clearly with more participants which may provide information about the age at which the average individual with ASD might achieve enough experience with faces to become a holistic processor.

Finally, further research is required to explore the explanation proposed by Gauthier et al. (2009) that the atypical patterns of holistic processing evident in the adult ASD group in the current study are due to a qualitatively different type of *contextual* holistic processing. A study that involved both non-face objects as well as faces in the same study with the CCFT should shed light on whether individuals with ASD process faces and objects differentially with respect to alignment. According to this theory, it might be expected that adults with ASD process both objects and faces with the same pattern of congruency that is not affected by alignment, whereas control adults should demonstrate that Congruency is affected by Alignment with faces (reflecting automatic holistic processing) but that with novel non-face objects, congruency should not be modulated by Alignment, or in other words, holistic congruency effects should still be evident even in the misaligned condition.

Like all research with ASD, the heterogeneity of the ASD population poses problems with application of research findings to interventions and other practical applications in the real world. The relationship between social skills, communication skills, repetitive behavior patterns, and the development of holistic processing are all still poorly understood, and therefore the direction of causality between social skills impairments in ASD and the development of face processing is still unclear. Understanding whether innate differences in visual processing cause individuals with ASD to be less efficient at retrieving information from the faces, leading to less attention to faces and related social impairments, or whether for some other reason, individuals with ASD pay less attention to faces which leads to deprivation of experience with visual processing of faces, will help us further target interventions surrounding these visual processing abnormalities within ASD.

Unfortunately, this puzzle becomes even more difficult to solve when considering the range of impairments in ASD as well as the uncertainty and debate surrounding the current grouping of such diverse individuals under the same spectrum in terms of diagnosis in the Diagnostic and Statistical Manual of Mental Disorders (DSM-5). However, it is an active area of research which will surely shed much more light on the cognitive processes related to ASD in the near future.

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Table 1.

Demographics by Group

	n	Age (years)			IQ		SRS	
		M	*SD*	Range	*M*	*SD*	*M*	*SD*
Child ASD	14	14.0	2.9	9-18	107.3	13.8	70.0	15.6
Adult ASD	14	32.6	11.7	19-58	119.1	8.1	71.0	10.9
Child Control	14	12.4	2.2	8-16	107.5	6.4	43.5	4.6
Adult Control	14	23.8	4.1	21-34	113.9	11.5	50.5	5.1

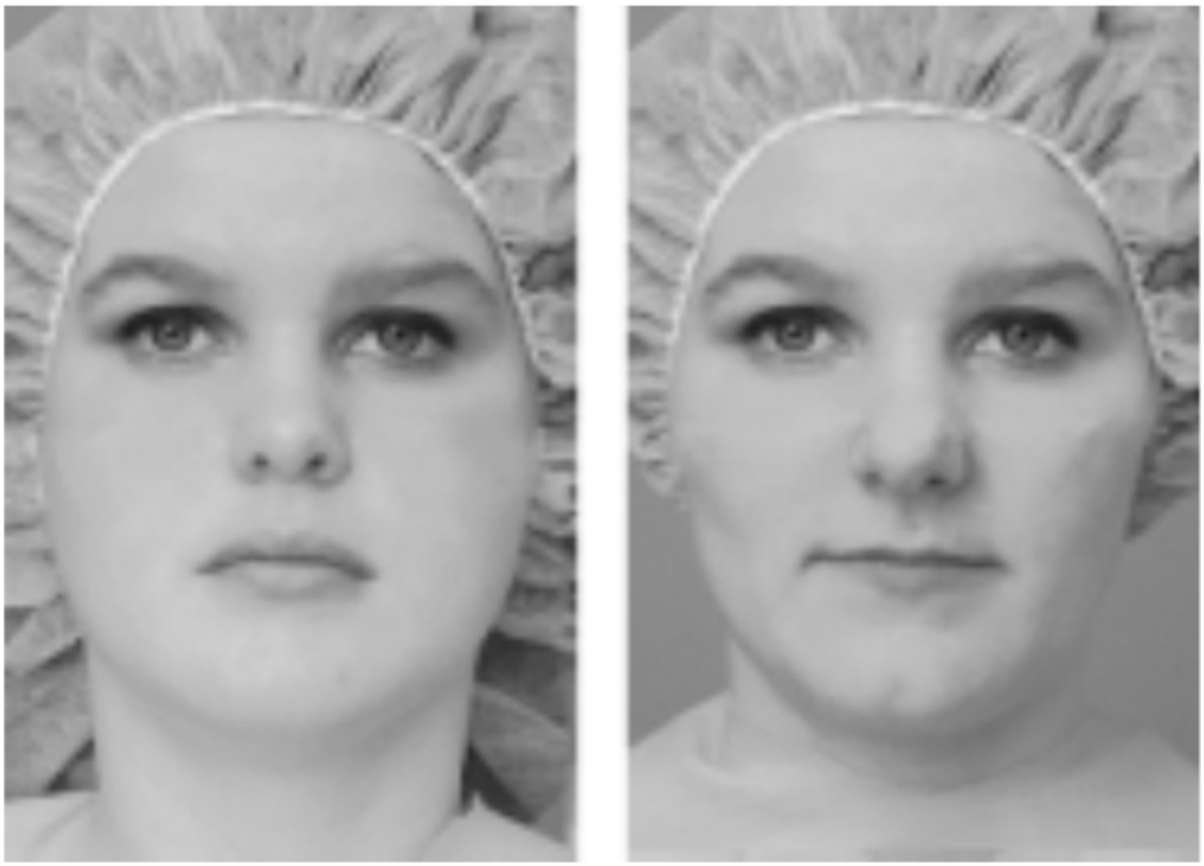

Figure 1. The Composite Face Effect (from Maurer, LeGrand, & Mondloch, 2002): The tops of these faces are identical but when fused with different bottoms, the illusion of two different face identities is produced.

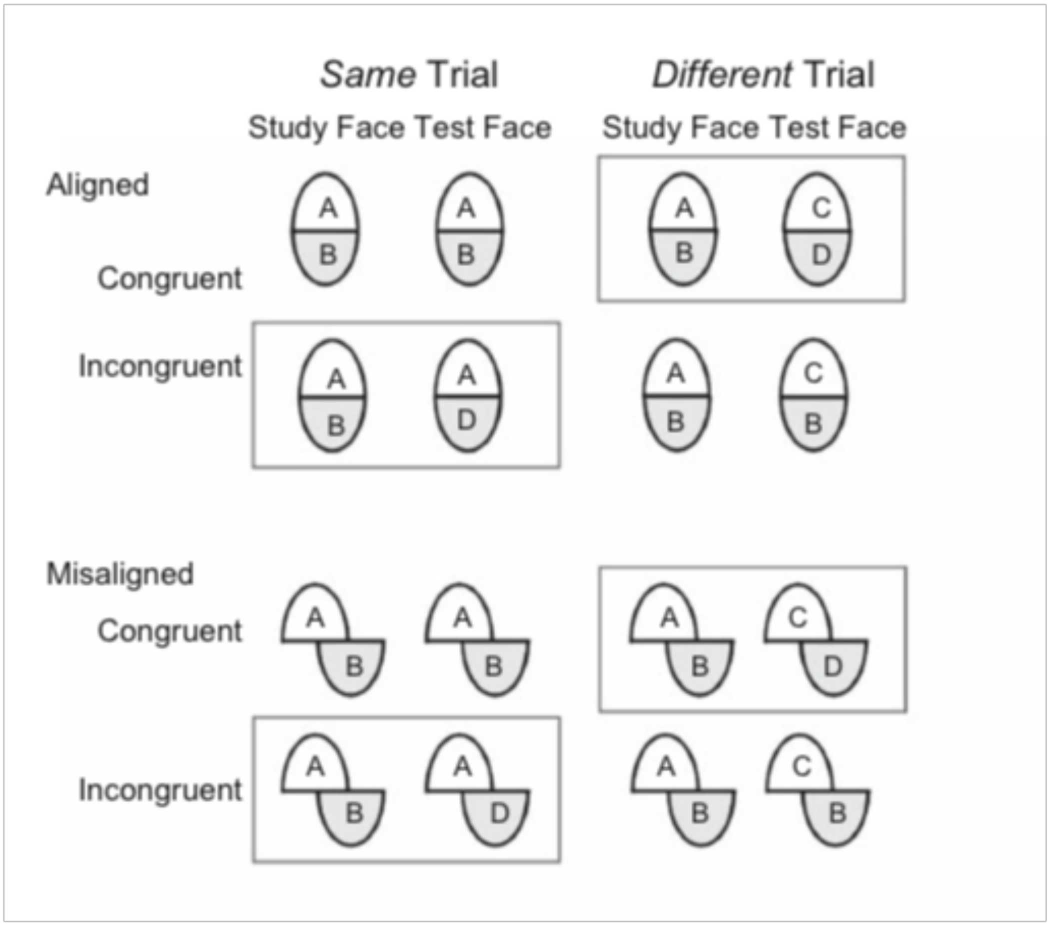

Figure 2. The Complete Composite Face Task design. Square outlines indicate trial types that are included in the partial design, whereas *all* trial types are included in the Complete Composite Face Task (CCFT) (Richler, Cheung, & Gauthier, 2011).

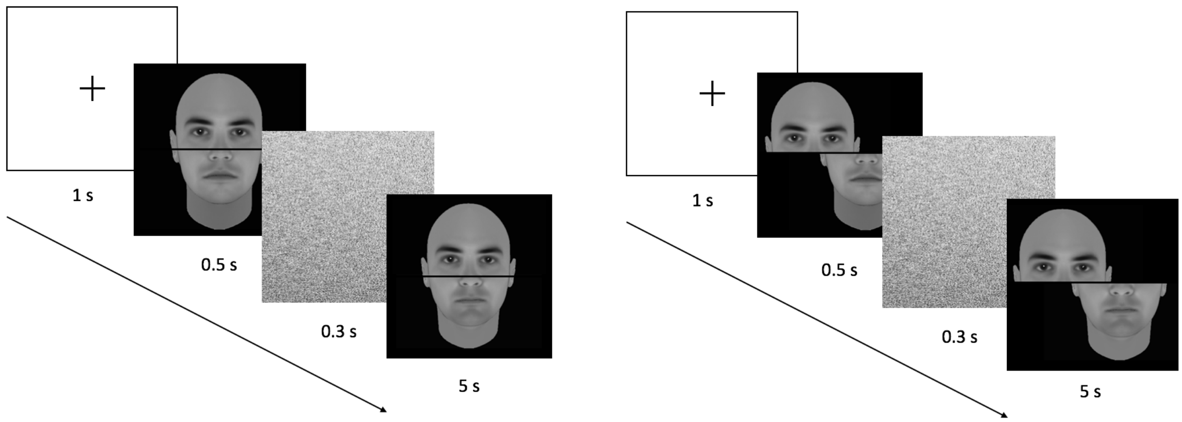

Figure 3. The order and duration of stimuli presentation in aligned trials (left) and misaligned trials (right).

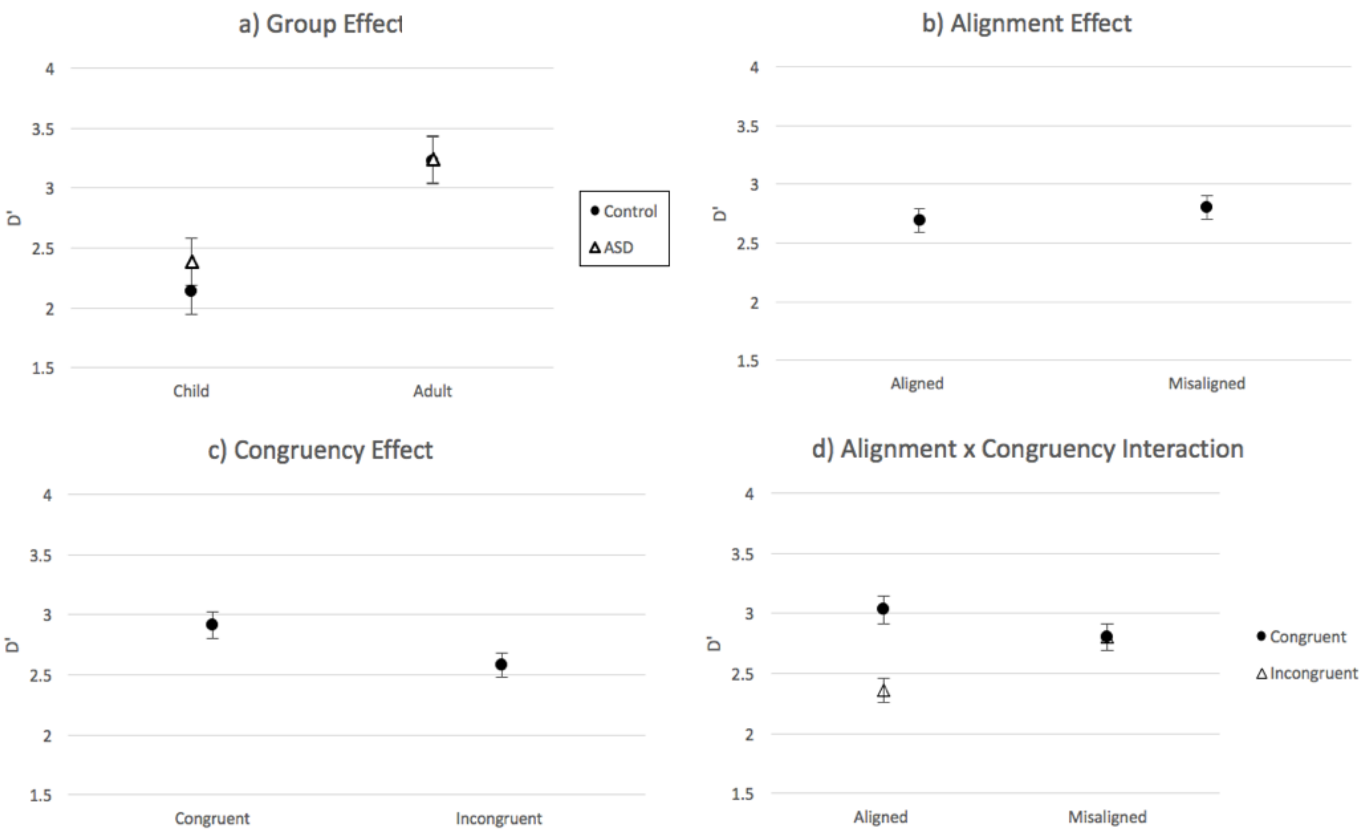

Figure 4. Illustrations of Mean d-prime (d') values in the 3-way mixed ANOVA depicting the main effects of a) Group, b) Alignment, and c) Congruency, and d) the interaction of Alignment and Congruency.

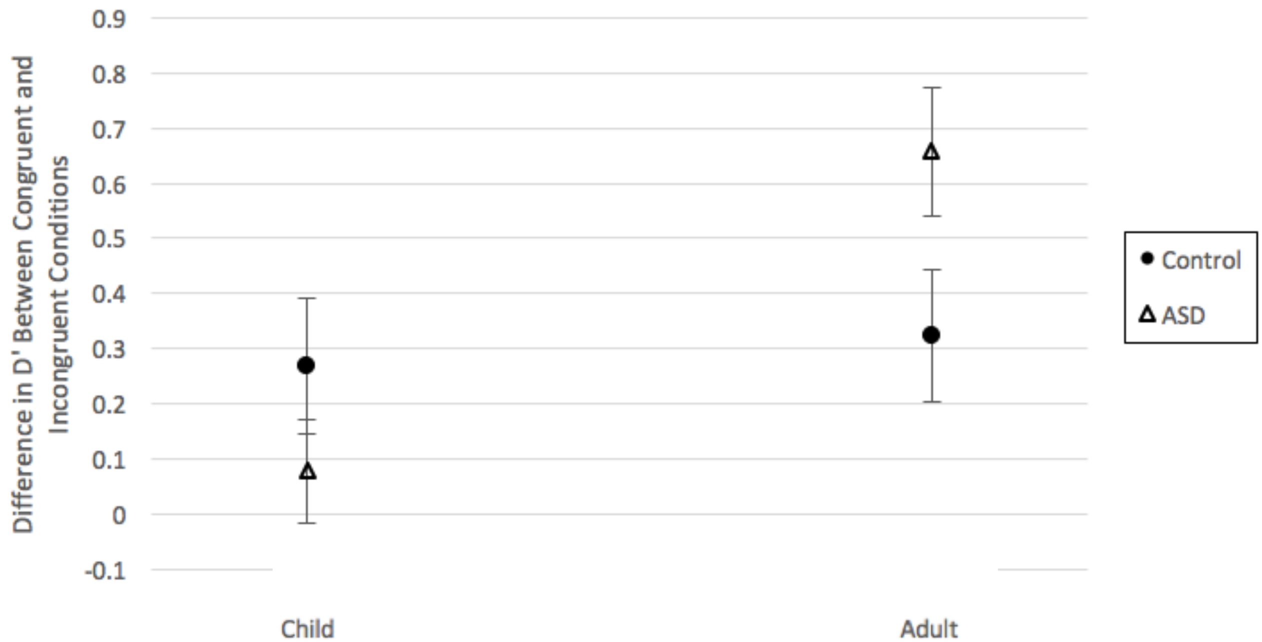

Figure 5. The difference between incongruent and congruent conditions for each group between Congruency and Group where the adult ASD and child ASD are significantly different from one another and the adult control and adult ASD groups are marginally different from one another.

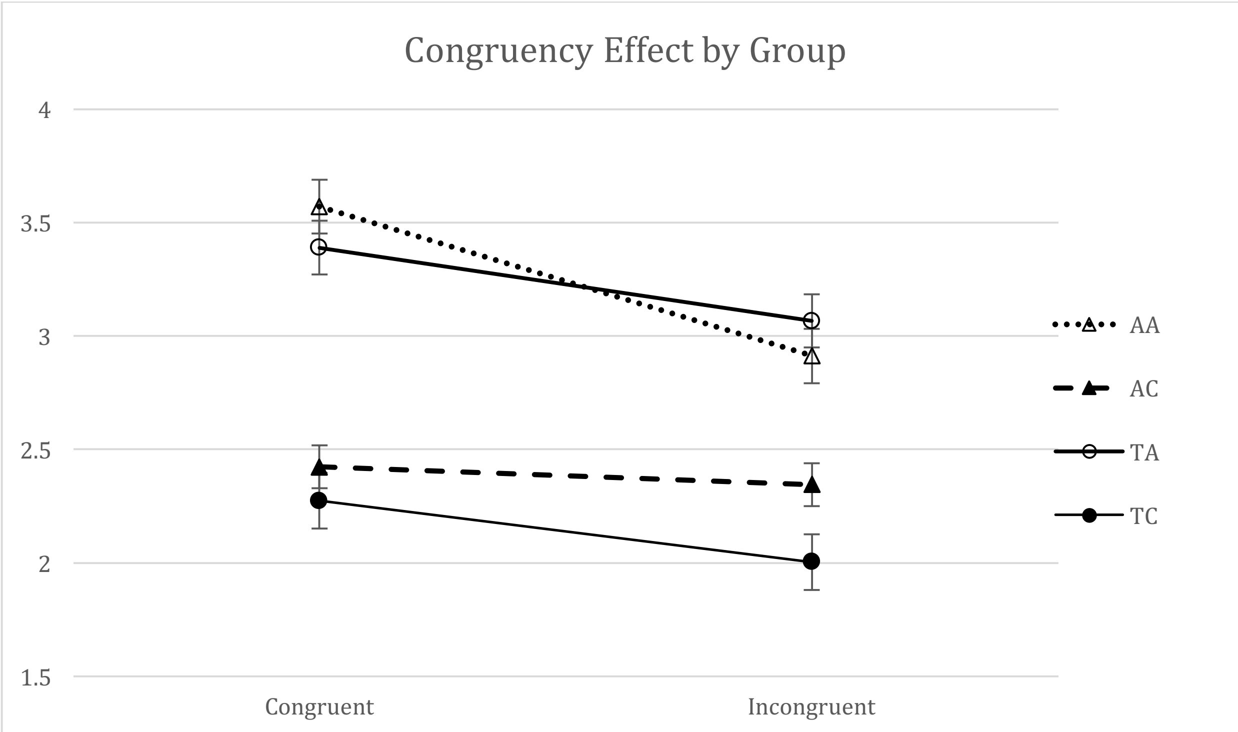

Figure 6. The main effect of Congruency in the adult ASD, adult control, child ASD, and child control groups.

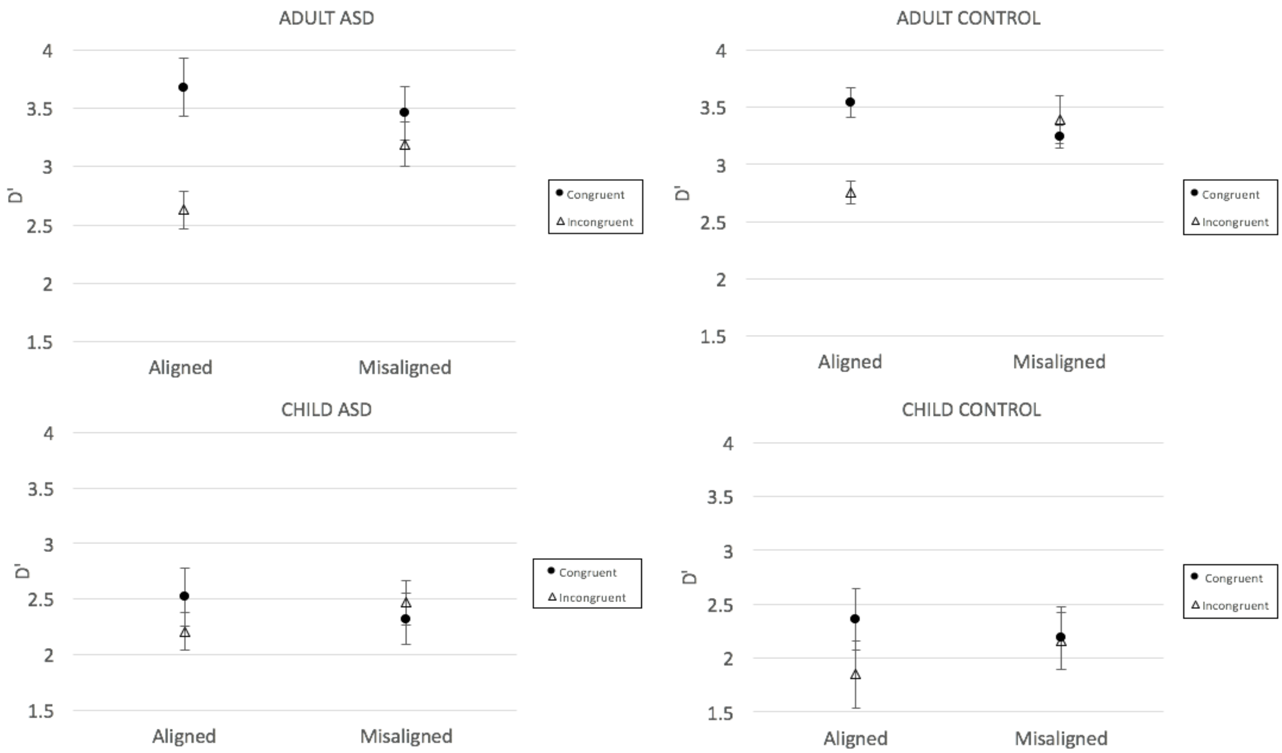

Figure 7. Mean d-prime (d’) values for the aligned/congruent, aligned/incongruent, misaligned/congruent, and misaligned/incongruent conditions in each of the four groups of participants.

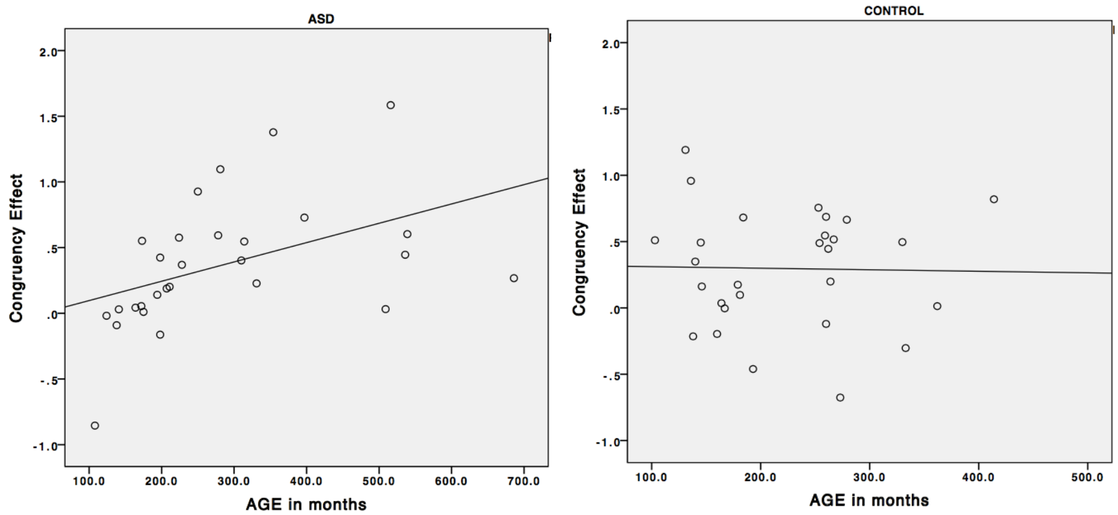

Figure 8. Scatterplots of correlation analyses between Age (in months) and the magnitude of the Congruency effect for the ASD participants and for the control participants.

Appendix A

In the Complete Composite Face Task (CCFT), the top and bottom halves of the Test face can bear different relationships to the Study face; the tops might be the same in both the Study and Test face, or they might be different. The bottom halves of the face might also be the same or they might be different. The underlying key concept is that when individuals process a face holistically, they have difficulty perceptually isolating the top half of the face from the bottom half of the face when the top and bottom are presented in an upright and intact way, i.e. the way we typically encounter faces in our environment. Holistic processing causes the perceptual fusion of the top and bottom into a single entity. When a top of a face is combined with a bottom of a new face, it creates the perception of an entirely new face identity. For a compelling (and critical to understanding the interpretation of the CCFT) example of how a different bottom half of a face can cause the illusion of an entirely different face identity, see Figure 1.

Within the CCFT there are congruent and incongruent trials. Consider a trial where the Study face has the same top as the Test face. If an individual were *not* processing holistically and was able to selectively ignore the bottom half of the face, it should be easy to accurately respond that the two top halves of the faces were the same. However, for most individuals who process faces holistically, it is not so easy to perceptually block out the bottom half of the face. There is typically no problem arising due to holistic processing if the bottom half of the Study and Test faces are also the same, when the tops and bottoms that are identical are fused together, they still create the perception of two identical faces, eliciting the response ‘same’. This is a congruent trial: the top and the bottom elicit the same response (in this example, they are both ‘same’). However, when the bottoms of the Study and Test face are different, even if the tops of the Study and Test faces are identical, the tops may *appear* to be different. This creates the illusion that the

Study face and Test faces are two different faces, causing an increased likelihood of an incorrect response of ‘different’. This is an ‘incongruent’ trial, where the tops halves of the Study and Test face are either both the same but the bottoms are different, or vice versa, where the tops are different and the bottoms are the same. Again, congruent trials contain bottoms that do not cause interference with response decisions, whereas incongruent trials contain bottom halves that, when processing holistically, will interfere with a participant’s ability to respond correctly. Trials with a bottom half of the face that causes the Test face to appear to be a whole new individual (incongruent trials) are harder to respond accurately to, therefore, when participants are processing holistically, they typically perform worse on incongruent trials than on congruent trials where the bottoms do not cause any perceptual interference. Evidence of this performance discrepancy between congruent and incongruent trials is taken as evidence of holistic processing and is called the *congruency effect.*

To further complicate matters, half of the congruent and incongruent trials are presented with the tops and bottoms horizontally aligned, and half with tops and bottoms vertically misaligned (offset) so that they can not fused together holistically. Misalignment is thought to disrupt holistic processing because this is not the way that faces are typically processed in the environment and therefore this type of arrangement of face parts should not trigger holistic processing. In this case, it is thought that the top and bottoms of the face when misaligned are processed on a feature-by-feature basis, much like other non-face objects are processed. Combining the variables of alignment and congruency result in a matrix of congruent/aligned, incongruent/aligned, congruent/misaligned, and incongruent/misaligned trials.

Appendix B