Face perception develops similarly across viewpoint in children and adolescents with and without autism spectrum disorder

Jacalyn Guy
Perceptual Neuroscience Laboratory for Autism Spectrum Disorder and Development, McGill University, Montréal, Quebec, Canada
Integrated Program in Neuroscience, McGill University, Montréal, Quebec, Canada

Claudine Habak
Educational Neuroscience Research Centre, Health and Special Education, Emirates College for Advanced Education, Abu Dhabi, UAE

Hugh R. Wilson
Centre for Vision Research, York University, Toronto, Ontario, Canada

Laurent Mottron
Centre d'excellence en Troubles envahissants du développement de l'Université de Montréal (CETEDUM), Hôpital Rivière-des-Prairies, Montréal, Quebec, Canada

Armando Bertone
Perceptual Neuroscience Laboratory for Autism Spectrum Disorder and Development, McGill University, Montréal, Quebec, Canada
Centre d'excellence en Troubles envahissants du développement de l'Université de Montréal (CETEDUM), Hôpital Rivière-des-Prairies, Montréal, Quebec, Canada
School/Applied Child Psychology, Department of Educational and Counseling Psychology, McGill University, Montréal, Quebec, Canada

Atypical face perception has been associated with the socio-communicative difficulties that characterize autism spectrum disorder (ASD). Growing evidence, however, suggests that a widespread impairment in face perception is not as common as once thought. One important issue arising with the interpretation of this literature is the relationship between face processing and a more general perceptual tendency to focus on local rather than global information. Previous work has demonstrated that when discriminating faces presented from the same view, older adolescents and adults with ASD perform similarly to typically developing individuals. When faces are presented from different views, however, they perform more poorly—specifically, when access to local cues is minimized. In this study, we assessed the cross-sectional development of face identity discrimination across viewpoint using same- and different-view conditions in children and adolescents with and without ASD. Contrary to the findings in adults, our results revealed that all participants experienced greater difficulty identifying faces from different views than from same views, and demonstrated similar age-expected improvements in performance across tasks. These results suggest that differences in face discrimination across views may only emerge beyond the age of 15 years in ASD.

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Introduction

Successful navigation through the social intricacies of our daily environment depends on the ability to correctly identify a face. The ability to efficiently recognize, identify, or discriminate a face is critical to the early development of communication and day-to-day interactions (Schultz et al., 2000). Individuals with autism spectrum disorder (ASD), however, encounter a unique set of challenges in dealing with the demands of daily functioning, and face perception is among them. There is now a large body of research that demonstrates differences in face perception in ASD, though the findings from much of this work remain highly contentious (for reviews, see Jemel, Mottron, & Dawson, 2006; Sasson, 2006; Weigelt, Koldewyn, & Kanwisher, 2012). Two leading theoretical accounts explain such differences. One account suggests that a higher-level general deficit in social cognition is at the origin of atypical face perception in ASD (Baron-Cohen & Belmonte, 2005; Baron-Cohen et al., 2000; Baron-Cohen et al., 1999; Dziobek, Bahnemann, Convit, & Heekeren, 2010; Pelphrey, Morris, & McCarthy, 2005; Schultz et al., 2000). Another account, however, proposes that these differences may relate to atypical visual perception, particularly to a unique preference or bias for detailed information in ASD (Behrmann, Thomas, & Humphreys, 2006; Davies, Bishop, Manstead, & Tantam, 1994; Mottron, Dawson, Soulieres, Hubert, & Burack, 2006). Although there is evidence to support both accounts, this paper will focus uniquely on those that support the perceptual account.

Support for the perceptual account stems largely from studies using nonsocial, visuo–spatial stimuli, demonstrating strengths in local (Mottron et al., 2006) and sometimes weaknesses in global (Happé & Frith, 2006) processing in ASD (discussed in Behrmann et al., 2006). These findings extend to differences in face perception, given that faces are typically processed with configural and/or holistic (i.e., global) strategies, in which the relationship between facial features and overall shape are integrated (Carey & Diamond, 1977; Farah, Wilson, Drain, & Tanaka, 1998). An established literature reports that typically developing (TD) individuals perform poorly when faces are experimentally inverted (Yin, 1969). Specifically, the rotation of a face from an upright to inverted orientation disrupts the "configural" or "global" processing of its facial features and overall shape. As such, TD individuals respond slower and perform more poorly when faces are inverted than when they are upright (Maurer, Le Grand, & Mondloch, 2002). Similarly, TD individuals have greater difficulty identifying the individual features of two faces when the top and bottom halves are aligned, rather than misaligned (Young, Hellawell, & Hay, 1987). The alignment of the top and bottom halves facilitates a global analysis of all features simultaneously, meaning that two face images containing identical top halves are perceived as different when their bottom halves belong to separate identities. The misalignment of the top and bottom halves, however, facilitates the parsing of individual features and the correct identification of identity (Rossion, 2013). Further, TD individuals are more accurate at identifying the features of an individual face when they are presented in the context of the entire face than when they are presented in isolation (Tanaka & Farah, 1993; Tanaka, Kay, Grinnell, Stansfield, & Szechter, 1998). The poorer performance across all of these manipulations is taken as evidence of the predominance of a global processing strategy in TD individuals.

Studies employing similar experimental designs in ASD, however, report alternate findings. Some report that children and adults with ASD are either unaffected or less affected by the disruption of global information, suggesting a preferential use of isolated features and thereby, a local strategy (Hobson, Ouston, & Lee, 1988; Langdell, 1978; Rose et al., 2007; van der Geest, Kemner, Verbaten, & Van Engeland, 2002). Conversely, others demonstrate typical face inversion effects (Falck-Ytter, 2008; Lahaie et al., 2006; Rutherford, Clements, & Sekuler, 2007), suggesting the use of a global strategy. Some even report typical face inversion effects coupled with overall poorer performances in children and adults with ASD compared to TD participants (Hedley, Brewer, & Young, 2015; Scherf, Behrmann, Minshew, & Luna, 2008). One possibility for these inconsistencies is the heterogeneity among the population of individuals with ASD. Participant groups across studies often encompass differing ages, sex distributions, intellectual abilities, and importantly, diagnostic labels. For example, many include small, unmatched samples of individuals with Asperger's syndrome, autistic disorder, and pervasive developmental disorder, not otherwise specified (according to the *Diagnostic and Statistical Manual of Mental Disorders IV*; American Psychiatric Association [APA], 2000). The recent consolidation of these diagnostic categories will limit inconsistencies in future research, but diagnostic heterogeneity plagues much of the existing literature, thereby limiting the interpretation and generalizability of findings across studies.

In addition to these findings, the perceptual account is further supported by studies investigating the use of different spatial frequency information for face processing. Spatial frequencies convey specific facial information: high spatial frequencies convey the features or local information of the face, while low spatial frequencies convey the global information (Costen, Parker, & Craw, 1996; Fiorentini, Maffei, & Sandini, 1983). A number of investigations have examined local and global processing using face stimuli subjected to spatial frequency filtering, specifically manipulating the spatial frequency content in a face image. Among these studies, some have reported that children and adolescents with ASD rely more on high than low spatial frequency information for face perception, suggesting a preference for details or features (i.e., local information; Deruelle, Rondan, Gepner, & Tardif, 2004; Deruelle, Rondan, Salle-Collemiche, Bastard-Rosset, & Da Fonséca, 2008; Kikuchi, Senju, Hasegawa, Tojo, & Osanai, 2013; Vlamings, Jonkman, van Daalen, van der Gaag, & Kemner, 2010). However, others have found a similar reliance on midspatial frequency information in individuals with and without ASD, suggesting that the critical spatial frequency content for face recognition is neither low nor high but somewhere within the midrange (Leonard, Annaz, Karmiloff-Smith, & Johnson, 2010; but see Leonard et al., 2013). This inconsistency in findings may relate to the consideration of age—the former studies did not consider the effects of age, whereas the latter studies did.

Although the research reviewed here indicates that perceptual differences may influence face perception in ASD, little is known about how this emerges throughout development. Few studies have explored the *development* of local and global face processing strategies in ASD. Behavioral and electrophysiological studies of face perception have shown that TD children transition from a local to global strategy as they mature into adults (Carey & Diamond, 1977; Itier & Taylor, 2004; Mondloch, Geldart, Maurer, & Le Grand, 2003; Mondloch, Le Grand, & Maurer, 2002; but see McKone, Crookes, Jeffery, & Dilks, 2012). Similar studies in ASD have, however, yielded mixed findings; some have indicated a similar transition as seen in TD individuals, whereas others have not (e.g., O'Hearn, Schroer, Minshew, & Luna, 2010; O'Hearn et al., 2014; Pallett, Cohen, & Dobkins, 2014).

In one study, Pallett et al. (2014) investigated the development of local and global face processing strategies using upright and inverted faces in adolescents with ASD. Participants with ASD showed a more robust face inversion effect with age, whereas TD participants did not. This finding suggested that global face processing developed more slowly, but was still present, in participants with ASD. In another study, however, O'Hearn and colleagues (2014) found a different developmental pattern of face processing abilities in children, adolescents, and adults with ASD. Specifically, they examined local and global face processing using immediate memory, whole-face and face part tasks of the *Let's Face It!* skills battery (Tanaka et al., 2010). Consistent with their previous findings (O'Hearn et al., 2010), the authors demonstrated a lack of improvement in face recognition from adolescence to adulthood in tasks using both whole faces and face parts as stimuli. These results indicated that while TD participants improved in their ability to process whole faces (i.e., global information) and face parts (i.e., local information) with age, participants with ASD did not. That is, participants with ASD showed a lack of typical improvement and adults with ASD demonstrated more generalized and severe impairments than children with ASD. Together, the findings across these studies suggest that individuals with ASD do not transition to a global strategy as quickly or effectively as TD individuals, and perhaps continue to use a local strategy throughout adulthood.

Although the studies described above provide a useful developmental perspective, the interpretation of their findings is limited by the grouping of participants into arbitrarily defined child, adolescent, and adult age bins. Using this approach, researchers can only identify developmental periods but not age-specific differences. The exploration of mean differences makes it difficult to interpret the variability within the data and whether some individuals with ASD show a typical improvement with age.

Relatively few developmental studies of face perception in ASD have taken an alternate approach, considering age as a continuum. Both cross-sectional and longitudinal developmental trajectories are therefore lacking in this specific field of study. In one of the few examples, Dimitriou, Leonard, Karmiloff-Smith, Johnson, and Thomas (2015) used cross-sectional, developmental trajectories to examine changes in face inversion effects in high-functioning children with ASD. These trajectories demonstrated that unlike the TD group, the ASD group did not reveal any face inversion effects with age. These authors argued that the absence of an increasing face inversion effect with age suggested a greater exploitation of featural processing in ASD (also see Annaz, Karmiloff-Smith, Johnson, & Thomas, 2009). Using a comparable approach, Leonard, Annaz, Karmiloff-Smith, and Johnson (2010) investigated the effects of spatial frequency information on face recognition in children with ASD. Their results revealed similar trajectories in both TD and ASD groups, showing a decrease in the use of local information, conveyed by high spatial frequencies, and a bias for more optimal, midspatial frequency information with age. In a follow-up study, however, Leonard and colleagues (2013) obtained different findings by constructing trajectories according to mental and not chronological age. Children with ASD, unlike TD children, showed no preference for high, mid, or low spatial frequencies, and therefore exhibited no clear reliance on local or global face information with age. Thus, as indicated by the variety of studies mentioned, the discrepancy in findings from both age bins and trajectories illustrates that there is no clear consensus in terms of the development of local and global face perception strategies in ASD.

Interestingly, one methodological strategy often overlooked in investigations of face perception is the manipulation of face views, including viewpoint change. In most studies, faces are presented from the same viewpoint, and participants can match the target and choice faces using any individual feature or set of features (Habak, Wilkinson, & Wilson, 2008). Using this approach, participants can discriminate facial identities based on any given attribute, such as the eyes, nose, or mouth. However, when faces are presented from different views, such as in profile, access to certain facial features is limited (e.g., one eye or part of nose), and the shape of a specific feature differs between front and side views. For example, from a front view, both sides of the nose and the outer nostrils are visible, whereas from a side view, only of the bridge and one nostril are apparent. As another example, an eye in a front view looks like the shape of a football, whereas an eye in a side view looks like open triangle with a rounded end. A truly global representation is needed to adequately link the changes in the shapes of these local features across views. In this case, discrimination requires the consideration of multiple features simultaneously and a global rather than local strategy (Mondloch et al., 2003). Given that an individual's face is constantly moving in day-to-day settings, and thereby varying in viewpoint, this type of approach is particularly useful to assess local and global strategies.

Findings from studies examining the effects of viewpoint change on face perception have demonstrated differences in performances between TD individuals and individuals with ASD. Gepner, Gelder, and Schonen (1996), for instance, found that children with ASD performed comparably to TD children in same-view conditions, but more poorly in view-change conditions. Similarly, Wolf et al. (2008) asked participants to match facial identities across a 45° change in viewpoint, and reported that children with ASD were significantly less accurate than TD children. In a more recent study from our group, Morin et al. (2015) presented target and choice faces in same-view (front, side, inverted) and view-change (front [target], side [choices]) conditions, and asked participants to discriminate between facial identities. Results indicated that adolescents and adults with ASD performed poorer than TD participants only in conditions of viewpoint change, consistent with the findings from previous studies. The selectivity of this difference led us to suggest that atypical face perception in ASD may stem from a perceptual rather than social origin.

The present study expanded upon the findings of Morin et al. (2015) with a novel focus on age-related changes, and the transition from childhood to adolescence. We examined the development of face perception in a large and clinically well-defined sample of children and adolescents with ASD. Specifically, we assessed face identity discrimination across viewpoint, manipulating access to local and global facial information. We included synthetic face images similar to those used by Morin and colleagues (Morin et al., 2015; Wilson, Loffler, & Wilkinson, 2002) but adapted the testing procedures for younger participants (see Method). These images were unique in that they allowed for the precise control of facial geometry and excluded extraneous, detailed information, such as wrinkles, shadows, and texture (Habak et al., 2008). Given the paucity and diversity of developmental findings in ASD, we constructed cross-sectional, developmental trajectories incorporating age on a continuum (Thomas et al., 2009). Based on the previous findings of Morin et al. (2015), we expected that children and adolescents with ASD would perform selectively worse than those without ASD only in conditions of viewpoint change in which access to local information was limited.

Method

Participants

Thirty-three participants with ASD and 35 TD participants were recruited for the study (see Table 1). The ASD group had a mean age of 12.2 years ($SD = 2.7$ years, range = 6–15) and the TD group had a mean age of 11.3 years ($SD = 2.5$, range = 6–15). Participants with ASD were recruited from the Rivière-des-Prairies hospital database. These individuals had a diagnosis of autistic disorder (APA, 2000), as established by the Autism Diagnostic Observation Scale (Lord et al., 2000) and/or the ASD Diagnostic Interview–Revised (Lord, Rutter, & Le Couteur, 1994), along with expert clinical opinion. The TD participants were recruited from the community and the same database as mentioned above. No participant had a history of brain injury or a coexisting neurological condition, as reported by parents.

The general intelligence of all participants was assessed using the Wechsler Intelligence Scale for Children (Wechsler, 2003) or the Wechsler Abbreviated Scale of Intelligence (Wechsler, 1999, 2011), in addition to the Raven's Standard Progressive Matrices (Raven, Raven, & Court, 1998). Both assessments were conducted to ensure that the intelligence of participants with ASD was not underestimated or misrepresented by the Wechsler scales, which rely heavily on verbal skills (Barbeau, Soulières, Dawson, Zeffiro, & Mottron, 2013; Dawson, Soulières, Gernsbacher, & Mottron, 2007). Participant groups were matched on sex, performance IQ, and scores on the Raven Standard

	TD (34 males, 1 female)			ASD (32 males, 1 female)			
	Mean	*SD*	Range	Mean	*SD*	Range	*p*
Age (years)	11.3	2.5	6–15	12.2	2.7	6–15	.14
Full–Scale IQ	107.5	13.9	88–151	96.5	12.4	76–119	<.01*
Performance IQ	110.9	14.8	85–156	108.0	9.4	85–124	.34
Verbal IQ	107.0	13.7	89–136	93.1	15.1	55–120	<.001**
RSPM (scores)	39.0	9.73	19–52	42.6	11.4	26–58	.17
RSPM (%ile)	70.9	18.0	40–99	70.9	27.1	9–99	.99

Table 1. Demographic Information for TD and ASD Groups, Including Age (years), Wechsler IQ, and Raven Standard Progressive Matrices Scores (raw score and percentile). *Notes*. RSPM = Raven Standard Progressive Matrices; %ile = percentile.

Progressive Matrices (raw and percentile scores). Independent t tests indicated that the scores from these assessments were not significantly different between groups ($p > 0.05$; see Table 1).

All participants were screened for visual acuity (the Runge Pocket Card with Lea Symbols and the Snellen letter chart for near and far vision, respectively) and had normal or corrected-to-normal vision. Written, informed consent was provided by the parents or legal guardians of participants. This study was approved by the Rivière-des-Prairies Hospital and McGill University research ethics committees, and conducted in accordance with tenets of the Declaration of Helsinki.

Apparatus and stimuli

The face images were presented using MATLAB, as well as custom routines and extensions from the Psychophysics and Video Toolbox (Brainard, 1997; Kleiner et al., 2007; Pelli, 1997) on a MacBook Pro laptop computer (Apple, Cupertino, CA). Stimuli were displayed on a 17-inch LCD monitor with a pixel resolution of 1600×1000 pixels and a mean luminance of 50.0 cd/m^2 ($x = 0.2783$, $y = 0.3210$ in CIE [Commission Internationale de l'Eclairage] u*, v* color space). A Minolta Chroma Meter CS-100 (Konica Minolta, Ramsey, NJ) was used for reading the color and brightness, and the monitor was gamma corrected. Participants viewed the face images binocularly from a distance of 57 centimeters. Face images were filtered at 10 cycles per face-width with a bandwidth of 2 octaves, which is optimal for face perception (Gold, Bennett, & Sekuler, 1999; Näsänen, 1999). The stimuli subtended 5° of visual angle in width, with a peak spatial frequency of 2 c/°, consistent with the spatial frequency content of faces seen in everyday, natural settings.

The synthetic face images of the present study were similar to those used by Wilson et al. (2002), Habak et al. (2008), and Morin et al. (2015). A detailed description of these stimuli is provided in Wilson et al. (2002). Briefly, 40 female and 40 male faces were photographed from front (0° rotation) and profile (20° rotation) views. The photographs were digitized and defined by 37 points of measure, outlining the structure of the head, hairline, and internal facial features (e.g., nose, mouth, eyes) These points were then averaged across all faces to create respective, "average" male and female faces from both front and side views. Next, the vector representing each individual face was normalized relative to the average face to create a face-space with separate identities. The geometric difference between an individual and the average face was then used to manipulate the strength of each individual identity (i.e., percent geometric change). That is, individual faces with a smaller change in facial geometry better resembled the average face (i.e., closer to the average face), whereas those with a larger change in facial geometry appeared as a more exaggerated version of their own identity (i.e., further from the average; see Figure 1). One clear advantage of these synthetic faces was that they were simplified in terms of facial attributes. The removal of featural aspects, such as skin texture, hair, and color, limited the influence of extraneous visual elements typically found in photographic images. Moreover, previous work has validated their ecological suitability (Loffler, Yourganov, Wilkinson, & Wilson, 2005; Wilson et al., 2002) and use in clinical populations (Lee, Duchaine, Wilson, & Nakayama, 2010).

Procedure

Participants were asked to complete a two-alternative forced choice (2AFC) match-to-sample, face identity discrimination task. This was administered in two conditions in which the type of available information was varied: a same-view (front–front) and view-change (front–side; hereafter referred to as "same-view" and "view-change," respectively) condition. The same-view condition included all facial features (i.e., local information), whereas the view-change condition did not. The limited access to facial features in the

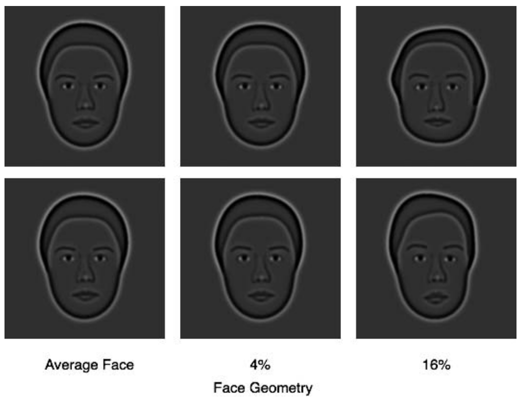

Figure 1. An example of synthetic face images manipulated from the average face. The images represent an average synthetic face (0%) and faces with 4% and 16% difference from the mean, which share the same identity but differ in distinctiveness. The top row represents one identity, while the bottom row represents another, separate identity.

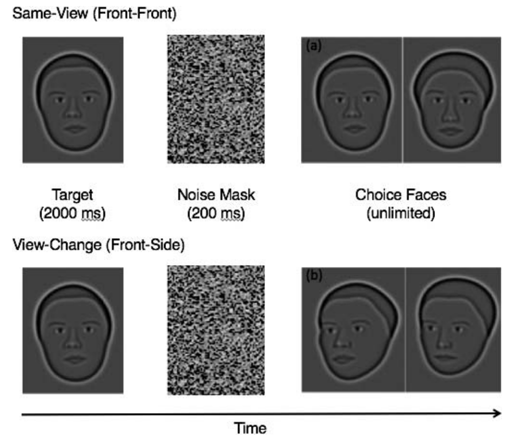

Figure 2. Example of a trial in the same-view (front–front; top) and view-change (front–side; bottom) conditions. In the same-view condition, both the target and choice faces were presented from the front. In the view-change condition, the target was presented from the front and the choice faces from a 20° side view.

view-change condition therefore required participants to preferentially use a global visual strategy. Previous work has demonstrated that the view-change condition is inherently more difficult than the same-view condition for both TD and ASD groups (Morin et al., 2015). For this reason, participants performed the same-view condition first to maintain their motivation throughout the session.

Each session began with a familiarization and practice phase consisting of 20 trials. Participants completed a second practice if they failed to obtain a threshold after their first attempt. Following the practice, participants completed the testing phase. The examiner initiated each trial, which began with the presentation of a target face for 2000 milliseconds (ms). Next, a noise mask was presented for 200 ms (i.e., random visual noise) and followed by two choice faces shown side-by-side (see Figure 2). The choices contained one identity that was an exact match to the target (i.e., facial geometry and identity), and another identity that was different but had the same level of facial geometry. An example trial could therefore include a target face A at 8% facial geometry and choice faces A (i.e., correct response) and B (i.e., incorrect response), both at 8% facial geometry.

In the same-view condition, both the target and choice faces appeared from the front (0° rotation). Conversely, in the view-change condition, the target appeared from the front and the choices from the side (20° side, profile view). This meant that side or profile views were included only in the view-change but not same-view condition. A 20° side view was chosen so that facial features were partially but not fully occluded. Participants were instructed to point to the choice face that matched the target in terms of identity and the experimenter recorded their response. The choice faces remained on the screen until a response was made. The testing phase took approximately 30 min to complete (i.e., 15 min per condition). Within the same-view condition, 20 faces were randomly presented at five different levels of facial geometry. Similarly, within the view-change condition, 20 faces were presented at six different levels of facial geometry. Thus, a total of 100 trials were presented in the same-view condition and 120 trials in the view-change condition. It is important to note that the practice and testing phases in both the same-view and view-change conditions incorporated different facial identities to limit the effects of learning or familiarity.

Performance measures included face identity discrimination thresholds, which were defined as the minimum percent change in facial geometry needed to correctly identify the target face 75% of the time. This was done using a method of constant stimuli. The threshold values for the data were calculated by fitting a Quick (Quick, 1974) or Weibull (Weibull, 1951) function, using a maximum likelihood estimation. Higher thresholds meant that participants required a greater percent change in facial geometry to correctly identify the target face. The use of a threshold measure represents a clear strength over many previous developmental investigations that have relied on accuracy. This is because accuracy measures often lead to ceiling and floor effects across large ranges, thereby limiting the potential to detect developmental differences (for a discussion, see McKone et al., 2012).

Our study was comparable to Morin et al.'s (2015) but differed in three important ways. First, we used two instead of four face viewing conditions to shorten the duration of the task; that is, same-view (front–front)

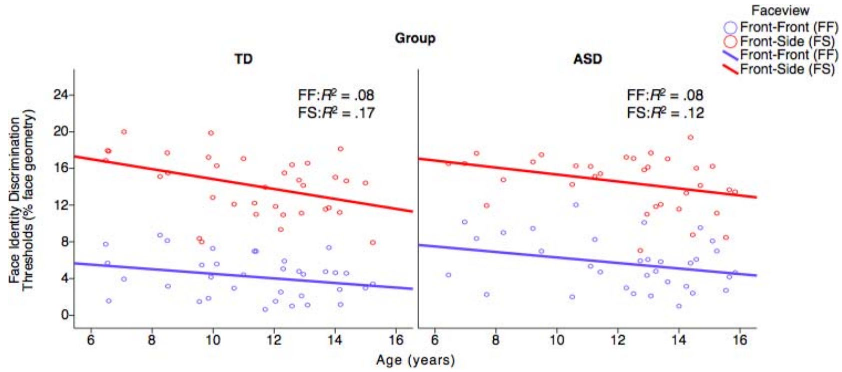

Figure 3. Face identity discrimination thresholds as a function of age for the same-view (front–front) and view-change (front–side) conditions. The left panel depicts the performance of the TD group and the right panel the performance of the ASD group. Circles show individual task performance (blue = same-view (front–front); red = view-change (front–side). Blue and red lines represent the regression lines, or trajectories, for the front–front and front–side conditions, respectively. R^2 indicates the strength of the linear relationships (proportion of variance explained by each trajectory).

and view-change (front–side). Second, we used a wider range of facial geometry to make the differences between facial identities more distinct. Third, we increased the presentation time of the target face from 1000 ms to 2000 ms. These adaptations followed piloting procedures to ensure that the youngest participants could successfully complete the task.

At this point, it is important to mention terminology. The existing face literature is riddled with inconsistencies in the use of the terms local and global. The term "local" is often used interchangeably with the terms "piecemeal" and "featural." Similarly, the term "global" is often used interchangeably with the terms "holistic" and "configural." Maurer and colleagues (2002) attempted to clarify these definitions in suggesting that the term configural could refer to the processing of first-order relations, the basic configuration of faces (i.e., two eyes situated above a nose, which are both, located above a mouth), or second-order relations (i.e., the spacing among individual features). They further suggested that the term holistic could refer to the integration of individual facial features into a gestalt. Despite these distinctions, the exact nature of global processing is not completely resolved (McKone et al., 2012). In the interest of this paper, however, local and global may be understood as the processing of individual features and integration of information across the whole face, respectively.

Statistical analyses

We constructed cross-sectional, developmental trajectories to understand how face perception changed with age. This approach allowed us to compare performances specifically in terms of the youngest participants (intercept) and the rate of development (slope). One advantage of this approach was that it considered age as a continuum, which, unlike most other studies, accounted for the influence of development. Using these trajectories, we conducted our analyses in two steps. First, to examine performances within each group, we conducted individual repeated measures analyses of covariance (ANCOVA), with face-view condition as a within-subjects factor (same-view [front–front], view-change [front–side]) and age as a covariate. Second, to compare performances between groups, we conducted a mixed-design ANCOVA, with group as a between-subjects factor, face-view condition as a within-subjects factor, and age as a covariate. We scaled age in years from the youngest participants (i.e., 6 years), which meant that we interpreted the intercept at 6 instead of 0 years. We did so to directly examine trajectories from their onset and in terms of their rate of development between the ages of 6 to 15 years.

Results

To rule out the possibility that differences in task performance were related to cognitive abilities, we examined the relationship between face-identity discrimination thresholds and Wechsler intelligence scores (i.e., FSIQ, VCI, PRI). Pearson bivariate correlations between threshold measures and standard scores obtained on the Wechsler scales revealed no significant correlations in either the TD or ASD groups, all $p > 0.05$. These results suggested that there was no significant influence of intelligence on task performance and consequently, we did not include IQ as an additional covariate in our analyses (Supplementary Table 1).

Age-related changes in face-identity discrimination within groups

Figure 3 illustrates the linear trajectories of face-identity discrimination thresholds and age for the respective same-view and view-change conditions within each group. Higher thresholds indicate that a greater difference in facial geometry was needed to identify the target face and thereby, reflect of a poorer performance. The negative, linear relationships for both same-view and view-change conditions demonstrate that face identity discrimination thresholds decreased with age, and thus improved in both groups.

The rates of developmental change in performance were compared across conditions using individual repeated measures ANCOVAs for each group, with face-view condition (front–front [same-view], front–side [view-change]) as a within-subjects factor and age as a covariate. These analyses revealed significantly higher face identity discrimination thresholds in the front–side than front–front condition in both the TD group (main effect of face-view condition[1]), $F(1, 34) = 218.98$, $p < 0.0001$, $\eta_p^2 = 0.87$, and the ASD group, $F(1, 32) = 219.00$, $p < 0.0001$, $\eta_p^2 = 0.87$. Overall, face identity discrimination thresholds also decreased with age in both groups, (main effect of age), TD: $F(1, 33) = 10.62$, $p = 0.003$, $\eta_p^2 = 0.24$; ASD: $F(1, 31) = 5.62$, $p = 0.024$, $\eta_p^2 = 0.15$. There was no significant interaction between face-view condition and age in either the TD, $F(1, 33) = 1.15$, $p = 0.290$, $\eta_p^2 = 0.03$, or ASD group, $F(1, 31) = 0.12$, $p = 0.727$, $\eta_p^2 = 0.004$, demonstrating similar rates of development across front–front (i.e., local; same-view) and front–side (i.e., global; view-change) conditions within each group.

Age-related changes in face-identity discrimination between groups

Comparisons of trajectories revealed that performance in both groups developed similarly across conditions $F(1, 64) = 0.36$, $p = 0.553$, $\eta_p^2 = 0.006$, (Face-View Condition × Age × Group); $F(1, 64) = 1.10$, $p = 0.298$, $\eta_p^2 = 0.017$ (Face-View Condition × Age); $F(1, 64) = 0.09$, $p = 0.770$, $\eta_p^2 = 0.001$ (Group × Age; Figures 4a and b). Moreover, there was no significant interaction between face-view condition and group, indicating that both groups had similar thresholds for the front–front and front–side conditions at 6 years, $F(1, 64) = 0.91$, $p = 0.344$, $\eta_p^2 = 0.014$ (Face-View Condition × Group). Face-identity discrimination thresholds did not differ significantly by group (main effect of group), $F(1, 64) = 0.59$, $p = 0.444$, $\eta_p^2 = 0.009$, but differed by condition and were higher in the front–side than the front–front condition

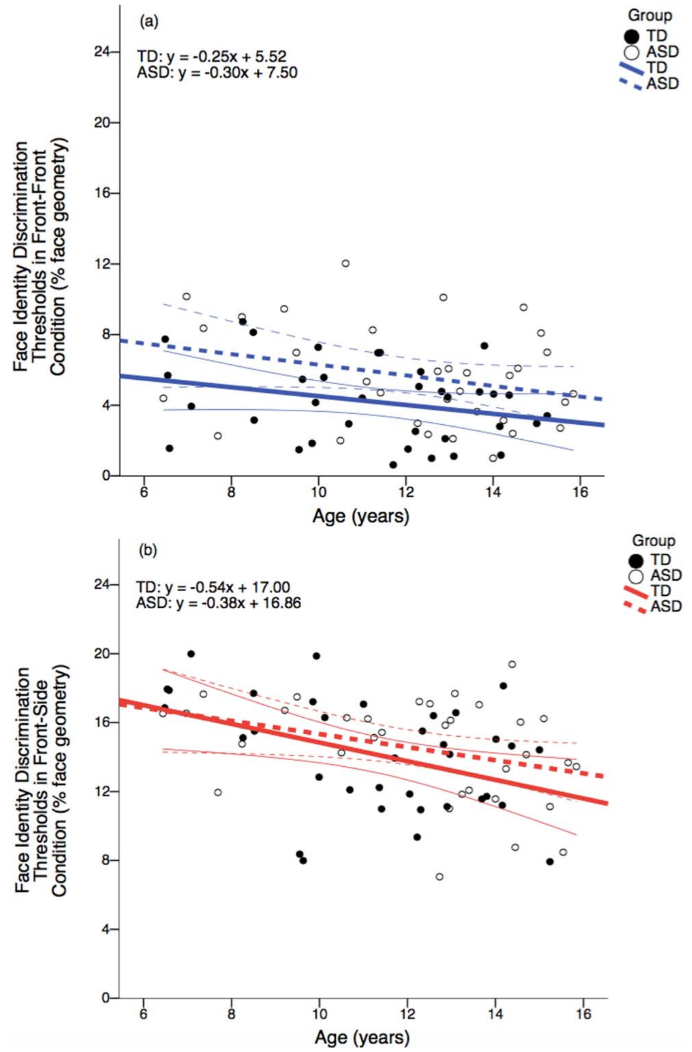

Figure 4. Developmental trajectories of the TD and ASD groups in the (a) same-view (front–front) and (b) view-change (front–side) conditions. Circles represent the individual face identity threshold values (closed = TD group; open = ASD group). Bold and dotted lines show the developmental trajectories of the TD and ASD groups, respectively. Thin lines show ±95% confidence intervals.

at 6 years, $F(1, 64) = 87.54$, $p < 0.0001$, $\eta_p^2 = 0.58$ (main effect of face-view condition). Additionally, thresholds decreased with age, and performance improved from 6 to 15 years, $F(1, 64) = 15.27$, $p < 0.0001$, $\eta_p^2 = 0.19$ (main effect of age). Though these results confirmed that trajectories were similar between the TD and ASD groups, visual inspection revealed a slight divergence of thresholds in the front–side condition (see Figure 4b), particularly in the oldest participants. Thresholds in the ASD group appeared to be slightly higher than those in the TD group. This trend raises an interesting possibility that performances may differ later in development.

Discussion

The face perception literature indicates that the development of local and global processes may contribute to differences in performances between individuals with and without ASD. To our knowledge, no published study has addressed the question of whether face perception develops atypically across viewpoint in children and adolescents with ASD. This is important because the use of arbitrary age bins, uncontrolled face stimuli, and heterogeneous participant groups confound many existing developmental comparisons. The aim of this study was therefore to assess the development of face identity discrimination across viewpoint (same-view and view-change), specifically manipulating access to facial features (i.e., local information). We constructed cross-sectional, developmental trajectories to characterize age-related changes in face identity discrimination thresholds and compared performances within and between participant groups with and without ASD. These comparisons yielded two important findings. First, comparisons *within* each group revealed that performance improved similarly across face-view conditions, though participants from both groups obtained higher thresholds in the view-change condition. Second, and contrary to our predictions, comparisons *between* groups demonstrated that the participants with and without ASD improved similarly with age in both face-view conditions. Participants with ASD did not show a poorer performance relative to the TD participants in the view-change condition. However, an interesting trend emerged in the oldest participants whereby trajectories began to diverge slightly between groups. The trajectory for the ASD group remained relatively flat, while the trajectory for the TD group continued to decrease. The current findings indicate that although there are no developmental differences between children and adolescents with and without ASD, trajectories for face perception across views—wherein access to local information is limited—may begin to diverge in late adolescence.

Unsurprisingly, both groups performed most poorly in the view-change, front–side condition, consistent with our previous report in older adolescents and adults (Morin et al., 2015). Comparable studies in typical adults (i.e., 20 to 30 years) have also found that thresholds for matching face identity across a 20° change in view were approximately 1.5 times higher than those for same-view matching (Habak et al., 2008; Lee, Matsumiya, & Wilson, 2006; Wilson et al., 2002). A possible explanation for these findings may relate to the availability of local information: the same-view, front–front condition included all local information, while the view-change, front–side condition, did not. This therefore meant that participants could perform the same-view condition using any individual facial feature. However, the view-change condition, by its very nature, required participants to perform a complex integration of visual information to match the identity across views. This is consistent with the notion that matching identity across views follows a more protracted development than other abilities of face perception, such as identity matching across gaze and facial expression (Mondloch et al., 2003). Although other factors, such as mental rotation or memory, could have played a role in the effects reported here, this is unlikely for several reasons. First, face matching across views is independent of mental rotation, as suggested by electrophysiological (Perrett, Oram, & Ashbridge, 1998) and brain-imaging (Grill-Spector & Malach, 2001) evidence for cell populations tuned to different face views. Second, if matching faces across views relies on mental rotation, then performances would decrease substantively for very brief exposure durations. However, a study by Habak et al. (2008) confirmed that this was not the case. In their study, typical adults did not show any decrement in matching faces across views when the presentation time of the target was reduced from 200 to 110 ms. In light of this evidence, our findings are more likely to suggest that both TD and ASD groups have greater difficulty identifying faces when access to local information is limited than when all information is available.

When we compared performances between groups, we found no differences in the same-view and view-change conditions. To our surprise and contrary to predictions, participants with ASD performed similarly to TD participants, particularly in the view-change condition (front–side). This finding contrasts those previously reported by Morin et al. (2015), who found that older adolescents and adults with ASD performed similarly to typical comparisons in the same-view conditions (i.e., front–front, side–side, inverted–inverted), but significantly worse in the view-change condition (i.e., front–side). These findings indicated that older adolescents and adults with ASD encounter greater difficulty identifying faces only when local information is limited and a global analysis is optimal.

Our findings taken together with those of Morin et al. (2015) suggest the possibility of a trend whereby global perception may develop at a slower rate in individuals with ASD, resulting in group differences in the front–side condition only in adulthood. Although performances in the view-change condition were comparable for the youngest participants in our study, performance appeared to diverge somewhat with age; thresholds in the ASD group decreased at relatively lesser rate than those in the TD group. Further, when the performances of the ASD groups were compared across studies, similar threshold values were found across adolescents and adults. The adolescent participants with ASD (i.e., 14–15 years) in the present study required approximately a 14% mean change in face geometry to discriminate between identities, consistent with the means reported in Morin et al. (2015) for participants with a mean age of 20 years. Conversely, the TD participants appeared to improve across studies, with threshold values decreasing from approximately 13% in early adolescence to 11% in adulthood. The similarity of thresholds in participants with ASD possibly suggests that face perception may reach a developmental plateau in conditions of global, view-change. Alternatively, the decrease in thresholds in TD participants perhaps suggests that they may continue to develop a bias for global information, and consequently improve in tasks measuring global processing (Scherf, Behrmann, Kimchi, & Luna, 2009). Thus, one can speculate that, based on the comparison across studies and the trend in the present study, greater group differences might emerge as global processing matures over time in TD individuals. Although promising, this suggestion warrants caution, as the trend reported here was nonsignificant. A single developmental study including children, adolescents, and adults is needed to clarify whether a true deviation between TD and ASD groups emerges in adolescence and manifests in adulthood. Yet, if true, this would be consistent with other findings reported across visual *and* auditory modalities. For example, Stevenson and colleagues (2014) showed that there was a similar improvement in feature integration (i.e., global processing) in audio–visual speech signals throughout adolescence in their TD group but not their ASD group.

An alternative interpretation for the discrepant findings in the view-change condition may relate to the use of visual strategies. It is possible that individuals with ASD use and hone an alternate, feature-based strategy through years of practice. This strategy may be more flexible or underdeveloped in childhood and only impact performance once it is established in adulthood. Studies examining face perception with eye-tracking methods have found that children and adults with ASD use atypical local and global strategies (e.g., Albrecht et al., 2014; Falkmer, Larsson, Bjällmark, & Falkmer, 2010). Specifically, compared to TD children, some studies have shown that children with ASD fixate more on individual features, such as the eyes and mouths, but show no differences in recognition accuracy (Albrecht et al., 2014). In contrast, others have demonstrated that adults with ASD fixate more on irrelevant facial features than eyes and perform poorer than neurotypical adults (Falkmer et al., 2010). These findings may be evidence that individuals with ASD continue to use a local strategy from childhood through to adulthood and as a result, perform poorer than TD individuals in tasks that limit access to local information. In light of such evidence, we are currently examining how viewing strategies differ in children, adolescents, and adults with and without ASD using eye-tracking methods.

Discrepancies between the previous and present findings may also be due to key methodological differences, as described earlier. Yet, this seems unlikely as these adaptations were implemented specifically to reduce the attentional demands of the task and capture the wider range of performances in younger participants. For instance, the target face was presented for a much longer duration in the present study to ensure that the younger participants had a sufficient amount of time to scan and encode the identity. As mentioned above, a study exploring the effects of exposure time in viewpoint change has confirmed that abilities of facial identity discrimination remain relatively stable across exposure durations in young, typical adults (Habak et al., 2008). It would therefore seem unlikely that a difference in presentation times would explain the discrepancies between studies.

Instead, the lack of consistency between our child and adult findings indicates that age is an important consideration for understanding the face perception literature in ASD. The trend for diverging trajectories between groups in the view-change condition, specifically in the oldest participants tested, adds to a growing literature identifying adolescence as an important developmental stage for visual perception in ASD. Both theoretical proposals and experimental findings are advancing this view. Picci and Scherf (2014) recently proposed a "two-hit" model of ASD in which they argue that the transition from adolescence to adulthood exacerbates difficulties in ASD. This model is supported by developmental studies of face perception in ASD that have demonstrated a lack of typical, age-related improvements throughout adolescence and significant differences in adulthood (O'Hearn et al., 2010; O'Hearn et al., 2014). As an example, a study by O'Hearn and colleagues (2010) revealed that performances in the Cambridge Face Memory Test (Duchaine & Nakayama, 2006) improved from adolescence to adulthood in TD individuals, but not in individuals with ASD. Consistent with this idea, recent evidence has also indicated that differences in face and object recognition become more robust in adults with ASD, suggesting that difficulties in visual object processing become more general over time (O'Hearn et al., 2014). Investigations of visual processes other than face perception, such as individuation and element grouping (O'Hearn, Franconeri, Wright, Minshew, & Luna, 2013), multiple-object tracking (O'Hearn, Lakusta, Schroer, Minshew, & Luna, 2011), and emotion recognition (Rump, Giovannelli, Minshew, & Strauss, 2009), have further corroborated these findings by showing no improvement from adolescence to adulthood in ASD, and greater differences between adults with and without ASD. Taken together, these findings along with ours, suggest that important changes in visual perception may occur in adolescents with ASD. A developmental approach, focused uniquely on the transition from adolescence to adulthood, is critical to understand how differences in local and global processing emerge and impact face and object perception in ASD. Moreover, a longitudinal design is needed to identify exactly when such changes develop over time.

Limitations

There are two important limitations to our study that should be noted. First, participants completed a delayed-matched to sample paradigm that included the presentation of two sequential frames: one including the target and the other including the choices. Therefore, participants had to momentarily maintain the target in memory. Though commonly used, this type of procedure has recently been called into question in a critical review of face perception in ASD. Weigelt et al. (2012) determined that individuals with ASD appear to show more deficits in tasks with a delay in presentation between the target and choice faces. In light of this evidence, there is a possibility that our task may have been too difficult for some participants with ASD. A simultaneous presentation of target and choice faces could overcome this issue by eliminating any delay or small memory demand. We are currently investigating this possibility using an adaptation of our task that includes a simultaneous presentation of target and choice faces.

Second, we cannot completely rule out that the negative findings may be attributable to our limited sample size. Although we conducted an a priori power analysis, there is a possibility that there would have been a difference between groups with a larger sample size. However, more traditional analyses, using a 2×2 mixed ANOVA with Group as a between-subjects factor and Face-view condition as a within-subject factor confirmed the results obtained in the present study: no statistically significant group differences. We are therefore confident that the use of a covariate and trajectory analysis did not prevent us from drawing the same conclusions as more traditional analyses. Certainly, the selective recruitment of participants with autistic disorder (APA, 2000) reduced the number of participants included in the study. Further cross-sectional and longitudinal investigations are obviously warranted to trace truer developmental trajectories and draw firmer conclusions with respect to face identity discrimination in ASD.

Conclusions

This work, taken together with that of Morin et al. (2015), emphasizes that a greater body of developmental research is needed to advance our understanding of face perception in ASD. Our findings that children and adolescents with ASD identify faces similarly to TD peers in both same-view and view-change conditions is indicative that there is no general deficit in face perception in ASD, consistent with the findings of critical review (Weigelt et al., 2012). Still, the observation of a trend in the view-change condition raises the interesting possibility that adolescence is an important period of developmental transition in ASD. These findings underscore the importance for future research in local and global visual perception in ASD, particularly during the vulnerable yet understudied period of adolescence.

Keywords: autism spectrum disorder, face perception, development, local-global processing, viewpoint

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Commercial relationships: none.
Corresponding author: Jacalyn Guy.
Email: jacalyn.guy@gmail.com.
Address: Perceptual Neuroscience Lab for Autism Spectrum Disorder and Development, McGill University, Montréal, Quebec, Canada.

Footnote

[1] The within-subjects effects (face-view condition) are reported independently from the analyses including the covariate, as described by Thomas et al. (2009) and in previous studies (Annaz et al., 2009; Leonard et al., 2010; Leonard et al., 2013).

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