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Face processing in autism: Reduced integration of cross-feature dynamics

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Highlights

- Individuals with and without autism completed a dynamic face processing task
- Asynchronous mouth movements typically induce illusory slowing of eye transitions
- Individuals with autism show no susceptibility to this illusion
- Poor integration of feature dynamics may hamper social interaction in autism

Abstract

Characteristic problems with social interaction have prompted considerable interest in the face processing of individuals with Autism Spectrum Disorder (ASD). Studies suggest that reduced integration of information from disparate facial regions likely contributes to difficulties recognizing static faces in this population. Recent work also indicates that observers with ASD have problems using patterns of facial motion to judge identity and gender, and may be less able to derive global motion percepts. These findings raise the possibility that feature integration deficits also impact the perception of moving faces. To test this hypothesis, we examined whether observers with ASD exhibit susceptibility to a new dynamic face illusion, thought to index integration of moving facial features. When typical observers view eye-opening and -closing in the presence of asynchronous mouth-opening and -closing, the concurrent mouth movements induce a strong illusory slowing of the eye transitions. However, we find that observers with ASD are not susceptible to this illusion, suggestive of weaker integration of cross-feature dynamics. Nevertheless, observers with ASD and typical controls were equally able to detect the physical differences between comparison eye transitions. Importantly, this confirms that observers with ASD were able to fixate the eye-region, indicating that the striking group difference has a perceptual, not attentional origin. The clarity of the present results contrasts starkly with the modest effect sizes and equivocal findings seen throughout the literature on static face perception in ASD. We speculate that differences in the perception of facial motion may be a more reliable feature of this condition.

Key words: face perception, facial motion, cross-feature integration, dynamic elements, autism spectrum disorder

1. Introduction

Autism Spectrum Disorder (ASD) is a neurodevelopmental condition characterized by social-communicative atypicalities, and a restrictive and rigid repertoire of behaviors (American Psychiatric Association, 2013). Characteristic problems with social interaction have prompted considerable interest in the face processing of individuals with ASD. Where observed, deficits of face perception may hamper social interaction, contributing to the emergence of wider socio-cognitive features of ASD (Klin, Schultz, & Jones, 2015; Schultz, 2005). Although the literature is somewhat mixed, many studies have found evidence of atypical processing of facial identity or expression in this population (Harms, Martin, & Wallace, 2010; Jemel, Mottron, & Dawson, 2006; Morin et al., 2015; Weigelt, Koldewyn, & Kanwisher, 2012). Most recently, it has been reported that observers with ASD are less able to recognize faces from their characteristic patterns of motion (O'Brien, Spencer, Girges, Johnston, & Hill, 2014). Previous work suggests that a failure to integrate information from different facial regions may contribute to *static* face recognition difficulties experienced by observers with ASD (Behrmann, Thomas, & Humphreys, 2006; Gauthier, Klaiman, & Schultz, 2009; Teunisse & de Gelder, 2003). The present study is, to our knowledge, the first to examine whether reduced integration of information from *dynamic* features underlies the poor recognition and interpretation of facial motion in this population.

1.1 Feature integration – static faces

When presented upright, the individual features of static faces are thought to be integrated into coherent representations of the whole for interpretation and analysis. Within a laboratory context, feature-integration has been studied using the composite face paradigm. When upper and lower regions from different faces are aligned to form a facial composite, observers exhibit a tendency to 'fuse' the two halves together. The resulting illusory interference hinders performance when participants are asked to judge the identity (Young, Hellawell, & Hay, 1987), expression (Calder, Young, Keane, & Dean, 2000) or attractiveness (Abbas & Duchaine, 2008) of one face half, while disregarding the other. The composite-face effect reveals a tendency to integrate feature information from disparate regions of upright static faces – possibly mediated by the fusiform gyrus (Schiltz, Dricot, Goebel, & Rossion, 2010) – consistent with theories of holistic face processing (Maurer, Le Grand, & Mondloch, 2002; Young et al., 1987).

Sensitivity to orientation inversion is widely regarded as a hallmark of holistic representation, i.e., the feature integration processes recruited by static faces (Maurer et al., 2002; Tanaka & Farah, 1993). For example, composite interference is greatly reduced when stimulus arrangements are shown upside-down (Abbas & Duchaine, 2008; Calder et al., 2000; Susilo, Rezlescu, & Duchaine, 2013; Young et al., 1987). Disrupted holistic processing forms the rationale for a popular account of the well-known face inversion effect, whereby the recognition of faces is disproportionately impaired by orientation inversion compared to other objects (Yin, 1969). Whereas the perception of upright faces may benefit from the efficient, accurate analysis afforded by holistic representation, inverted faces may be subject to a slower, effortful, piecemeal analysis (e.g., Maurer et al., 2002; Piepers & Robbins, 2013).

Diminished integration of static features may contribute to difficulties recognizing faces from photographic images experienced by some individuals with ASD (Simmons et al., 2009; Weigelt et al., 2012). Observers with ASD often focus on local features and may therefore experience problems forming integrated global representations (Behrmann et al., 2006; Happe & Frith, 2006). Moreover, it has been argued that extensive visual experience of a stimulus class is necessary to acquire holistic representation (Diamond & Carey, 1986; Richler, Mack, Palmeri, & Gauthier, 2011). Should individuals with ASD attend less to social stimuli (Chevallier, Kohls, Troiani, Brodkin, & Schultz, 2012; Riby & Hancock, 2008; Swettenham et al., 1998), members of this population may exhibit problems acquiring holistic face representation. Although findings have been mixed (Nishimura, Rutherford, & Maurer, 2008; Watson, 2013), some observers with ASD do appear to show reduced susceptibility to the composite-face illusion (Gauthier et al., 2009; Teunisse & de Gelder, 2003), indicative of weaker integration of static facial features.

1.2 Feature integration – dynamic faces

While the overwhelming majority of face perception research conducted to date has addressed the perception of static faces, the faces we typically encounter outside of the lab are *moving*. It is therefore essential that we develop our understanding of dynamic face perception, both in typically and atypically developing populations (O'Toole, Roark, & Abdi, 2002). Motion cues are thought to play a valuable role in face recognition. For example, when avatar faces are animated using facial motion captured from human actors, observers can recognize the identity and gender of the actor from their ‘motion signature’ (Cook, Johnston, & Heyes, 2012; Hill & Johnston, 2001; Knappmeyer, Thornton, & Bulthoff, 2003).

Motion cues may be particularly valuable when we encounter faces under impoverished viewing conditions, such as those created by negation (Knight & Johnston, 1997), or pixilation and blurring (Lander, Bruce, & Hill, 2001) and have been shown to aid face recognition in individuals who exhibit poor face perception (Bennetts, Butcher, Lander, Udale, & Bate, 2015; Longmore & Tree, 2013). Moreover, responding appropriately during social interactions, often challenging for individuals with ASD, depends on the accurate perception of correlated feature changes over time (Jack, Garrod, & Schyns, 2014).

The ability of typical observers to recognize identity and gender from facial motion cues is sensitive to orientation (Cook et al., 2012; Hill & Johnston, 2001; O'Brien et al., 2014), a finding that suggests that moving faces also recruit feature integration processes (see also, Favelle, Tobin, Piepers, Burke, & Robbins, 2015). Recently, this possibility was confirmed by a novel dynamic face illusion reported by Cook and colleagues (Cook, Aichelburg, & Johnston, 2015). Adopting a similar logic to the composite face paradigm, observers were asked to judge the speed of eye-opening and -closing, whilst ignoring asynchronous mouth-opening and -closing. The presence of the concurrent mouth movements altered how observers perceived the eye-opening and -closing. The motion of the eyelids was subject to illusory slowing; transitions (from eyes-open to eyes-closed and *vice versa*) with a physical duration of 140 ms, were judged to take ~180ms. Interestingly, illusory feature slowing was observed only when stimulus arrangements were shown upright, suggesting that dynamic and static feature-integration processes behave in similar ways. Feature slowing may reflect the adjustment of feature dynamics, whereby transitions are delayed to match the preferred phase of internal models of global facial change (Cook et al., 2015).

Recent findings suggest that observers with ASD not only have difficulties processing static faces, but are also less able to recognize gender and identity from facial motion cues (O'Brien et al., 2014). Moreover, unlike typical observers, the observers with ASD derived little benefit from upright stimulus presentation. In addition, there has been speculation that observers with ASD have problems integrating motion cues presented across an array into coherent percepts of global motion (Atkinson, 2009; Pellicano, Gibson, Maybery, Durkin, & Badcock, 2005; Simmons et al., 2009). In light of difficulties recognizing motion signatures, and reports of higher global motion thresholds, the present study sought to test the hypothesis that the diminished feature integration seen in ASD may extend to dynamic faces. We therefore examined the susceptibility of adults with ASD and matched neurotypical controls to the feature slowing illusion, thought to depend on dynamic feature integration over time (Cook et al., 2015).

2. Method

2.1 Participants and Diagnostic Procedures

Thirty-two right-handed adults with (*n* = 16) and without (*n* = 16) ASD participated in the Experiment. All participants had normal or corrected-to-normal vision. All had received a diagnosis of ASD from a clinical practitioner in the United Kingdom. All participants also met the criteria for autism or ASD on the Autism Diagnostic Observation Schedule – Generic (ADOS-G; Lord et al., 2000). All participants completed a measure of autistic traits, the Autism-Spectrum Quotient (AQ: Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001), on which the ASD group scored significantly higher than the control group (Table 1). Sample size was determined a priori based on power analysis assuming a large effect size (Cohen, 1988). Ethical clearance was granted by the local ethics committee and the study was conducted in line with the ethical guidelines laid down in the 6th (2008) Declaration of Helsinki. All participants gave informed consent.

Table-1

2.2 Stimuli and materials

Stimulus frames (see Figure 1a) were created by posing the eyes and mouth of an avatar face in Poser 7 (e frontier America, Inc.). Frames were saved as bitmaps and compiled into uncompressed audio-visual interleave (.avi) files using Matlab (The MathWorks, Inc.). Each movie comprised 40 frames saved and presented at 50 frames per second (fps). Irrespective of transition duration, one stimulus cycle always lasted .80 secs. During the experiment, stimuli completed 8 cycles and were therefore visible for 6.4 secs. Each avatar stimulus subtended 8° vertically when viewed at 60 cm. Experimental programs were written in Matlab with Psychtoolbox (Brainard, 1997; Pelli, 1997) and presented on a high-speed Samsung SyncMaster 2233RZ LCD monitor (refresh rate of 120 Hz).

2.3 Procedure

On each trial, participants viewed two avatar faces side-by-side (Figure 1b), a standard and a comparison. Both faces opened and closed their *eyes* periodically at 1.25 Hz. Participants were told that the mouth movements were task-irrelevant and simply asked to report whether the eye transitions were faster for the standard or comparison. Responses were recorded using a keypad. Participants were free to fixate each face in turn. Concurrent *mouth*-opening and -closing movements were presented on the standard, also at 1.25 Hz. The eye transitions, open-to-closed and *vice versa*, exhibited by the standard stimulus always lasted 140 ms. The mouth on the comparison stimulus remained closed throughout. Comparison eye transitions varied in duration from 20 ms (rapid transition) to 260 ms (slow transition) in steps of 40 ms (see Figure 1c). Orientation was manipulated by presenting the standard upright or inverted; the comparison stimulus was always presented upright. Whether the standard appeared on the right or left was counter-balanced. Trial type was interleaved within mini-blocks of 70 trials. Participants always completed 280 trials (7 comparison durations × 2 orientations × 20 presentations). The procedure was completed in a dimly lit and sound-proofed room.

Figure-1

3. Results

Separate psychometric functions (each modelling the probability the comparison eye-transition was judged slower than the standard eye-transition as a function of the comparison duration; Table 2) were estimated for the upright and inverted conditions by fitting cumulative Gaussian functions in Matlab using the Palamedes toolbox (Prins & Kingdom, 2009). The perceived duration of the standard eye transition was inferred from the point of subjective equality (PSE) on each psychometric function; an estimate of the comparison transition duration necessary for the comparison and standard to be judged equivalent. In addition to the transition durations, we also estimated participants' sensitivity to the physical differences between the different levels of eye transition, inferred from the slope of the psychometric function (Figure 2). Sensitivity estimates represent the standard deviation of the symmetric Gaussian distribution underlying the modelled cumulative Gaussian function, subjected to a log transform to attenuate positive skewing. The mean transition durations and sensitivities estimated for the ASD and control group are shown in Table 3.

Table-2 / Table-3

3.1 Perceived transition duration

The data were analyzed using ANOVA with Orientation (upright, inverted) as a within-subjects factor and Group (control, ASD) as a between-subjects factor. The analysis revealed a significant main effect of Orientation [$F(1,30) = 6.957$, $p = .013$, $\eta_p^2 = 0.19$] and crucially, a Group × Orientation interaction [$F(1,30) = 12.431$, $p = .001$, $\eta_p^2 = 0.29$]. The transition durations estimated for the control group were greater in the upright condition than in the inverted condition [$t(15) = 3.728$, $p = .002$, $d = 0.72$]. The upright transition durations estimated for the control group also exceeded the veridical duration of 140 ms [$t(15) = 3.716$. $p = .002$, $d = 0.94$] as well as the transition durations estimated for the ASD group in the upright condition [$t(25.970) = 2.570$, $p = .016$, $d = 0.91$]. In contrast, the transition durations on inverted trials were not significantly different from the veridical duration [$t(15) = 0.583$, $p = .57$, $d = 0.15$]. The transition durations estimated for the observers with ASD did not vary as a function of stimulus orientation [$t(15) = .789$, $p = .442$, $d = 0.20$]. Neither their upright [$t(15) = .966$, $p = .349$, $d = 0.24$] nor inverted duration estimates [$t(15) = 1.026$, $p = .321$, $d = 0.26$] exceeded the veridical duration of 140 ms. Acrorss the two groups the *difference* in perceived duration between the upright and inverted conditions was negatively correlated with autistic traits ($r = - 0.37$, $p = .038$).

Figure-2

3.2 Sensitivity to comparison transitions

The data were analyzed using ANOVA with Orientation (upright, inverted) as a within-subjects factor and Group (control, ASD) as a between-subjects factor. The analysis revealed a significant Group × Orientation interaction [$F(1,30) = 8.118$, $p = .008$, $\eta_p^2 = 0.21$]. Whereas the controls exhibited a trend towards less sensitivity in the upright condition [$t(15) = 1.993$, $p = .065$, $d = 0.49$], likely a product of the illusion, the ASD group displayed less sensitivity in the inverted condition [$t(15) = 2.286$, $p = .037$, $d = 0.56$]. Importantly, the sensitivity of the two groups did not differ significantly in either the upright [$t(30) = 1.608$, $p = .118$, $d = 0.57$] or inverted [$t(30) = .048$, $p = .962$, $d = 0.02$] conditions. We note, however, that the non-significant trend observed in the upright condition was for *superior* sensitivity to changes in the comparison eye transitions in the ASD group.

4. Discussion

Previous research employing the composite-face paradigm suggests that ASD may be associated with reduced integration of information derived from different regions of static faces (Gauthier et al., 2009; Teunisse & de Gelder, 2003; but see Nishimura et al., 2008). The present study examined whether observers with ASD also exhibit diminished integration of dynamic feature changes by comparing the susceptibility of observers with ASD and matched neurotypical controls to illusory feature slowing (Cook et al., 2015). The difference in the groups' susceptibility to the illusion was striking: When neurotypical observers viewed eye-opening and -closing, the presence of asynchronous mouth movements induced illusory slowing thought to index the integration of feature dynamics. Consistent with the original description of the illusion (Cook et al., 2015), feature slowing was observed only in the upright orientation. The observers with ASD, however, showed little evidence of illusory slowing in either orientation, suggestive of reduced cross-feature integration. Free from the interference induced by feature integration processes, the estimated transition durations of the ASD observers were in fact *more* accurate, closer to the veridical duration of 140 ms, than the typical observers, when the avatar was viewed upright.

Observers with ASD experience difficulties recognizing facial motion signatures (i.e., the idiosyncratic changes associated with different genders and identities) and unlike typical observers, derive little benefit from upright presentation (O'Brien et al., 2014). The present results suggest that difficulties interpreting upright patterns of facial motion reflect problems integrating feature transitions into coordinated representations, possibly reflecting aberrant internal models of global facial change. Many segments of facial motion, including displays of facial emotion, yawning, sneezing and laughter, are defined by closely correlated eye and mouth transitions. In many cases, the timing of one feature change relative to the onset or offset of another, can drastically alter the communicative or affective message conveyed (Jack et al., 2014). Internal models of global facial change are thought to mediate efficient, accurate coding of this dynamic variation (Cook et al., 2015). While the lack of feature integration seen in ASD may enhance performance on contrived lab-based tasks requiring observers to judge one feature whilst disregarding another, it likely hinders face perception outside of the lab, where fast, accurate interpretation of facial motion is necessary to respond appropriately in social interactions.

Rather than reflecting aberrant internal models of global facial change, the insensitivity of the ASD group to the illusory slowing might conceivably be due to a failure to attend to the eye-region. For example, many observers with ASD find eye-contact uncomfortable (e.g., Senju & Johnson, 2009) or may be less-motivated to maintain mutual gaze (Chevallier et al., 2012). There is, however, compelling evidence that this was not the case. If the observers with ASD had failed to attend to the eye-region, they would have shown diminished sensitivity; i.e., they would have been less able to detect the physical differences when comparing eye transitions. Importantly, however, the two groups of observers showed comparable sensitivity to the physical differences between stimuli; indeed, the observers with ASD showed a trend towards *greater* sensitivity than controls when the avatar faces were upright. This is not what one would expect if the ASD group were simply looking away from the eyes and indicates that the striking group difference observed has a perceptual, not attentional, origin.

In summary, observers with ASD show little or no sign of illusory feature slowing, thought to index the perceptual integration of cross-feature dynamics. These findings suggest that atypical models of global facial change may underlie the poor recognition of facial motion in this population (O'Brien et al., 2014). Problems deriving coordinated perceptual representations of facial change may hinder responding during social interactions and have significant detrimental effects on socio-cognitive development. The clarity of the group difference observed here contrasts starkly with the modest effect sizes and equivocal research findings seen throughout the literature on static face perception in ASD (Harms et al., 2010; Jemel et al., 2006; Weigelt et al., 2012). We speculate that atypical perception of moving faces may be a more reliable feature of the ASD phenotype.

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Figure 1

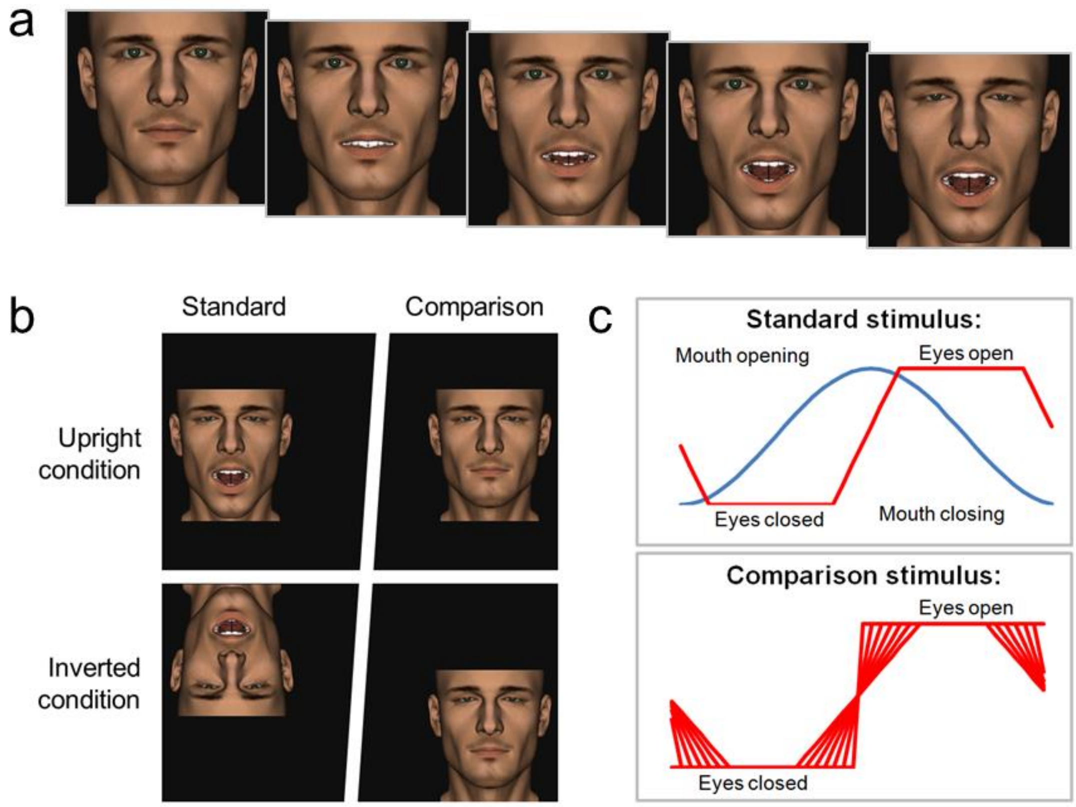

Figure 1: (a) Stimulus frames were created by posing the eyes and mouth of an avatar face and compiled into video files. (b) On each trial, participants viewed two avatar faces side-by-side, a standard and a comparison. Both faces opened and closed their eyes periodically at 1.25 Hz. Participants were asked to report whether the speed of eye transitions, open-to-closed and *vice versa*, were greater for the standard or comparison. Orientation was manipulated by presenting the standard upright or inverted. The distance between the avatar faces (~15°) was larger than implied in the illustration. (c) Concurrent mouth-opening and -closing movements were presented on the standard, also at 1.25 Hz, with a relative-phase asynchrony of 270°. The eye transitions exhibited by the standard stimulus always lasted 140 ms. The mouth on the comparison stimulus remained closed throughout. Eye transitions for the comparison stimulus varied in duration from 20 (rapid transition) to 260 (slow transition) ms in steps of 40 ms.

Figure 2

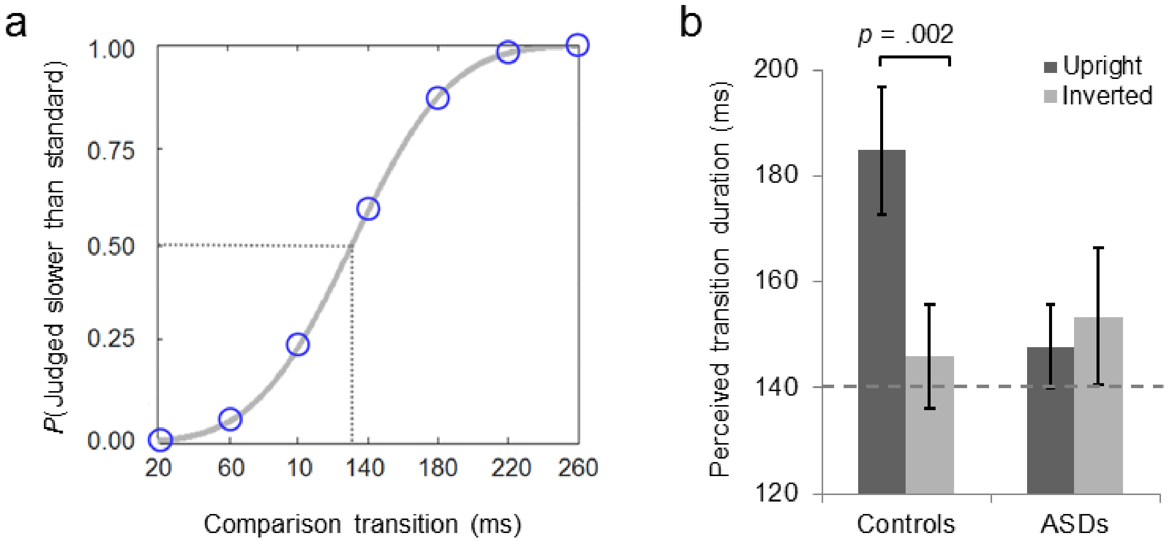

Figure 2: (a) Having modelled separate psychometric functions for the upright and inverted conditions, the perceived duration of the standard eye transition was inferred from the point of subjective equality (PSE); an estimate of the comparison transition duration necessary for the comparison and standard to be judged equivalent. (b) When typical observers viewed eye-opening and -closing, the asynchronous mouth movements induced illusory slowing, but only when viewed upright. Strikingly, observers with ASD showed no sign of the illusory slowing, in either the upright or inverted orientation. Dashed line denotes veridical transition duration. Error bars denote ± one standard error of the mean.

Table 1: Mean age, Gender, Autism-Spectrum Quotient (AQ) and IQ scores for the ASD group and the matched neurotypical controls. Autism Diagnostic Schedule (ADOS) score and classification for the ASD group. Standard deviations are shown in italics inside parentheses.

	ASD	**Controls**	**Comparison**
N	16	16	-
Gender	14 male, 2 female	14 male, 2 female	-
Mean Age (Years)	39.5 (*12.71*)	38.1 (*15.15*)	p = .773, d = 0.10
Mean Full Scale IQ	112.19 (*14.06*)	111.38 (*13.98*)	p = .871, d = 0.06
Mean AQ	33.63 (*6.26*)	16.88 (*5.40*)	p < .001, , d = 2.87
ADOS classification	9 Autism, 7 Autism Spectrum	-	-
Mean ADOS-G score	9.75 (*2.54*)		

Note. ADOS-G score is derived from a diagnostic algorithm with a higher score representing a greater number of autistic symptoms.

Table 2: The mean response probabilities for each Condition by Group.

		Comparison Transition						
		20 ms	60 ms	100 ms	140 ms	180 ms	220 ms	240 ms
Controls	Upright	0.03 (*.07*)	0.09 (*.10*)	0.22 (*.14*)	0.48 (*.19*)	0.62 (*.22*)	0.73 (*.19*)	0.67 (*.26*)
	Inverted	0.06 (*.09*)	0.10 (*.13*)	0.29 (*.22*)	0.68 (*.17*)	0.73 (*.18*)	0.81 (*.19*)	0.81 (*.17*)
ASD	Upright	0.03 (*.06*)	0.08 (*.08*)	0.29 (*.12*)	0.59 (*.15*)	0.79 (*.18*)	0.82 (*.16*)	0.85 (*.17*)
	Inverted	0.03 (*.06*)	0.15 (*.13*)	0.27 (*.11*)	0.58 (*.15*)	0.74 (*.20*)	0.82 (*.20*)	0.83 (*.18*)

Note: Larger values denote greater probability and standard deviations are shown in italics inside parentheses.

Table 3: The mean duration estimates for the two groups (left). The mean sensitivity estimates for the two groups (right). Standard deviations are shown in italics inside parentheses

	Duration estimates		**Sensitivity estimates**	
	Upright	*Inverted*	*Upright*	*Inverted*
Controls	184.6 (*48.0*)	145.7 (*39.4*)	1.875 (*.283*)	1.974 (*.280*)
ASD	147.7 (*31.7*)	153.3 (*51.7*)	1.880 (*.300*)	1.818 (*.268*)

Note: Larger values denote poor sensitivity.