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The effect of spatial frequency and face inversion on facial expression processing in children with autism spectrum disorder

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Abstract

To investigate whether facial expression processing in children with autism spectrum disorder (ASD) is based on local information of the stimuli, we prepared low spatial frequency (LSF) images with blurred facial features and high spatial frequency (HSF) images with rich facial features from broad (normal) spatial frequency (BSF) images. Eighteen children with ASD (mean age 11.9 years) and 19 typically developing (TD) children (mean age 11.4 years) matched on non-verbal IQ were presented these stimuli in upright and inverted orientations. Children with ASD had difficulty in processing facial expressions from BSF and LSF images, but not from HSF images. In addition, BSF and HSF images elicited the inversion effect in TD children, but not in children with ASD. By contrast, LSF images elicited the inversion effect in both groups of children. These results suggest that children with ASD are biased toward processing facial expression based on local information, even though their capacity to process facial expressions configurally is spared.

Key words: autism spectrum disorder, facial expression, local processing, spatial frequencies, inversion effect

Autism spectrum disorder (ASD) is a neurodevelopmental disorder characterized by difficulty in communicating effectively with other people and developing social relationships, and by restricted, repetitive, and stereotyped patterns of behavior, interests, and activities (APA, 1994). ASD is also characterized by a cognitive style biased toward local rather than global information processing, which is termed "weak central coherence (WCC)" (Happé, 1999; Happé & Frith, 2006). For example, children with ASD performed better than controls on an embedded-figures task (e.g. Pellicano, Gibson, Maybery, Durkin, & Badcock, 2005; Shah & Frith, 1983, but see also White & Saldaña, 2011). Plaisted, Swettenham, and Rees (1999) found a local advantage on the Navon task in children with ASD. Moreover, since individuals with ASD showed this detail-focused perception with intact global processing (Mottron, Burack, Iarocci, Belleville, & Enns, 2003), the enhanced perceptual functioning (EPF) model was proposed (Mottron, Dawson, Soulières, Hubert, & Burack, 2006). Local-based processing in children with ASD was found in face perception as well as non-face perception, which suggested a general perceptual deficit in children with ASD (Davies, Bishop, Manstead, & Tantam, 1994).

Face Processing in children with ASD

Mild to moderate deficits in face discrimination and recognition have been reported in children with ASD (Gliga & Csibra, 2007). Children with ASD perform less accurately than controls in face recognition (e.g. Klin, Sparrow, de Bildt, Cicchetti, Cohe, & Volkmar, 1999; Robel, Ennouri, Piana, Vaivre-Douret, Perier, Flament, & Mouren-Simeoni, 2004), even when the faces are familiar (Boucher Lewis, & Collis, 1998). However, several studies have failed to find deficits in face recognition in individuals with ASD (Celani, Battacchi, & Arcidiacono, 1999; Gepner, Deruelle, & Grynfeltt, 2001; Deruelle, Rondan, Gepner, & Tardif, 2004; Volkmar, Sparrow, Rende, & Cohen, 1989). Sasson (2006) proposed that the types of experimental tasks, participant age and developmental level (i.e., "classic" or high-functioning autism) may contribute to this discrepancy. Furthermore, as children with ASD grow older, they may develop compensatory strategies for processing faces, which could help minimize their general impairment (Klin et al., 1999). In this regard, it has been reported that individuals with ASD tend to process faces in an atypical way. They seem to have a more feature-based rather than configuration-based processing style for faces.

It appears that, compared to other stimuli, faces are disproportionately sensitive to inversion (Yin, 1969), and this difference in performance between upright and inverted faces is called the inversion effect. The inversion effect demonstrates that faces are processed as an overall template in a holistic manner and the spatial relationships between facial features are processed configurally. Inversion disrupts this holistic and configural processing, and inverted faces are then processed in a piecemeal fashion like objects. However, individuals with ASD performed well on tasks with inverted faces and showed only a small inversion effect. Langdell (1978) found that children with ASD were significantly better than controls at recognizing their peers in the inverted mode. Inversion of a face did not interfere with the ability to discriminate faces in children (Rose, Lincoln, Lai, Ene, Searcy, & Bellugi, 2007) and adolescents (Hobson, Ouston, & Lee, 1988) with ASD relative to controls. Although high-functioning adolescents (Teunisse & de Gelder, 2003) and adults (Lahaie, Mottron, Arguin, Berthiaume, Jemel, & Saumier, 2006; Nishimura, Rutherford, & Maurer, 2008) with ASD demonstrated a face inversion effect, Faja, Webb, Merkle, Aylward and Dawson

(2009) suggested that the inversion effect was weakened in individuals with ASD, based on the data that the difference in reaction time for upright versus inverted faces was only half as large in adults with ASD than in controls. This smaller inversion effect in individuals with ASD is taken as a sign of local rather than configural processing of faces because configural information is less available, and only local information is available when a face is presented upside-down.

An atypical style of face processing in individuals with ASD was demonstrated by another technique that exploits the composite effect (Young, Hellawell, & Hay, 1987). Teunisse and de Gelder (2003) failed to observe a normal composite effect in adolescents with ASD (but see Nishimura et al., 2008, for contrary evidence). In a study by Young et al (1987), the top and bottom halves of different faces fuse to form a new facial configuration when aligned with each other. In TD individuals, recognition of the upper face half took more time when aligned with the bottom half than when not aligned (e.g. Carey & Diamond, 1994; Nishimura et al., 2008; Teunisse & de Gelder, 2003; Young et al., 1987). This composite effect only occurred in the upright orientation. The absence of the composite effect in adolescents with ASD indicates that they make less use of the configurational information of a face.

Moreover, Deruelle et al. (2004) found that children with ASD exhibited better performance compared to a control group when using high rather than low spatial frequency (LSF) in an identity-matching task. Previous studies (e.g. Shulman & Wilson, 1987) demonstrated that LSF images conveyed more configural features than local ones, whereas the local features are primarily conveyed by high spatial frequency (HSF). When applied to face recognition, the low-pass filter makes facial features vague, whereas when faces are high-pass filtered, facial features appears to be emphasized. Deruelle et al. (2004) explained that fine details of facial features (i.e., local cues) are available when the stimulus contains HSFs but not when it contains only LSFs. Thus, the result indicates that children with ASD relied more on local (HSF) cues than on configural (LSF) cues when processing faces. This local advantage in face processing in children with ASD was discussed in line with the WCC theory (for an updated review, see Happé & Frith, 2006) and the EPF model (for an updated review, see Mottron et al., 2006). Deruelle et al. (2004) suggested that the local bias observed in children with ASD could appear in the early information processing like spatial frequency decoding. Superior processing of face parts may explain a preference for HSFs in matching faces. Individuals with ASD might become more dependent on local cues and thereby disadvantaged when local cues are reduced (Lahaie et al., 2006).

Facial Expression Processing in children with ASD

Facial expressions are important for nonverbal communication, and even neonates discriminate facial expression (Field et al., 1982; Meltzoff & Moore, 1977). Some studies have revealed that children with ASD performed less accurately than controls in facial expression matching tasks (Celani et al., 1999; Deruelle et al., 2004). Adults with ASD selectively showed a deficit in rapid emotion processing (Clark, Winkielman, & McIntosh, 2008). Rump et al. (2009) found that children (aged 5–7 years) and adults with ASD performed less accurately than the control group when they were asked to identify the emotion of actors presented in brief video clips whose facial expression varied subtly. These results suggest that the emotion recognition skills of children with ASD reach the level of those of their TD peers between the ages of 8 and 12 years and remain relatively comparable through adolescence, whereas TD children continue to develop proficiency for recognizing facial expressions through to adulthood; therefore, the control adults performed significantly better than the adults with ASD. In fact, others have reported that children (Buitelaar, van der Wees, Swaab-Barneveld, & van der Gaag, 1999; Gepner et al., 2001; Robel et al., 2004) and adolescents (Tracy, Robins, Schriber, & Solomon, 2011) with ASD do not perform significantly worse than their controls. However, facial expression processing in individuals with ASD was also somewhat different from that in TD individuals. In the sorting task, for example, children with ASD tended to sort faces by the hats and neglected the facial expressions, while TD children showed a preference for sorting by the facial expressions (Weeks & Hobson, 1987). Grossman, Klin, Carter and Volkmar (2000) found that children with Asperger syndrome may utilize compensatory strategies such as verbal mediation to process facial expressions. To summarize, school-age children with ASD show apparently typical performance in facial expression processing in some tasks, but could be using atypical strategy to process facial expression. Thus, it is critical to study the mechanism underlying facial expression processing in children with this age range.

Although analyses of expression and identity proceed independently (Young, McWeeny, Hay, & Ellis, 1986; Tranel, Damasio, & Damasio, 1988), TD individuals also process facial expression configurally. For example, the inversion effect (McKelvie, 1995; Valentine & Bruce, 1988) and the composite effect (Calder, 2000) were also found in facial expression processing. By contrast, adolescents with ASD also seem to process them locally because they performed better than controls at processing inverted orientation (Hobson et al., 1988). To our best knowledge, no studies have reported the composite effect of facial expressions in individuals with ASD.

TD children (5-6 years, 7-8 years) relied preferentially on high spatial frequencies in an emotion categorization task (Deruelle & Fagot, 2005). They were asked to indicate whether the person was smiling or grimacing as a hybrid high-pass/low-pass face was presented. This HSF bias was not significant for the 10-year-old TD children (Deruelle Rondan, Salle-Collemiche, Bastard-Rosset, & Da Fonséca, 2008) and adults (Deruelle & Fagot, 2005). By contrast, children with ASD (mean age: 10 years, 5 months) showed a high-pass bias contrary to controls (Deruelle et al., 2008), whereas adults with ASD showed a low-pass bias during emotion categorization (Santos, Rondan, Rosset, Da Fonséca, & Deruelle, 2008). In addition, adults with ASD were less accurate than controls in recognizing facial expressions from low-spatial frequencies (Kätsyri, Saalasti, Tiippana, von Wendt, & Sams, 2008).

As reviewed above, studies on facial expression processing in ASD are nevertheless scarce compared to those examining the processing of face identity, and the results are often inconsistent among different studies. In the current study, we used spatial filtering and inverted presentation in order to investigate whether facial expression processing in children with ASD is based primarily on local information. The combination of these two manipulations shed new light on the nature of facial expression processing in children with ASD. For example, if children with ASD showed the inversion effect in the LSF condition, it suggests that they retain configural processing for facial expressions even though they show impairment in processing LSF images. This is the first time spatial filtering of images of facial expressions in an inverted orientation for children with ASD has been presented. There are many studies using inverted faces in individuals with ASD, but results are not consistent (Faja et al., 2009; Hobson et al., 1988; Lahaie et al., 2006; Langdell, 1978; Nishimura et al., 2008; Rose et al., 2007; Teunisse & de Gelder, 2003). This suggests that further replication of the inversion effect in children with ASD is needed. According to the previous studies (Celani et al., 1999; Deruelle et al., 2004), children with ASD would show lower performance than TD children in the broad (normal) spatial frequency (BSF) condition. We predicted that the performance of children with ASD would be less accurate than that of TD children in the condition of upright LSF facial expression because the LSF conveys few local cues of faces and plays the dominant role in the configural processing of faces. Moreover, we predicted that the performance of children with ASD would not differ from the performance of TD children in the condition of upright HSF facial expression because the HSF conveys much local cues and it could be easier to process facial features locally. With respect to inversion effect, consistent with previous studies of adolescents with ASD (Hobson et al., 1988), we also predicted that no inversion effect would be found in the BSF and the HSF conditions. If no inversion effect would be found in all spatial frequencies, particularly in the LSF condition, children with ASD would process upright facial expressions locally. On the other hand, if children with ASD would show the inversion effect in the LSF condition, they could process facial expressions configurally when little featural information is available. By contrast, we predicted that TD children would process facial expressions configurally, and the inversion effect would be observed in all spatial frequencies. Note that HSF faces are not processed purely locally, because the HSF enables the extraction of fine metric relations amongst feature cues i.e. configural information (Goffaux, Hault, Michel, Vuong, & Rossion, 2005).

Method

Participants

The participants consisted of 18 children with ASD (17 males and 1 female—8.4–14.5 years old, mean age: 11.9 years, SD: 1.8) and 19 TD children (13 males and 6 females—6.4–15.3 years old, mean age: 11.4 years, SD: 2.3). All the children were students of a primary and junior high school for children both with and without ASD. The children with ASD had been diagnosed by at least one child psychiatrist when they enrolled in the school. In addition, after parental interviews and clinical observations, experienced clinical psychologists (YT and KY) confirmed the diagnoses according to DSM-IV criteria (American Psychiatric Association, 1994). The Japanese version of Raven's Coloured Progressive Matrices (RCPM; Raven, 1956; Sugishita & Yamazaki, 1993) was administered to all the children as a measure of visuospatial intelligence (children with ASD—mean score: 30.0, SD: 5.4; TD children—mean score: 32.3, SD: 4.2). Written informed consent was obtained from the children and their parents. The study was approved by the Research Ethics Committee of University of Tokyo.

Stimuli

Stimuli were gray scale 256 × 256-pixel photographs of adult faces (four males and four females) showing four different facial expressions (happy, angry, sad, surprised) (Kudo & Matsumoto, 1996). These eight photographs had a broad (normal) spatial frequency (BSF). Following Deruelle et al. (2004), each photograph was low-pass filtered (LSF, below two cycles/degree of visual angle) and high-pass filtered (HSF, above six cycles/degree of visual angle) (using ImageJ software), and the stimuli set contained 16 filtered faces (Figure 1). They were of 6°× 6° of visual angle and were presented in a two-alternative forced-choice (2AFC) matching task. The distance between a target image and probes was approximately 4.5° of visual angle, and the distance between probes approximately 9.5° of visual angle.

Procedure

Participants were tested individually in a quiet room at the University of Tokyo. The experiment was run on a laptop computer with a 14.1-inch TFT monitor. Participants were seated approximately 60 cm from the monitor to complete the 2AFC matching task. A target face was presented on one side of the monitor and a cursor was displayed on the opposite side. Participants controlled the cursor using a USB joy pad. When they moved the cursor to the target face, two probes (unfiltered BSF faces) appeared (Figure 1). Participants were asked to indicate which of the two faces showed the same facial expression as the target face by moving the cursor.

Design

The study consisted of two upright face blocks and two inverted face blocks, comprising 18 test trials for each block. Ten children with ASD and eight TD children observed the upright face block first, and the others observed the inverted face block first. Within each block, trials were presented in a random order. In the upright face condition, there were 36 trials, which included 12 (four expressions × three distracter expressions) target faces of three types of spatial frequencies (BSF, LSF, or HSF). In half trials, the gender of the target image and the correct probe was the same, (i.e. the target image and the correct probe image were exactly the same because we obtained only one facial expression photograph per gender) and in the other half trials, the gender was different. In the inverted face condition, the stimuli of the upright face condition were shown upside-down. The experimental design consisted of one between-participants factor of group (children with ASD or TD children) and two within-participants factors of orientation (upright or inverted) and spatial frequencies (BSF, LSF, or HSF).

Results

There was no significant group difference in the RCPM scores ($t = -1.43$, $p > .1$), indicating that the visuospatial intelligence of children with ASD and TD children did not differ. There was also no significant group difference in their chronological age ($t = .71$, $p > .4$). We analyzed correct rate on the upright and inverted face tasks.

The upright face task

Figure 2 and Table 1 show the correct rate on the upright face tasks by the two groups for the three conditions. The distribution of the correct rate made the use of parametric tests inappropriate. Therefore, nonparametric tests were used to examine these data. Bonferroni corrections were adopted for all multiple comparisons. Children with ASD exhibited lower performance than TD children in the BSF and LSF condition (BSF: $Z = -3.05$, $p < .01$; LSF: $Z = -2,22$, $p < .05$, Mann-Whitney U test). In the HSF condition, the group difference was not significant ($Z = -1.33$, $p > .3$).

The condition effect was significant in both groups (children with ASD: $\chi^2 = 11.1$, $p < .01$; TD children: $\chi^2 = 15.1$, $p < .01$, Friedman test), and a Wilcoxon test with Bonferroni correction was performed in each group. Within children with ASD, performance in the LSF condition was significantly lower than in the BSF and the HSF condition (LSF-BSF: $Z = -2.84$, $p < .05$; LSF-HSF: $Z = -2.74$, $p < .05$). There was no significant difference between the BSF and the HSF condition ($Z = -.16$, $p > .8$). Within

TD children, performance in the LSF condition was significantly lower than in the BSF condition (Z = –3.02, $p < .05$). There was a marginal difference between the LSF and the HSF condition (Z = –2.20, p = .08). There was no significant difference between the BSF and HSF condition (Z = –1.30, $p > .5$).

The inverted face task

Figure 2 and Table 1 show the correct rate on the inverted face tasks by the two groups for the three conditions. A marginally significant difference was found between children with ASD and TD children in the BSF condition (Z = –1.76, p = .08, Mann-Whitney U test). In the LSF and HSF condition, the group difference was not significant (LSF: Z = –1.08, $p > .2$; HSF: Z = –.83, $p > .4$).

The condition effect was significant in children with ASD (χ^2 = 23.3, $p < .01$, Friedman test) and in TD children (χ^2 = 19.9, $p < .01$), and a Wilcoxon test with Bonferroni correction was performed in each group. Within children with ASD, performance in the LSF condition was significantly lower than in the BSF and HSF condition (LSF-BSF: Z = –3.29, $p < .01$; LSF-HSF: Z = –3.44, $p < .01$). There was no significant difference between the BSF and HSF condition (Z = –.24, $p > .8$). Within TD children, performance in the LSF condition was significantly lower than in the BSF and the HSF condition (LSF-BSF: Z = –3.43, $p < .01$; LSF-HSF: Z = –2.70, $p < .05$). There was no significant difference between the BSF and the HSF condition (Z = –.94, $p > .3$).

The inversion effect

In each group, a Wilcoxon test was performed. Within TD children, performance with inverted faces was significantly lower than with upright faces in each spatial frequency condition (BSF: Z = –2.53, $p < .05$; LSF: Z = –3.23, $p < .01$; HSF: Z = –2.39, $p < .05$). Within children with ASD, the difference between upright faces and inverted faces in the BSF condition did not reach significance (Z = –1.90, p = .06). In the LSF condition, performance with inverted faces was significantly lower than with upright faces (Z = –2.90, $p < .01$). In the HSF condition, there was no significant difference between upright faces and inverted faces (Z = –.99, $p > .3$).

Correlation

We calculated the average correct rate of all conditions in each participant. Figure 3a show that in general, children with ASD performed better with age (ρ = .59, $p < .05$), while TD children did not (ρ = .34, $p > .1$). In children with ASD, there was a significant correlation between performance in the LSF condition and age with both the upright (ρ = .58, $p < .05$; Figure 3b) and inverted (ρ = .61, $p < .01$) faces. In addition, in TD children, the correlation of performance in the LSF condition and age was marginally significant with upright faces (ρ = .44, p = .06; Figure 3b). No significant correlations were found between other conditions and age (all $\rho < .46$, $p > .05$).

Discussion

First, as predicted, children with ASD showed lower performance than TD children in the LSF condition with upright faces. Because the LSF images convey more configural rather than local information, this result suggests that children with ASD had more difficulty in processing facial expression configurally than did TD children. This finding is consistent with Kätsyri et al. (2008), in which adults with ASD were less accurate than controls in recognizing facial expressions from low-spatial frequencies. Children with ASD also showed lower performance than TD children in the BSF condition, and this is consistent with some previous studies using a matching-to-sample paradigm (Celani et al., 1999; Deruelle et al., 2004). By contrast, the two groups showed no difference in the HSF condition. In the HSF images, in which local cues are more easily accessible due to the relative absence of LSF information, and children with ASD processed facial expression as well as TD children did. Since the group difference was found not in the HSF but in the BSF condition, the latter of which include the same amount of HSF components as the former, children with ASD might have difficulties in extracting local cues from the BSF image which also contains rich LSF components compared to the HSF image. This would cause children with ASD more dependent on local cues. These results indicate an HSF preference in children with ASD, which is consistent with previous studies (Deruelle et al., 2004; Deruelle et al., 2008).

Second, while TD children showed the inversion effect in both the BSF and the HSF condition, children with ASD did not. The TD children's results replicated previous findings in which facial expression processing became difficult when faces were presented in inverted compared to upright orientation (McKelvie, 1995; Valentine & Bruce, 1988). It should be noted that HSF faces are not processed purely locally as the configural information is also available, to some extent, from the HSF faces. Since TD children processed the HSF faces configurally, the inversion effect in the HSF condition was also observed. Meanwhile, the absence of the inversion effect for the BSF and HSF conditions in children with ASD suggests local rather than configural processing for facial expressions because only local information is available in inverted faces (e.g. Carey & Diamond, 1994). Moreover, in the inverted condition, there was no significant difference between children with ASD and TD children in any spatial frequency condition. This result contrasts with that of the upright condition, in which a group difference was found in both the BSF and the LSF conditions. The current result of non-inversion effect for the BSF and HSF faces in children with ASD is consistent with the previous study of adolescents with ASD (Hobson et al., 1988).

By contrast, in the LSF condition, children with ASD showed the inversion effect just like TD children, which is the novel finding of the current study. If children with ASD had no ability to process configural information, they should not show the inversion effect even in the LSF condition. Even if they process facial expressions from subtle local cues remaining in the LSF images, the inversion effect should not be observed after all, because the inversion effect does occur only when the upright facial expressions are processed configurally. Therefore, these results indicate that configural processing of facial expressions may not be completely absent in children with ASD, but they tend to process it locally when images have rich local information. These results are consistent with recent WCC theory (Happé, 1999; Happé & Frith, 2006) and EPF model (Mottron et al., 2006). The current study demonstrates the capacity for configural processing of facial expressions in children with ASD.

It was more difficult for both TD children and children with ASD to respond to the LSF faces compared to the BSF and HSF faces. This is consistent with the results of Leonard, Karmiloff-Smith and Johnson (2010) on the performance of TD 9-and 10-year-olds. TD adults were also significantly worse when the middle spatial frequencies of an upright face were masked than when only the LSFs or HSFs were masked. In addition, the recognition of the LSF face images was less accurate than that of the HSF images in TD adults (Fiorentini, Maffei, & Sandini, 1983; Nagayama, Yoshida, & Toshima, 1995).

In children with ASD who have difficulty in processing LSF images, which retain configural and little local information, there was a correlation between their age and performance in the LSF condition. This tendency was also found in TD children. These results might suggest that the skill of configural processing for faces develops with age. Children with ASD (Leonard, Annaz, Karmiloff-Smith, & Johnson, 2011) and TD children, at least those under 10 years old (Leonard et al., 2010; Leonard et al., 2011) tended to rely on the HSFs for face recognition. In addition, children aged less than approximately 10 years did not process faces configurally (Carey & Diamond, 1977), and adult expertise in configural processing is slow to develop (Mondloch, 2002). The correlation between performance in the LSF condition and age was consistent with these previous studies.

In this study, we could not test which part of the face children with ASD used as a cue to process the facial expressions. On identity tasks, some studies have reported that the mouth was a cue for children with ASD, while it was the eyes for TD children (Langdell, 1978; Joseph & Tanaka, 2003). Their ability to identify faces on the basis of mouth cues but not eye cues could extend to the recognition of facial expressions (Joseph & Tanaka, 2003). Contrary to these arguments, Rutherford and Towns (2008) used an eye-tracking device to demonstrate that adults with ASD, like TD adults, looked longer at eyes than mouth when identifying facial expressions. Further investigation of this issue is required, possibly with a composite paradigm (Calder et al., 2000).

What might account for the part-based face processing in children with ASD? Some argue that the developmental origin of atypical face processing in individuals with ASD is the result of insufficient facial orienting, which is possibly due to the lack of attentional bias (Schultz, 2005) or motivation (Dawson, Webb, & McPartland, 2005) toward others' faces. In fact, infants and children with ASD lack an attentional bias toward others' faces (e.g. Kikuchi, Senju, Tojo, Osanai, & Hasegawa, 2009; Osterling, Dawson, & Munson, 2002). Future studies should investigate whether an increased amount of attention to faces could lead to face expertise and possibly trigger holistic/configural face processing in children with ASD during their development.

Several limitations of the current study should be noted. First, we could not investigate the relationship between each facial expression and the spatial frequency because of the small number of trials used in this study. In addition, as is often the case with the studies with atypically developing children, the interpretation of the null results has to be treated carefully due to the smaller number of trials compared to adult studies, which is essential to minimize task loads but could increase the within-participant variability of the data. Further studies, ideally with adult participants who can tolerate longer experimental sessions than children, would be beneficial to examine these questions. Second, as we used a joypad for children's responses, we could not analyze the reaction time with sufficient temporal resolution. Further studies will be required to test whether the inversion effect, which was observed in the accuracy data, could also be observed with reaction time data. Third, the limited age range of children with ASD (8–14 years old) does not allow for analyses of the developmental trajectory in earlier and later age ranges. As we found a positive correlation between performance and age in children with ASD, further studies would be fruitful to follow up development in a wider age range. Fourth, we followed Deruelle et al. (2004) and Costen, Parker, & Craw (1996) for the application of the spatial filtering, although the units were different across studies. Some suggest that it might be relatively easy to identify faces from the

LSF images in the latter study (Endo & Kirita, 2004), and this might affect the results. We agree to the caution that researchers reach a consensus on the useful methodology for future investigations to promote ease of comparison across studies (Endo & Krita, 2004; Leonard et al., 2010).

In summary, we investigated facial expression processing in children with ASD by using LSF (facilitating configural processing), HSF (facilitating local processing), and BSF (normal) images. In a two-alternative forced-choice matching task, children with ASD performed less accurately in the BSF and LSF conditions, but not in the HSF condition with the upright orientation. In addition, both TD children and children with ASD showed the inversion effect in the LSF condition, whereas the inversion effects in the BSF and the HSF condition did not reach significance in children with ASD unlike TD children. These results suggest a local processing preference for facial expressions in children with ASD.

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Table 1. *Mean Correct Rates and Standard Deviations (M ± SD) of each condition (%).*

	BSF	LSF	HSF
Children with ASD (*n* = 18)			
Upright	94.0 ± 7.46	83.8 ± 11.9	93.5 ± 10.9
Inverted	88.4 ± 14.6	68.5 ± 16.6	89.8 ± 11.3
TD children (*n* =19)			
Upright	99.6 ± 1.91	92.1 ± 8.09	97.8 ± 5.44
Inverted	95.6 ± 6.44	75 ± 17.8	92.5 ± 9.97

Note. ASD = autism spectrum disorder; TD = typically developing; BSF = broad spatial frequency; LSF = low spatial frequency; HSF = high spatial frequency.

Figure 1. Examples of the BSF face (top left), the LSF face (top middle) and the HSF face (top right). An example of the two-alternative forced-choice (2AFC) matching task (below); the centre image is a target and the left and right images are probes. BSF = broad spatial frequency; LSF = low spatial frequency; HSF = high spatial frequency.

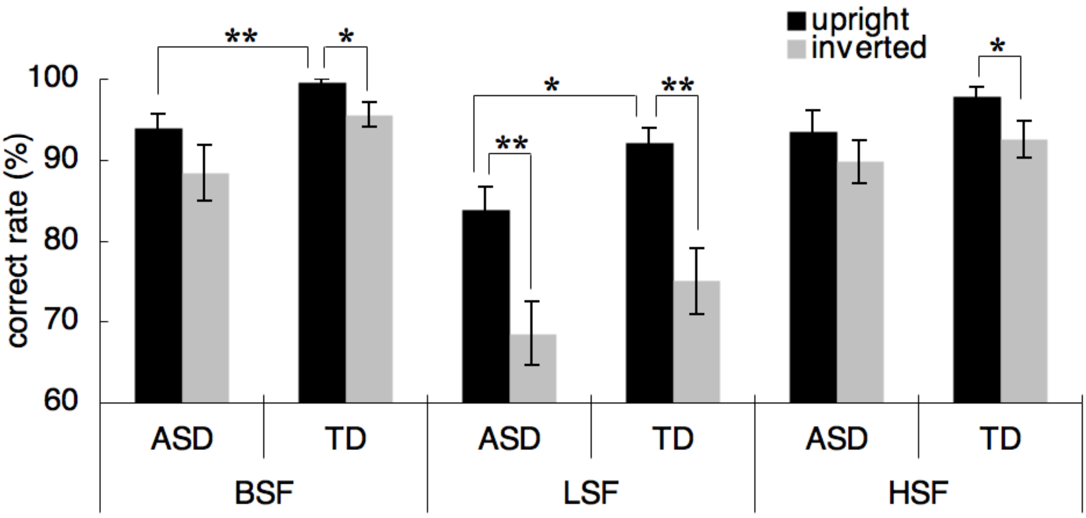

Figure 2. Mean correct rates for three spatial frequency conditions and two orientations in children with ASD and TD children. ASD: autism spectrum disorder, TD: typically developing, BSF: broad spatial frequency, LSF: low spatial frequency, HSF: high spatial frequency, *; $p < .05$, **; $p < .01$, error bar: standard error.

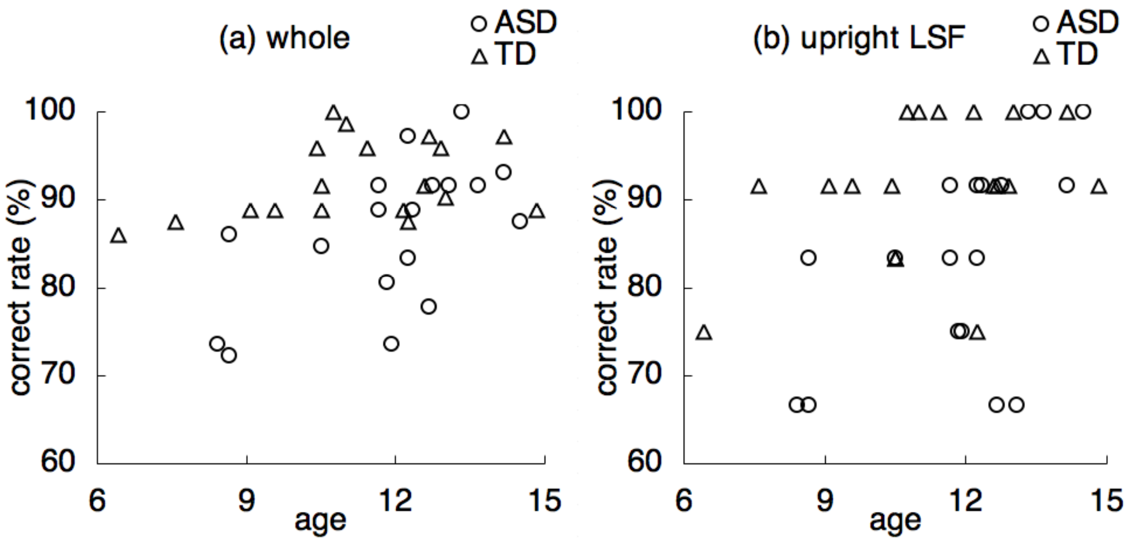

Figure 3. (a) Scatterplot of the age and the average correct rate of all conditions in each participant. (b) Scatterplot of the age and the correct rate of the upright LSF condition in each participant. ASD: autism spectrum disorder, TD: typically developing.