Title

Atypical recognition of dynamic changes in facial expressions in autism spectrum

disorders

Running title

Impaired recognition of dynamic expression in ASD

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Abstract

Previous studies have suggested that the processing of dynamic facial expressions is impaired in autism spectrum disorders (ASD). However, the specific component that is impaired in the processing of dynamic facial expressions has not been identified. We investigated the recognition of dynamic changes in facial expressions among individuals with ASD and age- and sex-matched typically developing controls. Morphing animations of facial expressions of six emotions were presented at four different changing speeds, and participants rated the naturalness of the expression changes. The correspondence between reduced speeds and decreased naturalness ratings was weaker in the ASD than in the control group. These results suggest that the atypical visual analysis of dynamic changes in facial expressions underlies the impairment in real-life social interaction among individuals with ASD.

Keywords

1. Introduction

Individuals with autism spectrum disorders (ASD) are characterized primarily by qualitative impairments in social interaction (American Psychiatric Association (APA), 2000). One of the most evident features of their social impairment is deficient communication involving emotional facial expressions (Hobson, 1993). For example, previous studies reported that individuals with ASD exhibited attenuated emotional behaviors (Corona, Dissanayake, Arbelle, Wellington, & Sigman, 1998) and reduced

and/or inappropriate facial reactions (Yirmiya, Kasari, Sigman, & Mundy, 1989) compared with typically developing individuals in response to the facial expressions of other individuals in social interactions.

However, previous experimental studies investigating emotional expression processing in ASD have reported inconsistent findings. For example, although some studies demonstrated impaired facial expression recognition in ASD (e.g., Braverman, Fein, Lucci, & Waterhouse, 1989; Celani, Battacchi, & Arcidiacono, 1999; Uono, Sato, & Toichi, 2011), other studies reported no such impairment (e.g., Grossman, Klin, Carter, & Volkmar, 2000; Adolphs, Sears, & Piven, 2001; Castelli, 2005). Almost all these studies, regardless of their findings, used photos of emotional facial expressions as stimuli.

In real-life social interactions, facial expressions are usually dynamic. Thus, normal facial expressions contain not only static form information but also dynamic motion information (cf. Matsumoto, Ekman, & Fridlund, 1991). Researchers who have observed facial expressions in real situations have described the rich dynamic information contained in emotional facial expressions (Darwin, 1872; Ekman & Friesen, 1975). Consistent with such observations, several experimental studies in typically developing individuals have found that participants showed sensitivity to the dynamic properties of facial expressions (Hoffmann, Traue, Bachmayr, & Kessler, 2010; Krumhuber & Kappas, 2005; Sato & Yoshikawa, 2004). For example, Sato and Yoshikawa (2004) tested the naturalness ratings of dynamic changes in facial expressions and found that expressions that changed too slowly were generally rated as unnatural. Additionally, the effects of changing speeds differed across emotions in that

the fastest and slowest changing were seen as relatively natural for surprised and sad expressions, respectively. These data indicate that the dynamic properties of the stimuli affect the visual processing of facial expressions.

Because previous studies reporting impairments in social interactions tested real communication (e.g., Corona et al., 1998; Yirmiya et al., 1989), facial expressions were dynamic in those studies. Consistent with this notion, several recent studies have shown that dynamic presentations of facial stimuli more clearly elicited the abnormal behavioral patterns in individuals with ASD than did static presentations (Kessels, Spee, & Hendriks, 2010; Tardif, Lainé, Rodriguez, & Gepner, 2007; Uono, Sato, & Toichi, 2009). For example, Uono et al. (2009) reported that experiments using dynamic facial expressions as stimuli revealed the facilitative effect of emotional expression on automatic gaze-triggered attentional shifts in typically developing individuals and the impairment in this regard among individuals with ASD, although such effects were not found in response to static presentations (Hietanen & Leppänen, 2003). Several neuroimaging studies have also shown reduced activation of some social brain regions, such as the superior temporal sulcus (STS), in response to dynamic facial expressions in individuals with ASD (Pelphrey, Morris, McCarthy, & Labar, 2007; Rahko et al., 2012; Sato, Toichi, Uono, & Kochiyama, 2012).

Although these studies demonstrated that individuals with ASD suffer from impairment in the processing of dynamic facial expressions, the particular component that is impaired in the processing of dynamic facial expressions has remained unclear. Because neuroimaging studies have reported weak activation in the visual cortices during the processing of dynamic facial expressions by individuals with ASD (e.g.,

Pelphrey et al., 2007), we hypothesized that individuals with ASD may be impaired in their ability to analyze the dynamic properties of emotional facial expressions, which has been proposed as the earliest component in facial expression processing (Haxby, Hoffman, & Gobbini, 2000). To test this hypothesis, we used the experimental paradigm employed in a previous study with typically developing individuals (Sato & Yoshikawa, 2004). We presented dynamic facial expressions at different speeds and asked participants to rate the naturalness of the changing speeds of expressions. We predicted that individuals with ASD would be less sensitive to the dynamic changes in facial expressions than typically developing individuals would be.

2. Materials and methods

2.1. Participants

The ASD group consisted of sixteen individuals (two females, fourteen males; mean ± standard deviation (*SD*) age = 24.6 ± 11.9 years); eight (males) had Asperger's disorder and eight (two females, six males) had pervasive developmental disorder not otherwise specified (PDD-NOS). As defined by the Diagnostic and Statistical Manual-Fourth Edition-Text Revision (DSM-IV-TR) (APA, 2000), PDD-NOS includes heterogeneous subtypes of ASD ranging from so-called atypical autism to a subtype with milder symptoms than those typically associated with Asperger's disorder. In this study, only high-functioning participants with PDD-NOS (i.e., those with milder symptoms than those associated with Asperger's disorder) were included. The diagnoses were based on the DSM-IV-TR (APA, 2000) criteria and were made by psychiatrists with expertise in developmental disorders. Neurological and psychiatric problems other than those

associated with PDD were ruled out. None of the participants was taking medication. The

full-scale intelligence quotient, measured by the Wechsler Adult Intelligence

Scale-Revised or the Wechsler Intelligence Scale for Children-Revised, of all participants

in the ASD group was in the normal range. The control group consisted of sixteen

participants (two females, fourteen males; mean ± *SD* age = 21.5 ± 1.1) who had been

matched for age ($t(30) = 1.04$, $p > .1$) and sex with the ASD group. All participants had

normal or corrected-to-normal visual acuity. After the procedure and purpose of the study

were explained fully, all participants provided informed consent for participation in the

study. This study was approved by the local institutional ethics committee.

2.2. Experimental design

The experiment was constructed as a three-factorial repeated-measures design, with

group (ASD or control) as a between-participant factor and speed (260, 520, 1040, or 2080

ms/clip) and emotion (anger, disgust, fear, happiness, sadness, or surprise) as

within-participant factors.

2.3. Apparatus

The events were controlled by a program written in Visual C++5.0 and implemented

on a Windows computer. The stimuli were presented on a 19-inch flat CRT monitor

(GDM-F400, Sony; refresh rate, 100 Hz) at a viewing distance of 0.57 m. Under this

condition, the stimuli subtended a visual angle of 15.0° vertical x 10.0° horizontal.

2.4. Stimuli

With one exception, the stimuli were almost identical to those used in a previous

study (Sato & Yoshikawa, 2004). Due to the limited refresh rate of the display device, the

total frame number was decreased from 51 to 26. The stimuli were created from six

emotional (anger, disgust, fear, happiness, sadness, and surprise) and one neutral expressions displayed by one female (C) and one male (JJ) model chosen from a standard set of photographs (Ekman & Friesen, 1976). Using these photos as raw material, we made animated clips of emotional facial expressions. First, using the computer-morphing software FUTON system (ATR, Kyoto) on a Linux computer, we created 24 images, separated by increments of 4%, which were intermediate between the neutral (0%) and emotional (100%) expressions. Next, to create a movie clip, we presented a total of 26 images in succession (Fig. 1a): one neutral image, 24 intermediate images, and a final emotional image. Each stimulus was presented at one of four speeds: 10, 20, 40, or 80 ms/frame and, accordingly, at 260, 520, 1040, or 2080 ms/clip, respectively (Fig. 1b).

2.5. Procedure

Participants were tested individually. As in previous emotion recognition studies (e.g., Sato et al., 2002; Uono et al., 2011), before testing began, participants were asked to provide examples of situations that would elicit each of the emotions to confirm adequate understanding of emotional labels. The data showed that all participants provided appropriate examples without difficulty.

Each participant completed 12 trials, corresponding to six basic emotions expressed by each model, and evaluated a total of 48 expression clips. The order in which the emotions were presented was counterbalanced across participants. The order of presentation of the speed conditions was counterbalanced across emotions and participants. Before the trials, participants completed a few practice trials to familiarize themselves with the procedure.

In each trial, a sequence consisting of four animated clips was presented after the

a)

b)
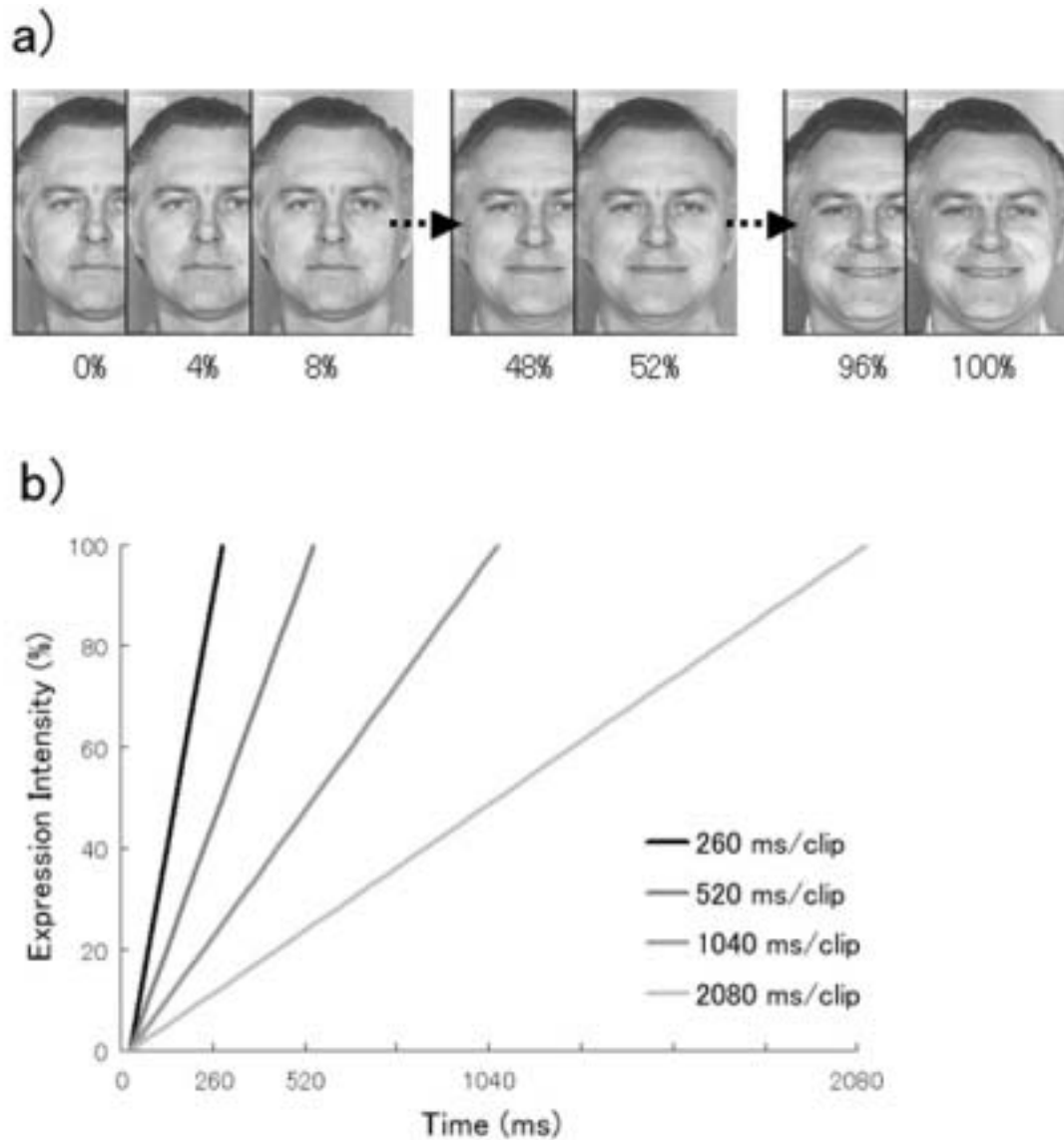
Fig. 1. a. An illustration of stimulus clips. A total of 26 frames were seamlessly transformed from a neutral expression (0%) to one of six emotional expressions (100%). b. Schematic illustration of the four speed conditions.

researcher had identified the emotion to be shown. The interval between clips was 1500 ms. Participant were asked to evaluate each clip in terms of the naturalness of the changing speed depicted for the emotion shown. Each clip was rated on a 7-point scale from 1 (not at all natural) to 7 (very natural). Participants were allowed to view the sequence repeatedly

by clicking a button on the CRT monitor until they were confident of their rating.

2.6. Data analysis

Naturalness ratings were analyzed using three-way repeated-measures analysis of variance (ANOVA) with the Greenhouse–Geisser adjustment; group was treated as a between-participant factor, and speed and emotion were treated as within-participant factors. Three types of follow-up analyses were conducted on significant interactions related to the factors of group. First, trend analysis was conducted on the speed factor for each group. Next, interaction contrasts were tested for group differences in speed effects. Finally, the simple effect of group was tested under each speed condition. Significant effects not related to the group factor were also further analyzed using simple effect analyses and multiple comparisons using Ryan's method. When higher-order interactions were significant, main effects were not interpreted due to the problematic possibilities associated with this procedure (cf. Tabachnick & Fidell, 2001). The results of all tests were considered statistically significant at $p < .05$.

A preliminary analysis was conducted on the effects of the sex and age of participants. An analysis was conducted with the factor of sex and the covariate of age as well as with the aforementioned three factors (i.e., group, speed, and emotion). The main effects and interactions related to sex and age were not significant ($p > .10$). Accordingly, these effects were disregarded in the reported analyses.

3. Results

The mean (with standard error (*SE*)) naturalness rating under each condition is presented in Table 1. The mean (with *SE*) naturalness ratings of the ASD and control
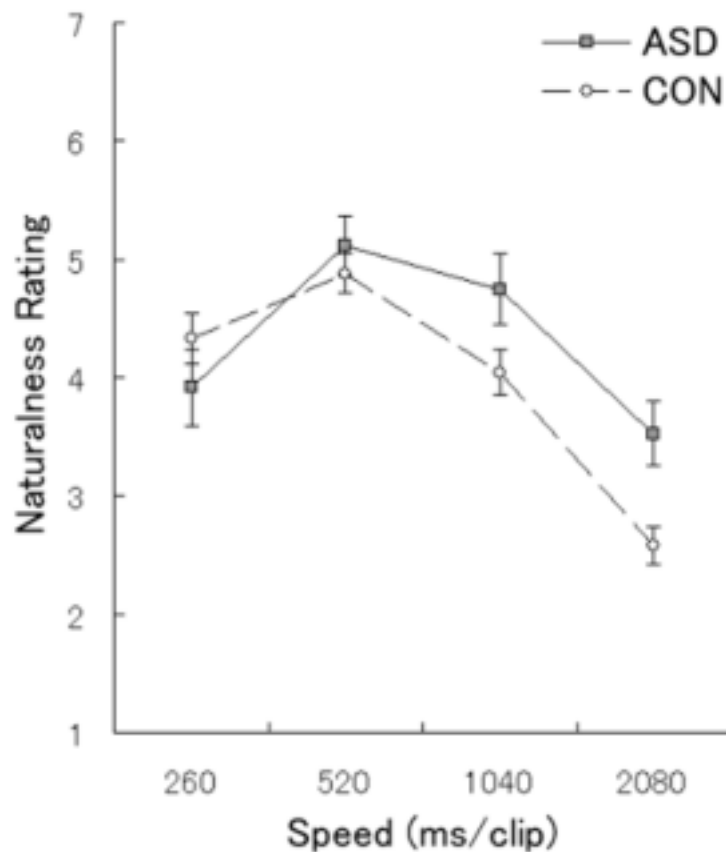
groups under each speed condition are shown in Fig. 2. The ANOVA on naturalness ratings using group, speed, and emotion as factors revealed a significant interaction between group and speed ($F(3,90) = 3.53, p < .05$). Additionally, the main effect of speed and the interaction between speed and emotion were significant ($F(3,90) = 25.96, p < .001$; $F(15,450) = 6.38, p < .001$). The main effect of group reached marginal significance ($F(1,30) = 3.30, p < .10$). We found no other significant main effects or interactions ($p > .10$).

To further examine the group × speed interaction, a trend analysis was conducted for each group to clarify changes in the patterns of naturalness ratings as a function of changes in speed. In the control group, the linear and quadratic trends were found to be significant ($F(1,15) = 78.90, p < .001$; $F(1,15) = 46.90, p < .001$), but the cubic trend was not ($p > .10$). The linear trend indicated that naturalness ratings declined as a function of decreased speed of change in facial expressions. In the ASD group, significant effects were found only for the quadratic trend ($F(1,15) = 26.00, p < .001$) but not for the linear and cubic trends ($p > .10$). Next, to clarify group differences in trends, interaction contrasts were tested. The results showed that groups differed significantly in terms of the linear trend, indicating that the correspondence between decreased naturalness ratings and slower speeds was weaker in the ASD than in the control group ($F(1,30) = 5.79, p < .05$). No significant group difference was found for quadratic or cubic trends ($p > .10$).

The simple main effect of group was tested under each speed condition to specify the speeds at which the groups differed. The results showed that the groups differed at 1040 and 2080 ms/clip ($F(1,120) = 4.27, p < .05$; $F(1,120) = 7.56, p < .01$). We found no significant group differences at other speeds ($p > .10$).

Table 1. Mean (with SE) naturalness ratings for the autism spectrum disorders (ASD) and control (CON) group.

Facial Emotion	ASD				CON			
	260	520	1040	2080	260	520	1040	2080
Anger	4.0	5.3	4.8	3.8	4.4	5.0	4.1	2.9
	(0.4)	(0.3)	(0.4)	(0.4)	(0.4)	(0.3)	(0.2)	(0.3)
Disgust	3.9	5.2	5.1	4.1	3.6	4.6	4.6	2.9
	(0.4)	(0.3)	(0.3)	(0.4)	(0.4)	(0.2)	(0.4)	(0.3)
Fear	4.6	5.0	4.4	3.0	4.9	4.8	4.1	2.4
	(0.5)	(0.5)	(0.5)	(0.4)	(0.4)	(0.4)	(0.4)	(0.4)
Happiness	3.6	5.4	5.0	3.3	4.4	5.0	3.3	2.2
	(0.4)	(0.3)	(0.3)	(0.4)	(0.2)	(0.2)	(0.3)	(0.2)
Sadness	2.8	4.5	5.2	3.9	3.8	4.5	4.6	3.0
	(0.3)	(0.3)	(0.3)	(0.3)	(0.4)	(0.3)	(0.3)	(0.4)
Surprise	4.5	5.3	4.0	3.0	4.9	5.5	3.6	2.1
	(0.4)	(0.3)	(0.4)	(0.4)	(0.3)	(0.3)	(0.3)	(0.3)

Fig. 2. Mean (with *SE*) naturalness ratings for the autism spectrum disorders (ASD) and control (CON) groups under each speed condition. The emotion factor is collapsed.

Follow-up analyses were also conducted for the speed × emotion interaction to investigate differences in the effect of speed across emotional expressions in both groups. Simple main effects of emotion were found under all speed conditions ($F(5,600) > 2.36$, $p < .05$). The multiple comparisons revealed the following results: under the 260-ms/clip condition, fearful and surprised expressions were rated as more natural than were disgusted and sad expressions, and angry expressions were rated as more natural than were sad expressions ($t(600) > 3.27$, $p < .005$); under the 520-ms/clip condition, surprised expressions were rated as more natural than were sad expressions ($t(600) = 3.06$, $p < .005$); under the 1040-ms/clip condition, sad and disgusted expressions were rated as more natural than were surprised expressions ($t(600) > 3.72$, $p < .001$); under the 2080-ms/clip condition, disgusted and sad expressions were rated as more natural than were surprised expressions, and disgusted expressions were rated as more natural than were fearful expressions ($t(600) > 3.05$, $p < .005$).

4. Discussion

Data from the control group showed that naturalness ratings for dynamic changes in emotional facial expressions decreased as a function of decreased speed of change. This result is consistent with those of a previous study (Sato & Yoshikawa, 2004). Our results confirm that typically developing individuals process not only the form but also the motion of the facial expressions of others. The results also revealed an interaction between speed and emotion, indicating that the influence of changes in the speed of facial expressions on naturalness recognition differed across emotions. For example, the ratings under the fastest and slowest speed conditions revealed a clear difference between surprised and sad

expressions. These patterns are similar to those reported in a previous study (Sato & Yoshikawa, 2004). As such patterns were shown in both the control and ASD groups, the data indicate that individuals with ASD adequately understood the task.

More importantly, our results showed differences between those with ASD and those in the control group with regard to how each group rated the naturalness of dynamic changes in facial expressions. The ASD group showed a weaker correspondence between decreases in the ratings for naturalness and decreases in the speed at which facial expressions changed. These results are consistent with some previous findings indicating that individuals with ASD suffer from impairment in the ability to process dynamic facial expressions (e.g., Uono et al., 2009). However, the details of this impairment remained unknown. To our knowledge, this is the first study to provide evidence that the ability to analyze the dynamic properties of facial expressions is impaired in individuals with ASD.

Our finding of impairment in the recognition of dynamic changes in facial expressions among individuals with ASD corroborates neuroscientific evidence. Several neuroimaging studies have shown that the observation of dynamic facial expressions induced less activation in some brain regions, including the STS, in the ASD than in the control group (e.g., Pelphrey et al., 2007). Several previous neuroimaging studies of typically developing individuals (e.g., Puce, Allison, Bentin, Gore, & McCarthy, 1998; for a review, see Allison, Puce, & McCarthy, 2000) have shown that the STS is involved in visual analyses of the dynamic or changeable aspects of faces. Anatomical neuroimaging studies have also reported structural abnormalities in the STS of individuals with ASD (Levitt et al., 2003; Boddaert et al., 2004; Hadjikhani, Joseph, Snyder, & Tager–Flusberg, 2006). These data suggest that dysfunction of the STS may serve as the neural background

for the impaired recognition of dynamic changes in facial expressions among those with ASD.

The abnormal recognition of dynamic changes in facial expressions in ASD may play an important role in everyday life. In real face-to-face interactions, it is necessary to process dynamic facial expressions. Some researchers have proposed that a visual analysis of dynamic changes in facial expressions elicits subsequent processes related to emotional reactions and facial mimicry (e.g., Haxby et al., 2000; Sato et al., 2012). Previous studies in typically developing individuals have shown that observation of dynamic facial expressions in other individuals elicited emotional reactions (e.g., Sato & Yoshikawa, 2007a) and that emotional reactions in response to emotional facial expressions induced behaviors involved in regulating social relationships (e.g., Camras, 1977; for a review, see Keltner & Gross, 1999). Previous studies in typically developing individuals have also reported that observation of others' dynamic facial expressions elicited spontaneous facial mimicry (e.g., Sato & Yoshikawa, 2007b) and that such face-to-face mimicking created empathic bonds and elicited affiliative social behaviors in recipients (e.g., Guéguen, 2009; for a review, see Hess & Fischer, 2013). Together with these data, our results suggest that atypical visual processing of dynamic changes in facial expressions may underlie impairments in social interactions in ASD, including deficits in sharing emotions and coordinating social relationships.

One may assume that the abnormal processing of dynamic changes in facial expressions in ASD found in the present study can be accounted for by the deficit in lower-level motion processing, which has been shown in some studies using stimuli such as dot motions (e.g., Spencer et al., 2000). However, other studies have found intact ability

in lower-level motion processing in individuals with ASD (e.g., de Jonge et al., 2007; for a review, see Grinter et al., 2010). Some studies have also reported a deficit in lower-level form processing (e.g., Spencer & O'Brien, 2006). Thus, it seems unlikely that the present results could be explained solely in terms of a problem with lower-level motion processing. We speculate that the impairment in the visual analysis of dynamic changes in facial expressions may be attributable, at least in part, to the role this process plays in integrating information from both lower-level motion- and form-processing streams, each of which is impaired in individuals with ASD, albeit less severely.

Our results showed that, in contrast to typically developing individuals, individuals with ASD did not recognize slower changes in facial expressions as unnatural compared with faster changes. These results may have practical implications about the use of intentionally slowed changes in facial expressions to transmit emotional messages to individuals with ASD. Consistent with this notion, some previous studies have demonstrated that slow presentations of dynamic facial expressions were effective in helping individuals with ASD recognize and imitate facial expressions of emotion (Tardif et al., 2007; Lainé, Rauzy, Tardif, & Gepner, 2011). Taken together, these data suggest that caregivers can utilize intentionally slow changes in facial expressions to communicate with individuals with ASD.

Several limitations of this study should be acknowledged. First, because we used only emotional facial expressions as stimuli, issues related to the recognition of dynamic changes in non-emotional facial signals in individuals with ASD remain unexamined. Indeed, dynamic properties are not restricted to emotional facial signals. For example, certain facial actions occurring during interactions, such as raising one's eyebrow to

indicate questioning, have been shown to have symbolic significance (Bavelas & Chovil, 1997). Several previous studies have shown that recognition of non-emotional communicative signals was impaired in individuals with ASD (e.g., Baron-Cohen, Jolliffe, Mortimore, & Robertson, 1997). Therefore, it appears reasonable to assume that the recognition of dynamic changes in non-emotional facial gestures may also be impaired in these individuals. Further investigation of the recognition of other types of dynamic facial signals by individuals with ASD is an important subject for future research.

Second, because we tested only adult participants, the developmental trajectory of this phenomenon remains unknown. Several previous studies have shown that the processing of static facial expressions changes during the course of development in typically developing individuals (e.g., Kolb, Wilson, & Taylor, 1992). A few studies have also shown abnormality in these developmental patterns in ASD groups (e.g., Uono et al., 2011). Although evidence is lacking, it seems highly plausible that we would observe analogous age-related differences in the processing of dynamic changes in facial expressions by typically developing individuals compared with those with ASD. Promising directions for further investigation include the elucidation of such developmental courses.

5. Conclusions

In summary, our results showed that the correspondence between decreases in naturalness ratings and reductions in speed of facial change was weaker in the ASD than in the control group. These results suggest that atypical visual processing of dynamic changes in facial expressions may underlie the impairments in real-life social interactions involving

emotional facial expressions experienced by those with ASD.

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