Running Head: Representational momentum in ASD

Reduced representational momentum for subtle dynamic facial expressions in individuals with autism spectrum disorders

Shota Uono[1], Wataru Sato[2], Motomi Toichi[1,3]

1 Graduate School of Medicine, Faculty of Human Health Science, Kyoto University, 53 Shogoin Kawahara-cho, Sakyo-ku, Kyoto 606-8507, Japan.

2 The Hakubi Project, Primate Research Institute, Kyoto University, Inuyama, Aichi 484-8506, Japan.

3 The Organization of Promoting Developmental Disorder Research, 40 Shogoin Sannou-cho, Sakyo-ku, Kyoto 606-8392, Japan.

Correspondence concerning this article should be addressed to Shota Uono, Graduate School of Medicine, Faculty of Human Health Science, Kyoto University, 53 Shogoin Kawahara-cho, Sakyo-ku, Kyoto 606-8507, Japan.

Tel: +81- 75-751-3965; Fax: +81-75-751-3965;

E-mail: uonoshota1982@gmail.com

Abstract

The cognitive mechanisms underlying social communication via emotional facial expressions are crucial for understanding the social impairments experienced by people with autism spectrum disorders (ASD). A recent study (Yoshikawa & Sato, 2008) found that typically developing individuals perceived the last image from a dynamic facial expression to be more emotionally exaggerated than a static facial expression; this perceptual difference is termed representational momentum (RM) for dynamic facial expressions. RM for dynamic facial expressions might be useful for detecting emotion in another's face and for predicting behavior changes. We examined RM for dynamic facial expressions using facial expression stimuli at three levels of emotional intensity (subtle, medium, and extreme) in people with ASD. We predicted that individuals with ASD would show reduced RM for dynamic facial expressions. Eleven individuals with ASD (three with Asperger's disorder and eight with pervasive developmental disorder not otherwise specified) and 11 IQ-, age- and gender-matched typically developing controls participated in this study. Participants were asked to select an image that matched the final image from dynamic and static facial expressions. Our results revealed that subjectively perceived images were more exaggerated for the dynamic than for the static presentation under all levels of intensity and in both groups. The ASD group, however, perceived a reduced degree of exaggeration for dynamic facial expressions under the subtle intensity condition. As facial expressions are often displayed subtly in daily communications, reduced RM for subtle dynamic facial expressions may prevent individuals with ASD from appropriately interacting with other people as a consequence of their difficulty detecting others’ emotions.

Keywords: Autism spectrum disorders; Dynamic facial expression; Representational momentum; Social impairment

Reduced representational momentum for subtle dynamic facial expressions in individuals with autism spectrum disorders

1. Introduction

Individuals with autism spectrum disorders (ASD) have difficulty with social interaction, including communication via emotional facial expressions (American Psychiatric Association [APA], 2000). Clinical observation studies have consistently confirmed that individuals with ASD are impaired in many types of social interactions involving facial expressions. For example, previous studies examining children's behavior under structured conditions have demonstrated that individuals with ASD exhibit reduced attention (Sigman, Kasari, Kwon, & Yirmiya, 1992), emotional behaviors (Corona, Dissanayake, Arbelle, Wellington, & Sigman, 1998), and facial reactions (Yirmiya, Kasari, Sigman, & Mundy, 1989) in response to the facial expressions of other individuals.

Extensive work has also been done to investigate the processing of emotional facial expressions in individuals with ASD, though findings still remain rather inconsistent. Almost all of these studies have used static facial expressions as stimuli. In some of these studies, individuals with ASD have shown more perturbation in the ability to recognize facial expressions than typically developing individuals (Ashwin, Chapman, Colle, & Baron-Cohen, 2006; Braverman, Fein, Lucci, & Waterhouse, 1989; Celani, Battacchi, & Arcidiacono, 1999). However, other studies have failed to show such impaired recognition (Adolphs, Sears, & Piven, 2001; Castelli, 2005; Grossman, Klin, Carter, & Volkmar, 2000).

Everyday communication of emotions is largely based on dynamic facial cues. Real-life facial expressions reflect dynamic, moment-to-moment changes in emotional state (Ekman & Friesen, 1975). A growing body of studies has consistently shown that various psychological activities including subjective perception (Yoshikawa & Sato, 2008), recognition (Ambadar, Schooler, & Cohn, 2005; Bould & Morris, 2008; Bould, Morris, & Wink, 2008), and emotional responses (Sato & Yoshikawa, 2007a, 2007b) are enhanced in response to dynamic expressions as compared with static facial expressions. Neuroimaging studies have also demonstrated that some brain regions show increased activity in response to dynamic, rather than static, facial expressions (LaBar, Crupain, Voyvodic, & McCarthy 2003; Sato, Kochiyama, Yoshikawa, Naito, & Matsumura, 2004). Taken together, these findings indicate that dynamic facial expressions are more effective for emotional communication than are static facial stimuli. These findings also suggest the possibility that individuals with ASD may have more difficulty processing dynamic facial expressions than static facial expressions.

To investigate the processing of dynamic facial expressions in individuals with ASD, pioneering studies have examined their recognition of these stimuli (Gepner, Deruelle, & Grynfeltt, 2001; Tardif, Lainé, Rodriguez, & Gepner, 2007). Gepner et al. (2001) showed that a strobe presentation (i.e., presentation of a few frames of a clip revealing changes in dynamic facial expressions, to produce the illusion of motion) improved facial expression recognition as measured by a matching-to-sample task, compared to static presentation, in typically developing controls but not in individuals with ASD. However, individuals with ASD were able to recognize both dynamic and static facial expressions. Using a similar matching-to-sample method, Tardif et al. (2007) demonstrated that individuals with ASD were less able than typically developing individuals to recognize dynamic and static facial expressions, but slowing down the presentation of dynamic facial expressions improved their recognition. These studies suggest differences in performance between individuals with ASD and typically developing individuals in the recognition of dynamic facial expression. However, dynamic presentation did not improve the recognition of facial expressions by typically developing individuals in these studies. Recently, Kessels, Spee, and Hendriks (2010) found that labeling of dynamic facial expressions, specifically those of fearful and disgusted emotions, was defective in individuals with ASD. However, recognition involved several processing stages; these included perceptual processing, interpretation of emotional meaning, and selection of an appropriate verbal label. Consequently, it is difficult to reach definite conclusions about which of the stages involved in processing dynamic facial expressions are impaired in individuals with ASD. To elucidate impairments specific to ASD, it is necessary to use an experimental paradigm in which dynamic presentation enhances the processing of facial expressions in typically developing individuals and to examine each component of this dynamic facial expression processing, such as the perception and interpretation of emotional meaning.

Functional magnetic resonance imaging (fMRI) studies have shown that dynamic facial expressions elicit atypical neural activation in several brain regions of ASD individuals (Pelphrey, Morris, McCarthy, & Labar, 2009; Sato, Toichi, Uono, & Kochiyama, 2012). Pelphrey et al. (2007) presented dynamic and static facial expressions depicting anger, fear, or neutral emotions, and found that observation of dynamic facial expressions elicited less activation in the superior temporal sulcus/middle temporal gyrus (STS/MTG), fusiform gyrus (FG), amygdala (AMY), and medial prefrontal cortex (MPFC) in individuals with ASD compared to typically developing individuals. Sato et al. (2012) extended these findings using happy and fearful emotional stimuli. The results showed that, compared to the typically developing group, the ASD group exhibited less activation in the brain regions described above, and also in the inferior frontal gyrus (IFG), in response to dynamic facial expressions. These regions are involved in various aspects of processing of social stimuli, including visual analysis of the dynamic aspects of faces (STS/MTG; Allison, Puce, & McCarthy, 2000); visual analysis of the invariant aspects of faces; the subjective perception of faces (FG; Haxby, Hoffman, & Gobbini, 2000); emotional processing (AMY; Calder, Lawrence, & Young, 2001); attribution of mental states (MPFC; Frith & Frith, 2003); and motor mimicry (IFG; Iacoboni, 2005). It is tempting to speculate that deficits in such psychological functions influence the processing of dynamic facial expressions in individuals with ASD. However, as fMRI has inherent technical limitations in terms of temporal resolution, and as the abovementioned brain regions are functionally and structurally connected, it remains unclear which level or levels of processing are impaired in the processing of dynamic facial expressions in individuals with ASD.

To investigate the more rapid components of dynamic facial expression processing, Uono, Sato, and Toichi (2010) recently studied the subjective perception of facial expressions in individuals with ASD. This study measured the representational momentum (RM) of dynamic facial expressions. RM refers to a phenomenon in which the perceived final position of a moving object shifts in the direction of the actually observed movement (Freyd & Finke 1984; Hubbard, 1990). This effect has also been reported in the perception of biological stimuli, including dynamic facial expressions (Hudson, Liu, & Jellema, 2009; Yoshikawa & Sato, 2008). Uono et al. presented dynamic or static facial expressions and asked participants to choose from a display of variable emotional expressions the image that matched the final image from the presented expression. In this task, dynamic presentation clearly enhanced processing of facial expressions in typically developing individuals (Yoshikawa & Sato, 2008). Further, the task allowed the perceptual processing of dynamic facial expressions to be investigated, because neither interpretation of emotional meaning nor selection of a verbal label was required. Contrary to expectations, both those with and without ASD perceived the final images from the dynamic facial expressions to be more emotionally exaggerated than the static facial expressions. This finding suggests that individuals with ASD have an intact ability to process dynamic information from facial cues, at least on a perceptual level.

However, one limitation of that study was that only a single intensity level of facial expression stimuli was used. The stimuli were at a facial expression intensity of 80% based on a standard set (Ekman & Friesen, 1976) and showed clear to moderately clear emotions.

One important area for exploration involves studying subtle facial expressions. In everyday communication, many facial expressions are displayed with subtle intensity (Ekman, 2003; Motley & Camden, 1988). Behavioral studies suggest that the detection of subtle expressions provides an advantage in social interactions (e.g., Warren, Schertler, & Bull, 2009; Yoon, Joormann, & Gotlib, 2009) because it allows us to notice others' subtle emotional changes and to regulate our own behaviors appropriately. Consistent with these notions, it has been suggested that dynamic information is more important when processing subtle than when processing intense emotional expressions (cf. Ambadar et al., 2005; Bould & Morris, 2008; Bould et al., 2008). If RM for dynamic facial expressions is an adaptive mechanism for detecting emotion, it is assumed to play a particularly crucial role in processing subtle expressions. Thus, one contributor to the social interaction difficulties of individuals with ASD may be compromised processing of subtle dynamic facial expressions. We hypothesize that individuals with ASD may perceive subtle dynamic facial expressions in a less exaggerated form than typically developing individuals do.

Another possible avenue of exploration would be to use more extreme facial expressions. In the previous study that tested RM in typically developing individuals (Yoshikawa & Sato, 2008), the researchers suggested that the effects of dynamic facial expressions tend to be weaker at 100% intensity compared with at 80% intensity. Yoshikawa and Sato speculated that the RM for 100% expressions might be suppressed because participants evaluate such expressions as extreme during realistic social interactions. A recent behavioral study (Rutherford & McIntosh, 2007) investigated the perception of facial expressions varying in intensity in ASD. Rutherford and McIntosh (2007) presented two emotional faces with different intensities and asked participants to select the more realistic image. The results showed that individuals with ASD were more likely to judge extremely exaggerated facial expressions as the most realistic. Based on these findings, dynamic facial expressions of extremely high intensity might trigger further changes in individuals with ASD, but not controls, whereas those of medium intensity did so in both groups. Thus, we hypothesized that individuals with ASD might perceive dynamic facial expressions as more exaggerated than normal controls do under the highest intensity condition.

This study investigated RM for dynamic facial expressions at various intensities among individuals with high-functioning ASD and IQ-, age-, and gender-matched typically developing controls. We presented dynamic and static facial expressions at subtle, medium, and extreme intensities and asked participants to change an emotional face display to match the perceived final image from dynamic and static facial expression stimuli. Based on a previous study (Uono et al., 2010) and the aforementioned evidence, we predicted that (1) both the ASD and control groups would perceive the final images from the dynamic facial expressions to be more emotionally exaggerated than the static facial expressions; (2) the ASD group would perceive subtle dynamic facial expressions as less exaggerated than would the control group; and (3) the ASD group, compared with the control group, would perceive dynamic facial expression as more exaggerated under the extremely intense emotion condition.

2. Materials and methods

2.1 Participants

The participants were 11 individuals with ASD and 11 typically developing controls. The two groups (ASD and control) were matched for chronological age (ASD group: mean ± *SD* = 22.1 ± 4.8; control: mean ± *SD* = 22.8 ± 2.5; independent *t*-test, $t(20) = 0.46$, $p > 0.10$), gender (ASD group: eight males, three females; control: seven males, four females; Fisher's exact test, $p > 0.10$) and IQ (mean ± *SD* verbal IQ, control: 117.1 ± 10.9, ASD: 113.1 ± 10.2, $t(20) = 0.86$, $p > 0.10$; mean ± *SD* performance IQ, control: 111.5 ± 10.7, ASD: 108.5 ± 13.9, $t(20) = 0.57$, $p > 0.10$; mean ± *SD* full-scale IQ, control: 116.1 ± 10.3, ASD: 111.6 ± 9.9, $t(20) = 1.03$, $p > 0.10$) . Verbal and performance IQ was measured using the Japanese version of the WAIS-R (Shinagawa, Kobayashi, Fujita, & Maekawa, 1990), WAIS-III (Fujita, Maekawa, Dairoku, & Yamanaka, 2006), WISC-R (Kodama, Shinagawa, & Motegi, 1982), and WISC-III (Azuma et al., 1998). Handedness was assessed in individuals with and without ASD using the Edinburgh Handedness Inventory (Oldfield, 1971). The scores did not differ between groups (control: mean ± *SD* = 80.0 ± 53.7; ASD: mean ± *SD* = 80.0 ± 41.0; independent *t*-test, $t(20) < 0.01$, $p > 0.10$). Both groups included 10 right-handed and one left-handed participants. All the participants had normal or corrected-to-normal visual acuity.

The participants in the ASD group were diagnosed with either Asperger's disorder (three males) or pervasive developmental disorder not otherwise specified (PDD-NOS; five males and three females) at the time of the present study according to the DSM-IV-TR criteria (APA, 2000). PDD-NOS includes heterogeneous subgroups of PDD with varying degrees of qualitative social impairment. The participants with PDD-NOS included in the present study did not satisfy criteria for Asperger's disorder because 1) they had similar impairments in qualitative social interaction without apparently restricted interests or stereotyped behaviors, or (2) their impairment in qualitative social interaction was milder than that observed in Asperger's disorder. Thus, our participants with PDD-NOS had milder pathologies than did those with Asperger's disorder. The final diagnoses were made by a child psychiatrist (MT) based on the reports of clinical psychologists, interviews with each participant, information from each participant's parents or teachers, and childhood clinical records when available. The participants in the ASD group were outpatients who had been referred to Kyoto University Hospital or to the Division of Human Health Science of Kyoto University Graduate School of Medicine due to social maladaptation. They were all free of neurological or psychiatric problems other than those derived from ASD, and none was receiving any medication. The members of the typically developing control group were students at several universities who were recruited using paper- and web-based advertisements. After acquiring the data from the ASD group, we collected IQ data from typically developing participants. Eleven typically developing participants who matched the ASD group in terms of age and IQ were selected for participation. The participants aged younger than 18 years received written informed consent from their parents to participate in the study. The study was conducted in accord with institutional ethical provisions and the Declaration of Helsinki.

The severity of symptoms was assessed using the Childhood Autism Rating Scale (CARS; Schopler, Reichler, & Renner, 1986), which was completed based on interviews with participants and their parents and direct observations of participants during these interviews. The evaluations were performed by psychiatrists. The CARS has been shown to be an effective tool for diagnosing autism in adolescents, adults, and children (Mesibov, Schopler, Schaffer, & Michal, 1989). The CARS scores of the ASD group (mean ± *SD* = 21.04 ± 2.67) were comparable to those of Japanese individuals with Asperger's disorder in a previous study (mean ± *SD* = 22.22 ± 3.57; $t(45) = 1.01$, $p > 0.10$) (Koyama, Tachimori, Osada, Takeda, & Kurita, 2007). These data indicate that the symptoms of individuals in the ASD group were severe enough to allow for the diagnosis of ASD.

2.2 Design

The experiment was constructed as a three-factorial mixed randomized–repeated design, with group (ASD or control) as the randomized factor and presentation condition (dynamic or static) and intensity (52%, 80%, or 108%) as the repeated factors.

2.3 Stimuli

From a set of facial images (Ekman & Friesen, 1976), we selected one neutral expression slide and two emotional expression (fearful and happy) slides for each of four actors (two men and two women). We used computer-morphing techniques (Mukaida et al., 2000) to produce images that were intermediate between the neutral expression and each of the two emotional expressions in 4% steps. We produced dynamic facial expression stimuli that changed from 4% emotional expression to a maximum of 52%, 80%, or 108% of the original emotional expression in 4% steps. To create the images of 108% emotional expression, we changed the facial features of the 100% emotional expression in the direction opposite from that depicted in the neutral face. We presented a total of 13, 20, and 27 image frames in succession for the 52%, 80%, and 108% conditions, respectively (e.g., under the 52% condition, the first image was followed by 11 intermediate images changing from 8% to 48% in 4% steps, ending with the final image). Under the dynamic condition, each frame was presented for 10 ms. Thus, the total presentation time was 130 ms, 200 ms, and 270 ms for the 52%, 80%, and 108% conditions, respectively. Fig. 1 shows the first image, some intermediate images, and the final image of a dynamic stimulus. Under the static condition, only the last frame of each dynamic facial expression stimulus was presented. The total presentation time was the same as that for the dynamic facial expression with the corresponding intensity.

****

Place Fig. 1 around here

****

2.4 Apparatus

Stimulus presentation and data acquisition were controlled using a program written in Visual C++ 5.0 (Microsoft) on a Windows computer (HP xw4300 Workstation). Stimuli were presented on a 17-in CRT monitor (Iiyama; screen resolution 1024 × 768 pixels; refresh rate 100 Hz). The distance between the monitor and participants was fixed at approximately 57 cm using a headrest.

2.5 Procedure

The procedure in this study was the same as that used in previous studies (Uono et al., 2010; Yoshikawa & Sato, 2008). On the monitor, two windows were presented. The left window was used for stimulus presentation, and the right window was used for responses. The vertical and horizontal visual angles of the stimulus and response windows were 11.1° and 7.8°, respectively. In each trial, a cross hair was first presented at the center of the stimulus window. The participants were instructed to fixate on this. Then, a dynamic or static stimulus was presented in the stimulus window, and 250 ms later, an initial face image was presented in the response window. Participants were instructed to match the image in the response window exactly with the last image shown in the dynamic or static stimulus, by using the mouse to drag a slider to the left or right. The face shown in the initial image in the response window had an emotional expression with -10%, 0%, or +10% intensity of the presented stimuli (e.g., under the 52% condition, 42%, 52%, or 62%). The upper or lower limit of the slide had one of three predefined ranges, each of which covered an 80% range of intensity (e.g., under the 52% condition, 2–82%, 12–92%, or 22–102%). The ranges of the scale varied randomly across trials and were not visible to the participants. After a participant selected an image, he or she clicked a button, and the image in the response window disappeared. Then, the stimulus was presented again in the left window, and 250 ms later, the image chosen by the participant appeared in the response window. If the participant thought the images matched, he or she clicked the button on the display and went on to the next trial; if not, the participant could modify the image until he or she thought it matched. No time limits were set for the first or second judgment. Before starting the experiment, each participant was given several practice trials and allowed to practice image manipulation using the mouse to move the slider. A total of 48 trials (eight trials per condition) were performed in blocks, and the order of trials was counterbalanced across participants.

2.6 Data analysis

Data were analyzed using SPSS10.0J (SPSS Japan). For each participant, the mean intensity of response images was calculated for each condition. Then, the ratio between the intensity of responses and of presented images was calculated for each condition. The ratios were analyzed with a 2 (group) × 2 (presentation) × 3 (intensity) repeated-measures analysis of variance (ANOVA). To test our predictions, follow-up simple interaction analyses and simple–simple main-effect analyses were conducted (cf. Kirk, 1995).

The CARS (Schopler et al., 1986) was used to assess the level of social dysfunction in individuals with ASD. As in our previous studies (Uono, Sato, & Toichi, 2011; 2013), we used the following CARS items, which were classified as elements of the social functioning construct: ‘‘imitation,’’ ‘‘nonverbal communication,’’ ‘‘relationship to people,’’ ‘‘verbal communication,’’ and ‘‘visual response.’’ We averaged the scores on these items to obtain the social dysfunction scale. To analyze the relationships between degree of RM and CARS scores, the ratio between the mean intensity of the responses to images under dynamic and static conditions was calculated for each intensity condition. Pearson's product–moment correlations between combinations of these variables were calculated. The significance of correlation coefficients was evaluated using *t*-tests (two-tailed). We excluded multivariate outliers by calculating the Mahalanobis distance for each case ($p < 0.10$).

3. Results

The mean response under each condition (with *SE*) is shown in Table 1. The ratios between the intensity of response images and presented images were calculated (Fig. 2) and subjected to a group × presentation × intensity ANOVA. Most importantly, the results revealed a significant three-way interaction ($F(2, 40) = 3.52$, $p = 0.04$). Additionally, the results revealed a main effect of presentation ($F(1, 20) = 52.20$, $p < 0.01$), indicating that participants perceived more exaggerated images under dynamic than under static conditions. A main effect of intensity was also found ($F(2, 40) = 26.75$, $p < 0.01$). Other main effects and interactions were not significant ($F < 2.37$, ps > 0.10).

****

Place Table 1 and Fig. 2 about here

****

As follow-up analyses for the three-way interaction, a simple interaction analysis was conducted for each intensity condition. The results revealed that the simple interactions between group and presentation condition were significant under the 52% intensity condition ($F(1, 60) = 6.93$, $p = 0.01$) but not under the 80% ($F(1, 60) = 0.46$, $p > 0.10$) and 108% intensity conditions ($F(1, 60) = 1.52$, $p > 0.10$). A follow-up simple–simple main-effect analysis of group under the 52% intensity condition revealed that typically developing controls perceived more exaggerated images than did individuals with ASD under the dynamic condition ($F(1, 120) = 6.76$, $p = 0.01$) but not under the static condition ($F(1, 120) = 0.08$, $p > 0.10$).

To confirm the main effect of presentation which would replicate our previous findings (Uono et al., 2010; Yoshikawa & Sato, 2008), a follow-up analysis was conducted for each group and intensity. For the control group, the simple–simple main effects of presentation were significant under all intensity conditions (52%: $F(1, 60) = 34.03$, $p < 0.01$; 80%: $F(1, 60) = 5.21$, $p = 0.03$; 108%: $F(1, 60) = 22.29$, $p < 0.01$). For the ASD group, the simple–simple main effects of presentation were significant under all intensity conditions (52%: $F(1, 60) = 4.46$, $p = 0.04$; 80%: $F(1, 60) = 10.50$, $p < 0.01$; 108%: $F(1, 60) = 8.88$, $p < 0.01$). In sum, the results indicated that both control and ASD groups perceived the final dynamic facial expression images to be more exaggerated than the static expressions under all intensity conditions.

The correlation between the degree of RM and the CARS score was significant under the 52% ($r(10) = -0.71$, $p < 0.05$) but not the 80% ($r(11) = 0.33$, $p > 0.10$) or 108% ($r(11) = 0.14$, $p > 0.10$) condition, indicating that the greater the reduction in RM for subtle dynamic facial expressions, the more severe the extent of social dysfunction in that ASD individual (see Fig. 3).

****

Place Fig. 3 about here

****

4. Discussion

Our results indicated that both control and ASD groups perceived the final images in dynamic facial expressions to be more exaggerated than static facial expressions. These results support our first prediction and replicate previous findings showing the existence of RM for dynamic facial expressions in individuals without (Yoshikawa & Sato, 2008) and with ASD (Uono et al., 2010).

More importantly, our results reveal that when dynamic, but not static, facial expressions with subtle emotion are presented, typically developing controls perceive more exaggerated images than do individuals with ASD. This group difference is in line with previous studies suggesting that dynamic information is more important for the processing of subtle emotional expressions than for intense emotional expressions (Ambadar et al., 2005; Bould & Morris, 2008; Bould et al., 2008). The results of the present study are also consistent with the impaired recognition of dynamic facial expression in individuals with ASD found in previous studies (Kessels et al., 2010; Tardif et al., 2007). However, as no work has yet investigated subtle emotions in this paradigm, using RM, this is the first study to show the compromised processing of dynamic facial expressions with subtle emotions at a perceptual level. The results suggest that individuals with ASD and typically developing individuals may see their social world differently, though dynamic presentation enhances the subjective perception of facial expression in both groups. Yoshikawa and Sato (2008) suggested that exaggerated perceptions of dynamic facial expressions are useful for detecting the emotions of others. It follows that we can predict another person’s behavior based on his or her emotional changes. Consistent with this notion, the results revealed that the extent of reduction in RM for subtle dynamic facial expressions was closely related to the degree of social dysfunction in ASD individuals. As it is difficult to detect emotion in subtle emotional facial expressions, the more exaggerated perceptions of subtle dynamic facial expressions, shown by typically developing individuals in comparison with individuals with ASD, may play a crucial role in difficulties experienced by the latter group with regard to efficiently extracting emotional meaning from faces. Consequently, the reduced RM for dynamic facial expressions reflecting subtle emotions may prevent individuals with ASD from noticing the subtle emotional changes of others and regulating their own behaviors appropriately.

One might argue that the short presentation time under the 52% condition contaminated the processing of the stimuli by individuals with ASD. However, participants were asked to exactly match the image in the response window with the last image of the stimulus. The presentation time for the last image (10 ms) was identical across dynamic conditions. The performance of the ASD group was comparable to that of the control group under the 80% and 108% dynamic conditions. Furthermore, no difference in the performance of the groups was found under the 52% static condition, which used the same presentation time as under the dynamic condition. Based on these results, the short presentation time under the 52% condition cannot explain the reduced RM for subtle dynamic facial expressions in individuals with ASD.

The finding that individuals with ASD have a less exaggerated perception of subtle dynamic facial expressions is important for understanding the nature of impaired social interactions and emotional expression processing in ASD. Difficulty with facial communication is one of the diagnostic criteria for ASD (APA, 2000). Observational studies under structured conditions have demonstrated that individuals with ASD exhibit reduced attention and emotion in response to others’ dynamic facial expressions (Corona et al., 1998; Sigman et al., 1992; Yirmiya et al., 1989). However, experimental studies investigating the processing of dynamic (Gepner et al., 2001; Kessels et al., 2010; Tardif et al., 2007) and static (Adolphs et al., 2001; Ashwin et al., 2006; Braverman et al., 1989; Castelli, 2005; Celani et al., 1999; Grossman et al., 2000) facial expressions with relatively intense emotions have reported conflicting findings. Emotional communication in daily life is mainly based on dynamic facial cues. Facial expressions are often displayed with subtle intensity (Ekman, 2003; Motley & Camden, 1988). Based on the results of the present study, the use of dynamic facial expressions depicting subtle emotion reveals impairments in the emotional communication of people with ASD, even in experimental settings. The less exaggerated perception of subtle dynamic facial expressions may explain the discrepancy between experimental settings and real-life in individuals with ASD as experimental settings have generally used dynamic facial expressions depicting intense emotion. The use of subtle dynamic facial expressions may be useful for revealing deficits in other components of the processing of dynamic facial expressions among those with ASD (e.g., recognition, physiological responses, and subjective feelings).

Impairment of low-level and biological motion processing might explain reduced RM to subtle dynamic facial expressions in ASD, as individuals who are at risk for the impairment of motion processing show reduced RM (Taylor & Jacobson, 2010). There is evidence that individuals with ASD have impairments in the perception of biological motion depicting human actions (Blake, Turner, Smoski, Pozdol, & Stone, 2003), particularly emotional actions (Hubert et al., 2007; Moore, Hobson, & Lee 1997). Moore et al. (1997) found that few children with ASD could correctly recognize biological motion when stimuli were presented briefly, although their performance did not significantly differ from that of children with mental retardation. Furthermore, Atkinson (2009) demonstrated that impaired recognition of biological motion depicting emotional actions was associated with a deficit in low-level motion processing in ASD, and recently, individual differences have been reported in the degree of this impairment (Milne et al., 2002; Pellicano, Gibson, Maybery, Durkin, & Badcock, 2005). Based on these findings, the reduced RM in dynamic facial expressions with subtle, but not intense, emotion might reflect variability in the impairment of low-level and biological motion processing. Subtle expressions are more likely to reveal varying levels of impairment in dynamic facial expression processing.

Our current findings provide insights into the neural mechanisms involved in processing of dynamic facial expressions. Previous studies reported reductions in brain activation of ASD individuals in response to dynamic facial expressions (Pelphrey et al., 2007; Sato et al., 2012). The brain regions affected were the STS/MTG and IFG, which are associated with processing of the dynamic aspects of social stimuli (Allison et al., 2000; Iacoboni, 2005). Moreover, it has been suggested that these two regions are directly connected (Catani, Howard, Pajevic, & Jones, 2002; Rilling et al., 2008; Thiebaut de Schotten et al., 2011). Sato et al. (2012) showed that effective bidirectional connectivity in the primary visual cortex–STS/MTG–IFG circuit is enhanced during observation of dynamic versus static facial expressions in typically developing individuals but not in those with ASD. In agreement with previous neuroimaging results, the current findings indicating diminished perception of emotional intensity in ASD individuals suggest that bidirectional information flow may play an important role in the enhancement of the perception of emotional intensity in dynamic facial expressions. The work of a previous behavioral study showing that facial imitation is associated with

IFG function (Iacoboni, 2005), and facilitates the recognition of dynamic facial expressions (Niedenthal, Brauer, Halberstadt, & Innes-Ker, 2001), encourages us to speculate that feedback input from the IFG and the STS to the visual cortex modulates the subjective perception of dynamic facial expressions.

Our results did not support our third prediction, namely that individuals with ASD would show stronger RM than would controls in response to extreme dynamic facial expressions. There might be several reasons for this result. First, the clear RM in typically developing individuals might mask any group difference. Yoshikawa and Sato (2008) noted that RM for dynamic facial expressions among typically developing individuals is suppressed at 100% intensity. In the present study, it is possible that facial expressions with intense emotion (108%) might seem equally natural to individuals with and without ASD. Using even more exaggerated facial expressions as stimuli may still induce a group difference in RM. Second, the speed of movement (10 ms per frame) might affect RM under the 108% condition. In research conducted by Yoshikawa and Sato, slowing down the presentation of dynamic facial expressions to 40 ms per frame induced a reduction in RM, particularly when facial expressions with intense emotion were used (Experiment 1). Tardif et al. (2007) found that slowing down presentation improved recognition of dynamic facial expression in individuals with ASD but not in typically developing individuals. Thus, slowing down the presentation of dynamic facial expressions with intense emotions might reveal a difference in RM between individuals with and without ASD.

It should be acknowledged that this study had several limitations. First, the dynamic facial expressions used in the present study represented a linear transition developed using a computer morphing technique because this approach is advantageous for controlling the amount of change and reducing the noise. However, actual facial expressions would differ from the present stimuli in terms of the pattern of kinematics in each facial feature. It may be helpful to use real dynamic facial expressions to further elucidate the deficits in RM for dynamic facial expressions. Second, the present study did not address the possibility that clinical symptoms other than ASD also affected perceptions of subtle dynamic facial expressions. Although the participants with ASD in the present study did not meet the criteria for neurological or other psychiatric disorders, previous studies have found that individuals with ASD have high rates of associated psychiatric problems, including anxiety and depression (e.g., de Bruin, Ferdinand, Meester, de Nijs, & Verheij, 2007). Interestingly, recent behavioral studies also suggest that the extent of co-morbid alexithymia contributes to emotional recognition impairments in ASD individuals (see Bird and Cook (2013) for a review). Promising directions for further research include analysis of the effects of psychological states and traits on individuals with and without ASD.

5. Conclusions

In summary, the present study showed that individuals with ASD perceived the final images in dynamic facial expressions to be more exaggerated than static facial expressions. However, when they observed facial expressions with subtle emotion, typically developing controls perceived them as more exaggerated than did individuals with ASD under dynamic but not under static conditions. Emotional communication in daily life is based principally on dynamic facial cues, and facial expressions are often subtle. It is possible that individuals with ASD, with their reduced perception of emotional intensity, have a reduced ability to detect subtle changes in other people's facial expressions for use as information for adaptive behavioral responses.

Acknowledgements

We would like to thank Dr. Sayaka Yoshimura for recruiting participants. We are grateful to both our volunteer study participants and their parents.

Role of the funding source

This study was supported by Grant-in-Aid for JSPS Fellows (08J07939; 11J05000); the JSPS Funding Program for Next Generation World-Leading Researchers (LZ008); grant support for graduate students awarded by the Kyoto University GCOE program (Revitalizing Education for Dynamic Hearts and Minds); the Organization for Promoting Developmental Disorder Research; and the Benesse Corporation. No funding source had any involvement in study design; in the collection, analysis, or interpretation of data; in the writing of the report; or in the decision to submit the article for publication.

References

Adolphs, R., Sears, L., & Piven, J. (2001). Abnormal processing of social information from faces in autism. *Journal of Cognitive Neuroscience*, *13*, 232–240.

Allison, T., Puce, A., & McCarthy, G. (2000). Social perception from visual cues: Role of the STS region. *Trends in Cognitive Sciences, 4*, 267–278.

Ambadar, Z., Schooler, J.W., & Cohn, J.F. (2005). Deciphering the enigmatic face: The importance of facial dynamics in interpreting subtle facial expressions. *Psychological Science*, *16*, 403–410.

American Psychiatric Association (2000). *Diagnostic and statistical manual for mental disorders (DSM-IV-TR).* Washington, DC: Author.

Ashwin, C., Chapman, E., Colle, L., & Baron-Cohen, S. (2006). Impaired recognition of negative basic emotions in autism: A test of the amygdala theory. *Social Neuroscience, 1*, 349–363.

Atkinson, A. P. (2009). Impaired recognition of emotions from body movements is associated with elevated motion coherence thresholds in autism spectrum disorders. *Neuropsychologia, 47*, 3023–3029.

Azuma, H., Ueno, K., Fujita, K., Maekawa, H., Ishikuma, T., & Sano, H. (1998). *Japanese Wechsler intelligence scale for children—III*. Tokyo:

Nihon-Bunka-Kagaku-sha.

Bird, G., & Cook, R. (2013). Mixed emotions: The contribution of alexithymia to the emotional symptoms of autism. *Translational Psychiatry, 3*, e285.

Blake, R., Turner, L.M., Smoski, M.J., Pozdol, S.L., & Stone, W.L. (2003). Visual recognition of biological motion is impaired in children with autism. *Psychological Science, 14*, 151–157.

Bould, E., & Morris, N. (2008). Role of motion signals in recognizing subtle facial expressions of emotion. *British Journal of Psychology, 99*, 167–189.

Bould, E., Morris, N., & Wink, B. (2008). Recognising subtle emotional expressions: The role of facial movements. *Cognition and Emotion, 22*, 1569–1587.

Braverman, M., Fein, D., Lucci, D., & Waterhouse, L. (1989). Affect comprehension in children with pervasive developmental disorders. *Journal of Autism and Developmental Disorders, 19*, 301–316.

de Bruin, E.I., Ferdinand, R.F., Meester, S., de Nijs, P.F.A., & Verheij, F. (2007). High rates of psychiatric co-morbidity in PDD-NOS. *Journal of Autism and Developmental Disorders, 37*, 877–886.

Calder, A. J., Lawrence, A. D., & Young, A. W. (2001). Neuropsychology of fear and loathing. *Nature Reviews Neuroscience, 2*, 352–363.

Castelli, F. (2005). Understanding emotions from standardized facial expressions in autism and normal development. *Autism, 9,* 428–449.

Catani M., Howard, R. J., Pajevic, S., & Jones, D. K. (2002). Virtual in vivo interactive dissection of white matter fasciculi in the human brain. *Neuroimage, 17*, 77-94.

Celani, G., Battacchi, M. W., & Arcidiacono, L. (1999). The understanding of the emotional meaning of facial expressions in people with autism. *Journal of Autism and Developmental Disorders, 29,* 57–66.

Corona, R., Dissanayake, C., Arbelle, S., Wellington, P., & Sigman, M. (1998). Is affect aversive to young children with autism? Behavioral and cardiac responses to experimenter distress. *Child Development, 69*, 1494–1502.

Ekman, P. (2003). *Emotions revealed.* New York: Times Books

Ekman, P. and Friesen, W.V. (1975). *Unmasking the face: A guide to recognizing emotions from facial clues.* Englewood Cliffs, NJ: Prentice-Hall.

Ekman, P., & Friesen, W.V. (1976). *Pictures of facial affect.* Palo Alto, CA: Consulting Psychologists Press.

Freyd, J. J., & Finke, R. A. (1984). Representational momentum. *Journal of Experimental Psychology: Learning, Memory and Cognition, 10*, 126–132.

Frith, U., & Frith, C. D. (2003). Development and neurophysiology of mentalizing.

Proceedings of the Royal Society of London B: Biological Sciences, 358, 459–473.

Fujita, K., Maekawa, H., Dairoku, H., & Yamanaka, K.. (2006). *Japanese Wechsler adult intelligence scale—III.* Tokyo: Nihon-Bunka-Kagaku-sha.

Gepner, B., Deruelle, C., & Grynfeltt, S. (2001). Motion and emotion: A novel approach to the study of face processing by young autistic children. *Journal of Autism and Developmental Disorders, 31,* 37–45.

Grossman, J. B., Klin, A., Carter, A.S., & Volkmar, F. R. (2000). Verbal bias in recognition of facial emotions in children with Asperger syndrome. *Journal of Child Psychology and Psychiatry, 41*, 369–379.

Haxby, J. V., Hoffman, E. A., & Gobbini M. I. (2000). The distributed human neural system for face perception. *Trends in Cognitive Sciences*, *4*, 223–233.

Hubbard, T. L. (1990). Cognitive representation of linear motion: Possible direction and gravity effects in judged displacement. *Memory and Cognition*, *18*, 299–309.

Hubert, B., Wicker, B., Moore, D. G., Monfardini, E., Duverger, H., Da Fonseca, D., et al. (2007). Recognition of emotional and non-emotional biological motion in individual with Autistic Spectrum Disorders. *Journal of Autism and Developmental Disorders, 37,* 1386–1392.

Hudson, M., Liu, C. H., & Jellema, T. (2009). Anticipating intentional actions: The effect of eye gaze direction on the judgment of head rotation. *Cognition, 112*, 423-434.

Iacoboni, M. (2005). Neural mechanisms of imitation. *Current Opinion in Neurobiology, 15*, 632–637.

Kessels, R. P. C., Spee, P., & Hendriks, A. W. (2010). Perception of dynamic facial emotional expressions in adolescents with autism spectrum disorders (ASD). *Translational Neuroscience*, *1*, 228-232.

Kirk, R. E. (1995). *Experimental design: Procedures for the behavioral sciences* (3rd ed.). Pacific Grove, CA: Brooks/Cole.

Kodama, H., Shinagawa, F., & Motegi, M. (1982). *Japanese Wechsler intelligence scale for children—revised.* Tokyo: Nihon-Bunka-Kagaku-sha.

Koyama, T., Tachimori, H., Osada, H., Takeda, T., & Kurita, H. (2007). Cognitive and symptom profiles in Asperger's syndrome and high-functioning autism. *Psychiatry and Clinical Neuroscience, 61*, 99–104.

LaBar, K. S., Crupain, M. J., Voyvodic, J. T., & McCarthy, G. (2003). Dynamic perception of facial affect and identity in the human brain. *Cerebral Cortex, 13*, 1023–1033.

Mesibov, G. B., Schopler, E., Schaffer, B., & Michal, N. (1989). Use of the Childhood

Autism Rating Scale with autistic adolescents and adults. *Journal of the American Academy of Child and Adolescent Psychiatry, 28,* 538–541.

Milne, E., Swettenham, J., Hansen, P., Campbell, R., Jeffries, H., & Plaisted, K. (2002). High motion coherence thresholds in children with autism. *Journal of Child Psychology and Psychiatry, 43*, 255–263.

Moore, D. G., Hobson, R. P., & Lee, A. (1997). Components of person perception: An investigation with autistic, non-autistic retarded and typically developing children and adolescents. *British Journal of Developmental Psychology, 15*, 401–423.

Motley, M., & Camden, C. (1988). Facial expression of emotion: A comparison of posed expressions versus spontaneous expressions in an interpersonal communications setting. *Western Journal of Speech Communication*, *52*, 1−22.

Mukaida, S., Kamachi, M., Kato, T., Oda, M., Yoshikawa, S., & Akamatsu, S. (2000). *Foolproof utilities for facial image manipulation.* Kyoto: ATR [unpublished computer software].

Niedenthal, P. M., Brauer, M., Halberstadt, J. B., & Innes-Ker, Å. H. (2001). When did her smile drop? Facial mimicry and the influences of emotional state on the detection of change in emotional expression. *Cognition and Emotion, 15*, 853–864.

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia, 9*, 97−113.

Pellicano, E., Gibson, L., Maybery, M., Durkin, K., & Badcock, D. R. (2005). Abnormal global processing along the dorsal visual pathway in autism: A possible mechanism for weak visuospatial coherence? *Neuropsychologia*, *43*, 1044–1053.

Pelphrey, K. A., Morris, J. P., McCarthy, G., & Labar, K. S. (2007). Perception of dynamic changes in facial affect and identity in autism. *Social Cognitive and Affective. Neuroscience, 2*, 140–149.

Rilling, J.K., Glasser, M.F., Preuss, T. M., Ma, X., Zhao, T., Hu, X., et al. (2008). The evolution of the arcuate fasciculus revealed with comparative DTI. *Nature Neuroscience, 11*, 426–428.

Rutherford, M. D., & McIntosh, D. N. (2007). Rules versus prototype matching: Strategies of perception of emotional facial expressions in the autism spectrum. *Journal of Autism and Developmental Disorders, 37*, 187–196.

Sato, W., Kochiyama, T., Yoshikawa, S., Naito, E., & Matsumura, M. (2004). Enhanced neural activity in response to dynamic facial expressions of emotion: An fMRI study. *Brain Research: Cognitive Brain Research, 20*, 81–91.

Sato, W., Toichi, M., Uono, S., & Kochiyama, T. (2012). Impaired social brain network for processing dynamic facial expressions in autism spectrum disorders. *BMC*

Neuroscience, 13, 99.

Sato, W., & Yoshikawa, S. (2007a). Enhanced experience of emotional arousal in response to dynamic facial expressions. *Journal of Nonverbal Behavior, 31*, 119–135.

Sato, W., & Yoshikawa, S. (2007b). Spontaneous facial mimicry in response to dynamic facial expressions. *Cognition, 104*, 1–18.

Schopler, R., Reichler, R. J., & Renner, B. R. (1986). *The Childhood Autism Rating Scale (CARS) for diagnostic screening and classification of autism.* New York: Irvington.

Shinagawa, F., Kobayashi, D., Fujita, K., & Maekawa, H. (1990). *Japanese Wechsler adult intelligence scale‒revised.* Tokyo: Nihon-Bunka-Kagaku-sha.

Sigman, M. D., Kasari, C., Kwon, J. H., & Yirmiya, N. (1992). Responses to the negative emotions of others by autistic, mentally retarded, and normal children. *Child Development*, *63*, 796–807.

Tardif, C., Lainé, F., Rodriguez, M., & Gepner, B. (2007). Slowing down presentation of facial movements and vocal sounds enhances facial expression recognition and induces facial‑vocal imitation in children with autism. *Journal of Autism and Developmental Disorders, 37*, 1469–1484.

Taylor, N., & Jacobson, L. (2010). Representational momentum in children born preterm and at term. *Brain and Cognition, 72*, 464–471.

Thiebaut de Schotten, M., Ffytche, D. H., Bizzi, A., Dell'Acqua, F., Allin, M., Walshe, M., et al. (2011). Atlasing location, asymmetry and inter-subject variability of white matter tracts in the human brain with MR diffusion tractography. *NeuroImage*, *54*, 49–59.

Uono, S., Sato, W., & Toichi, M. (2010). Brief report: Representational momentum for dynamic facial expressions in pervasive developmental disorder. *Journal of Autism and Developmental Disorders, 40*, 371–377.

Uono, S., Sato, W., & Toichi, M. (2011). The specific impairment of fearful expression recognition and its atypical development in pervasive developmental disorder. *Social Neuroscience, 6*, 452-463.

Uono, S., Sato, W., & Toichi, M. (2013). Common and unique impairments in facial-expression recognition in pervasive developmental disorder-not otherwise specified and Asperger’s disorder. *Research in Autism Spectrum Disorders*, *7*, 361-368.

Warren, G., Schertler, E., & Bull, P. (2009). Detecting deception from emotional and unemotional cues. *Journal of Nonverbal Behavior, 33*, 59–69.

Yirmiya, N., Kasari, C., Sigman, M., & Mundy, P. (1989). Facial expressions of affect in autistic, mentally retarded and normal children. *Journal of Child Psychology and Psychiatry, 30*, 725–735.

Yoon, K. L., Joormann, J., & Gotlib, I. H. (2009). Judging the intensity of facial expressions of emotion: Depression-related biases in the processing of positive affect. *Journal of Abnormal Psychology, 118*, 223–228.

Yoshikawa, S., & Sato, W. (2008). Dynamic facial expressions of emotion induce representational momentum. *Cognitive, Affective & Behavioral Neuroscience, 8*, 25–31.

Table 1
Mean (with SE) intensities of the selected images in individuals with ASD and typically developing controls (CON)

Group	Presentation	Intensity		
		52%	80%	108%
ASD	Dynamic	59.3 (1.5)	88.1 (1.3)	115.4 (1.6)
	Static	57.0 (1.2)	82.7 (1.3)	108.7 (1.6)
CON	Dynamic	63.0 (0.9)	89.5 (1.2)	119.4 (2.1)
	Static	56.7 (1.3)	85.7 (1.5)	108.8 (1.5)

Figure Captions

Fig. 1 a) Examples of the morphing image sequence for dynamic facial expressions of emotion. b) Final image of dynamic facial expressions under each intensity condition.

Fig. 2 Mean ratio between the intensity of the selected and presented images under each condition. The asterisk represents a significant interaction between group and presentation, indicating reduced RM for subtle dynamic facial expressions in ASD. Error bars show the SE.

Fig. 3 Correlation between degree of RM and CARS scores under the 52% condition. Black and white diamonds show participants with Asperger's disorder and PDD-NOS, respectively.

Fig. 1

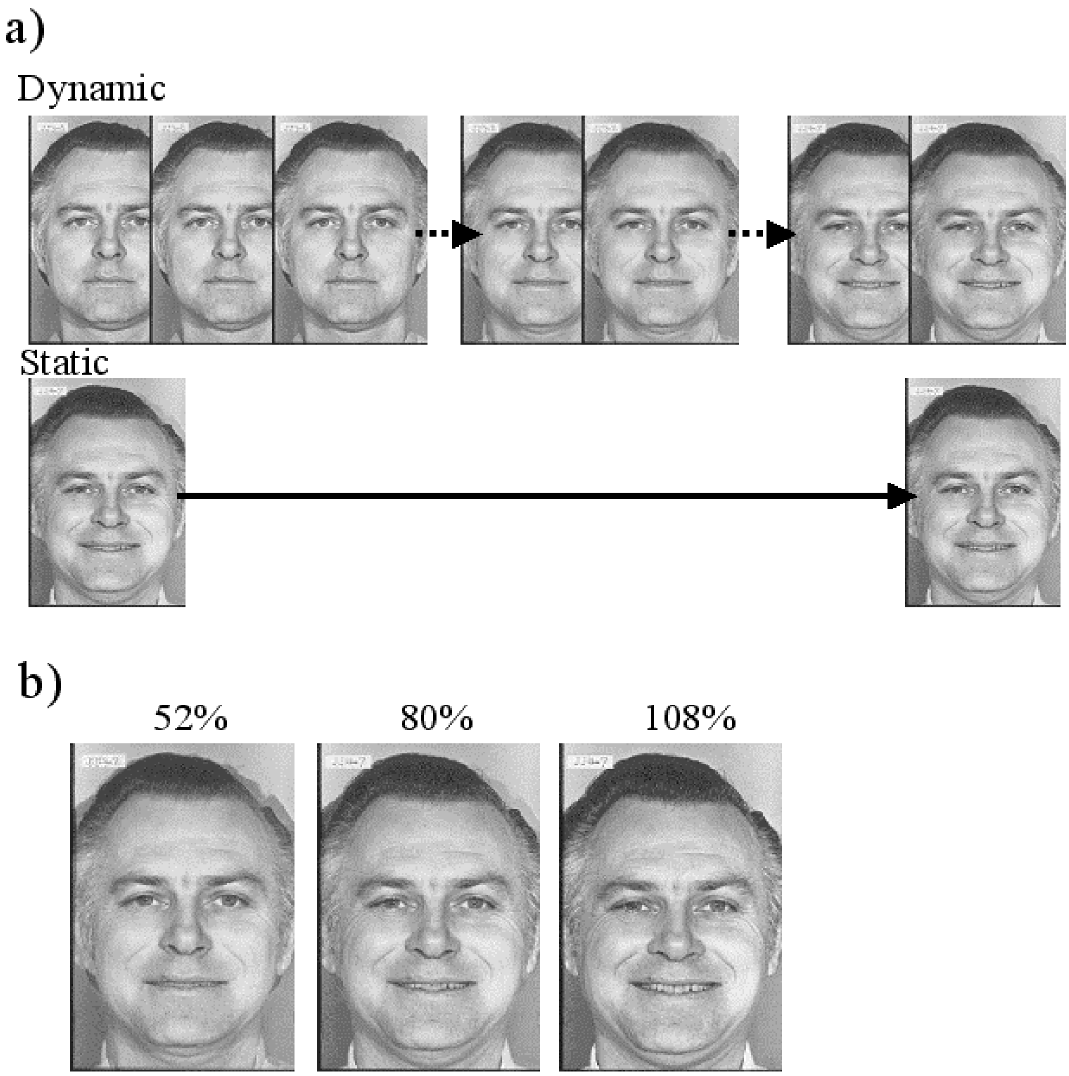


Fig. 2

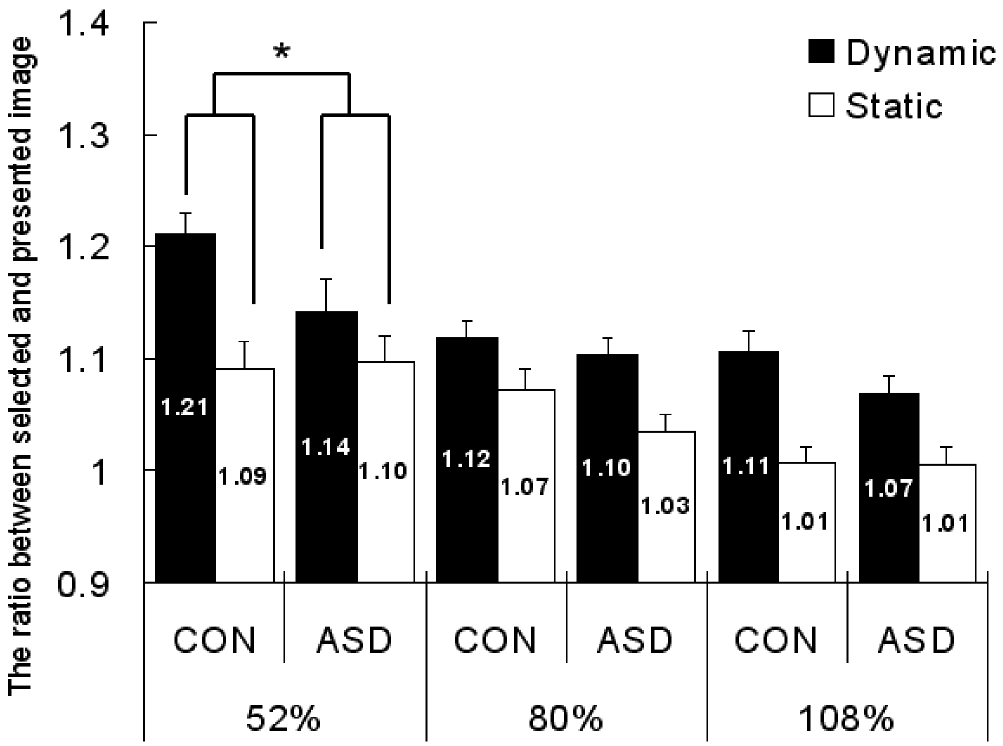
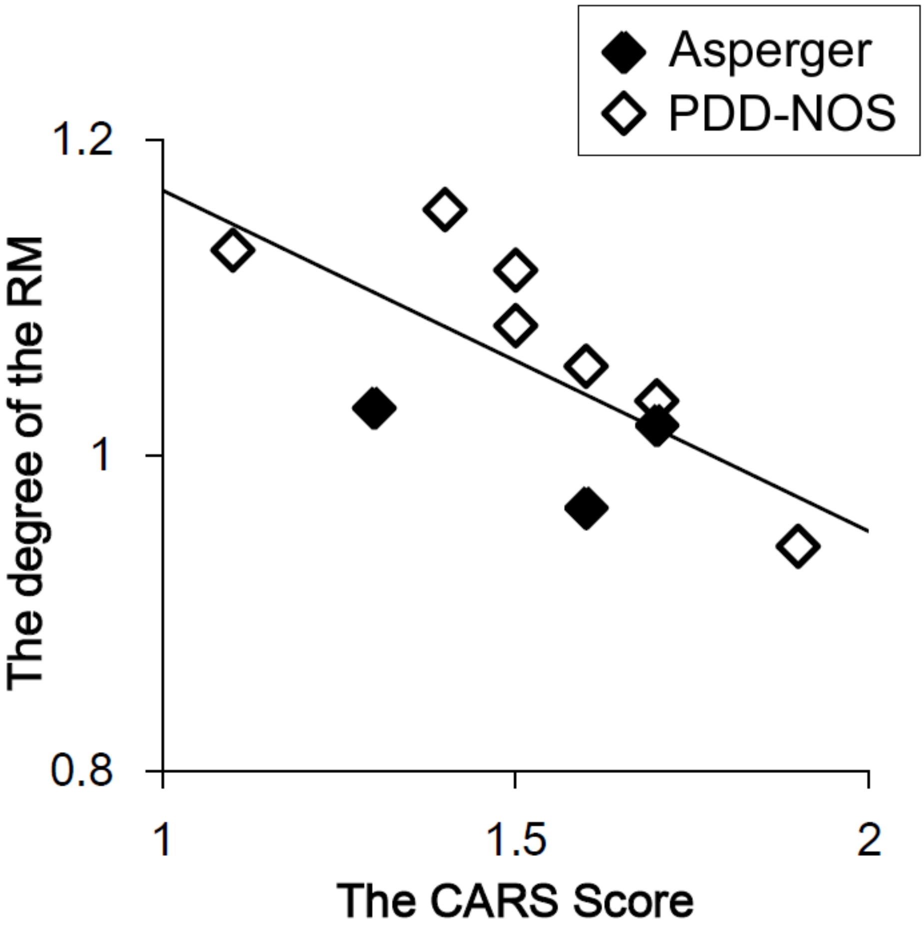

The ratio between selected and presented image
1.4
1.3
1.2
1.1
1
0.9
*
Dynamic
Static
1.21
1.09
1.14
1.10
1.12
1.07
1.10
1.03
1.11
1.01
1.07
1.01
CON
ASD
CON
ASD
CON
ASD
52%
80%
108%

Fig. 3


Asperger
PDD-NOS
The degree of the RM
1.2
1
0.8
1
1.5
2
The CARS Score