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The specific impairment of fearful expression recognition and its atypical development in pervasive developmental disorder

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Abstract

Several studies have examined facial expression recognition in pervasive developmental disorder (PDD), including autism and Asperger's disorder, but the results have been inconsistent. We investigated the relationship between facial expression recognition and age, face recognition, and symptom severity. Subjects were 28 individuals with mild PDD subtypes and 28 age- and gender-matched controls. Among six emotions, fearful expression recognition was specifically impaired in PDD subjects. Age had positive effects on fearful expression recognition directly and indirectly via the development of face recognition in controls, but not in PDD subjects. Furthermore, fearful expression recognition was related to the severity of PDD symptoms. We conclude that individuals with PDD show an atypical development of facial expression recognition. Moreover, impaired fearful expression recognition is closely related to social dysfunction.

Keywords: Face recognition; Facial expression recognition; Fear; Pervasive developmental disorder; Social dysfunction

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Individuals with pervasive developmental disorder (PDD), including autism and Asperger’s disorder, are characterized by a qualitative impairment of social interaction (American Psychiatric Association 2000). Kanner’s original clinical study emphasized that individuals with autism have innately impaired affective contact with others (Kanner, 1943), and difficulty in the expression and perception of emotion is proposed to contribute to a failure to establish interpersonal relationships (Hobson, 1993). Considerable research has focused on the ability to recognize emotion from the facial expressions of others to elucidate the cause of this social dysfunction.

However, previous studies investigating emotion recognition in PDD have reported inconsistent findings. Several studies have demonstrated impaired facial expression recognition in PDD (Braverman, Fein, Lucci, & Waterhouse, 1989; Celani, Battacchi, & Arcidiacono, 1999), with others further suggesting that individuals with PDD are specifically impaired in recognizing fearful expressions (Ashwin, Chapman, Colle, & Baron-Cohen, 2006; Corden, Chilvers, & Skuse, 2008; Howard et al., 2000; Humphreys, Minshew, Leonard, & Behrmann, 2007; Pelphrey et al., 2002). However, some studies have reported that individuals with PDD showed no impairment in facial expression recognition (Adolphs, Sears, & Piven, 2001; Castelli, 2005; Grossman, Klin, Carter, & Volkmar, 2000).

These inconsistent findings regarding facial expression recognition in PDD may be due to a number of potential factors. First, the majority of the previous studies lacked a developmental perspective for facial expression recognition in individuals with PDD. The ability to recognize facial expressions improves with age during childhood and adolescence in typically developing individuals (for review, see Herba & Phillips, 2004), but little is known about the development of facial expression recognition in individuals with PDD. However, the review described above suggests atypical development of facial expression recognition in individuals with PDD (for a review, see also Harms, Martin, & Wallace, 2010). Recent studies with a large number of participants have shown deficits in the recognition of facial expressions, specifically fear, in adults (Ashwin et al., 2006; Corden et al., 2008; Humphreys, Minshew, et al., 2007), but not children, with PDD (Castelli, 2005; Grossman et al., 2000). Given that the ability to recognize faces improves with age in typically developing individuals, these data suggest that the ability to recognize facial expressions does not improve with age in individuals with PDD.

Second, previous studies did not examine the effects of the ability to perceive faces on facial expression recognition. Theoretical cognitive psychological studies have proposed that emotional facial recognition occurs through the basic visual processing of faces (e.g., Bruce & Young, 1986). This notion is supported by experimental studies showing that the face-recognition skill involving perceptual matching was positively correlated with the ability to recognize others' emotions (e.g., Bruce et al., 2000; Williams, Wishart, Pitcairn, & Willis, 2005). Neuropsychological studies have shown that individuals with prosopagnosia, who have difficulty in perceptually discriminating faces, have impaired emotion recognition (e.g., de Gelder, Pourtois, Vroomen, & Bachoud-Levi, 2000; Humphreys, Avidan, & Behrmann, 2007). These data suggest that individual differences in the basic ability to perceptually process faces may explain the inconsistent findings for impairment of emotion recognition in PDD.

In typically developing individuals, face-perception ability improves with age during childhood and adolescence (Carey, Diamond, & Woods, 1980; Mondloch, Geldart, Maurer, & Le Grand, 2003). This evidence suggests that the development of face perception leads to improved facial expression recognition in typically developing controls. Face perception has been shown to be impaired in children and adolescents with PDD (e.g., Boucher, Lewis, & Collis, 1998; Klin et al., 1999), suggesting that the atypical development of face-perception skills affects facial expression recognition in individuals with PDD. Previous studies have investigated the relationship between face perception and facial expression recognition in individuals with PDD (Hefter, Manoach, & Barton, 2005; Riby, Doherty-Sneddon, & Bruce, 2008); however, the results are inconsistent. Hefter et al. demonstrated that participants with face-perception deficits recognize facial expressions as well as those with normal face-perception ability. On the other hand, Riby et al. showed that face-perception ability was positively correlated with facial expression recognition in individuals with PDD. However, these studies did not use all six basic facial expressions, and the chronological age of participants differed between studies. Thus, further studies are needed to clarify whether atypical development of face perception leads to deficits in the recognition of six basic facial expressions in individuals across a broader chronological age range.

Third, the degree of social dysfunction in individuals with PDD may relate to deficits in facial expression recognition. In normal participants, performance in face-perception tasks involving fearful faces correlates with higher social cognitive functions (e.g., theory of mind ability) (Corden, Critchley, Skuse, & Dolan, 2006; Marsh, Kozak, & Ambady, 2007).

Although the relationship between emotion recognition and symptom severities in individuals with PDD has been investigated (e.g., Braverman et al., 1989; Corden et al., 2008; Tardif, Lainé, Rodriguez, & Gepner, 2007), little evidence exists of a relationship between fear recognition and symptom severity (cf. Humphreys, Minshew, et al., 2007). Thus, we tested whether the degree of impairment in facial expression recognition positively correlates with social dysfunction in individuals with PDD.

We investigated facial expression recognition deficits across development in individuals with high functioning PDD and examined the recognition of facial expressions conveying the six basic emotions. We predicted that individuals with PDD would show impaired emotion recognition, particularly recognition of fearful expression. We also investigated the relationship between chronological age, face perception, and facial expression recognition. We tested the following model in typically developing controls and individuals with PDD by path analysis: (1) facial expression recognition and face perception improve with age; (2) the development of face perception leads to the improvement of facial expression recognition. Finally, we tested the relationship between impaired facial expression recognition and symptom severity in individuals with PDD. Based on the evidence described above, we predicted that recognition of fearful expressions would be negatively correlated with social dysfunction in individuals with PDD.

Methods

Participants

The participants were 56 Japanese individuals, 28 with PDD, and 28 typically developing controls. Table 1 summarizes the participants' demographic characteristics. The two groups (PDD and control) were matched for chronological age—PDD group: M ± SD = 17.6 ± 5.2, range 9–30; control: M ± SD = 18.0 ± 4.0, range 9–28; independent t-test, $t(54) = 0.29$, $p > .1$—and gender—PDD group: five females and 23 males; control: four females and 24 males; Fisher's exact test, $p > .1$. Verbal and performance IQ in the PDD group was measured by the Japanese version of the Wechsler Adult Intelligence Scale (WAIS) and Wechsler Intelligence Scale for Children (WISC). All PDD participants had IQs within the normal range (full-scale IQ: M = 103.3, SD = 13.4; verbal IQ: M = 105.2, SD = 14.7; performance IQ: M = 100.1, SD = 13.3). All participants had normal or correctedto-normal visual acuity.

Participants in the PDD group were diagnosed with either Asperger's disorder (12 males, three females) or pervasive developmental disorder not otherwise specified (PDD-NOS) (11 males, two females) at the time of the present study, using DSM-IV-TR (American Psychiatric Association, 2000). PDD-NOS includes heterogeneous subgroups of PDD with varying degrees of qualitative social impairment. The present study used subgroups that did not satisfy the criteria for Asperger’s disorder because (1) they had similar impairment in qualitative social interaction without apparent restricted interests and 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 those with Asperger’s disorder. The final diagnoses were made by a child psychiatrist (M.T.) based on the advice of clinical psychologists, interviews with each subject, information from each subject’s parents or teachers, and childhood clinical records (when available). Participants in the PDD group were outpatients who had been referred to Kyoto University Hospital or the Faculty of Human Health Science of Kyoto University Graduate School of Medicine because of their social maladaptation. The participants were referred from a variety of sources, and we found no systematic referral source bias between younger and older participants. They were all free of neurological or psychiatric problems other than PDD, and none were taking any medication. All participants aged 18 years and older and the parents of participants aged younger than 18 years provided written, informed consent to participate in this study, which was approved by the local ethics committee.

The level of symptom severity in individuals with PDD was assessed with the Childhood Autism Rating Scale (CARS) (Schopler, Reichler, & Renner, 1986) administered by a psychiatrist (M.T.). 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 includes 14 items assessing autism-related behavior and one item rating general impressions of autistic symptoms. Each item is rated on a scale of 1 to 4. A higher rating indicates more severe impairment. Total scores ranged from 15 to 60. The CARS scores (range 18–25.5) of all participants in the PDD group were below the cutoff score (27) for a diagnosis of autism (cf.Mesibov et al., 1989), indicating that symptom severity in the PDD group was milder than that of individuals with autism.

To investigate age differences in the PDD group according IQ and sex, we divided participants into younger ($n = 14$) and older ($n = 14$) groups. The results showed no significant differences in the distributions of IQ, $t(26) < 1.6$, $p > .1$, or of men and women (Fisher’s exact test, $p > .1$) in the younger and older PDD groups.

One participant in the PDD group scored below the cutoff score for face perception, as described below. However, we found no difference between analyses that included and those that excluded this individual; thus, we included this participant in all analyses.

Stimuli and Procedures

Expression Recognition Task.

A total of 48 photographs of facial expressions depicting six basic emotions (anger, disgust, fear, happiness, sadness, and surprise) were used as stimuli. Half of these were pictures of Caucasian models, and the remaining half were pictures of Japanese models. These pictures were chosen from standardized photograph sets (Ekman & Friesen, 1976; Matsumoto & Ekman, 1988). A label-matching paradigm previously used by Sato et al. (2002) was employed to assess participants' recognition of emotional facial expressions. Pictures of people whose faces expressed various emotions were presented on the monitor one by one in a random order. Verbal labels identifying the six basic emotions were presented next to each photograph. Participants were asked to select the label that best described the emotion shown in each photograph. They were instructed to consider all six alternatives carefully before responding. No time limits were set, and no feedback was provided about performance. Participants saw each emotional expression eight times, resulting in a total of 48 trials for each participant. Prior to the experiment, we established that all participants understood the meaning of the emotional label and the task instructions, and participants were given two training trials to become familiar with the procedure. After ensuring that participants understood the task requirements, the experimental trials were initiated.

Face-perception Task.

The shortened version (13 items) of the Benton Facial Recognition Test (Benton, Sivan, Hamsher, Varney, & Spreen, 1994) was conducted. Performance on this test is based on perceptual factors and reflects basic visual face-processing mechanisms (e.g., Bentin, Deouell, & Soroker, 1999). Caucasian models were used for all of the face stimuli. Participants were required to match a target face with one picture or with up to three pictures of the same person (with different orientation and lighting) presented in a six stimulus array of faces. No time limits were set, and no feedback was provided regarding performance.

Apparatus

The events were controlled by SuperLab Pro 2.0 (Cedrus, San Pedro, CA, USA) implemented on a Windows computer (HP xw4300 Workstation, Hewlett-Packard, Palo Alto, CA, USA). Stimuli were presented on a 19-inch CRT monitor (HM704UC, Iiyama, Tokyo, Japan; screen resolution 1024 × 768 pixels; refresh rate 100 Hz).

Data Analysis

The t-tests, analyses of variance (ANOVAs) and the follow-up tests, and correlation analyses were conducted with SPSS 10.0J (SPSS, Tokyo, Japan). Randomization tests were conducted with programs developed by Edgington and Onghena (2007). Path analyses were conducted with XLSTAT-PLSPM (Addinsoft, New York, NY, USA).

Accuracy percentages for the expression recognition task were tested for difference from chance (i.e., 16.7%), using one-sample t-tests (two-tailed). The accuracy data were then subjected to a 2 (group) × 6 (facial emotion) repeated-measures ANOVA. Significant interactions were followed up by simple effects analyses (cf. Kirk, 1995). Additionally, we conducted randomization tests using the same designs to confirm the results without parametric assumptions (cf. Edgington & Onghena, 2007). Because a debate about testing interaction terms by randomization persists (cf. Anderson & ter Braak, 2003), we tested only main and simple main effects. We further tested the effects of stimulus-face ethnicity and PDD subtypes by t-tests. Correlations with IQ scores were calculated for the relationship between IQ and the impairment of facial expression recognition in the PDD group.

For the face-perception task, the total number of correct responses was calculated for each participant. The mean score difference between groups was analyzed by a t-test (two-tailed). We further tested the effects of PDD subtypes with t-tests. Correlations were calculated between face-perception performance and IQ scores.

To analyze the relationships between expression recognition, age, and face perception, Pearson’s product-moment correlations between these variables were calculated for each group. We preliminarily confirmed that non-parametric correlation analysis (Spearman’s rank coefficient correlation) produced identical results. Based on the results of the ANOVA for facial expression recognition, the results from the fearful expression task were used as a measure of facial expression recognition. Differences in the correlation coefficients between the PDD and control groups were also tested with the chi-square test.

Furthermore, path analyses were conducted for each group. Path analysis assesses the direct and indirect effects of explanatory variables on dependent variables; this cannot be accomplished with correlational analyses (Kothari, 1990). Based on our prediction of a relationship between chronological age, face perception, and facial expression recognition, our model hypothesized that chronological age would have direct and indirect effects on emotion recognition via the development of face perception. Path analyses were conducted with structural equation modeling (SEM), using partial least squares (PLS). Compared with the widely used covariance-based approach for SEM, the variance-based PLS approach is a powerful method for analyzing data from small samples (Chin & Newsted, 1999; Falk, & Miller, 1992). Analyses in unity mode were conducted in which latent variables associated with a single manifest variable were created (cf. Ziersch, 2005). Path coefficients were also tested for a difference from zero using bootstrap analyses (two-tailed) (Efron & Tibishirani, 1993). We analyzed whether the path coefficients of the control group were larger than those of the PDD group in each path, using randomization tests.

The CARS (Schopler et al., 1986) was used to assess the level of social dysfunction in individuals with PDD. Although the CARS factors are structured, the items included in the social functioning construct have been inconsistent among studies (Dilalla & Rogers, 1994; Magyar & Pandolfi, 2007; Stella, Mundy, & Tuchman, 1999). Therefore, we used the CARS items that were commonly classified as elements of the social functioning construct in all previous studies (cf. Magyar & Pandolfi, 2007). In the present study, we used the items “imitation,” “nonverbal communication,” “relationship to people,” “verbal communication,” and “visual response,” and calculated the average score for these items. We calculated Pearson’s correlation coefficients to investigate the relationship between impaired recognition of fearful expressions and symptom severity related to social domains.

The number of participants in the present study was relatively small for a correlational analysis; thus, we further analyzed whether outliers affected the results. In each correlational analysis, the Mahalanobis distance for each case was calculated to identify outliers (probability of group membership: $p < .05$). However, the results of the correlational analyses including outliers did not differ from those excluding them; thus, all participants were included in the analyses.

Results

Expression-recognition Task

One-sample t-tests showed that the accuracy percentage of expression recognition for each emotion category was greater than chance in both groups, $t(27) > 36.2$, $p < .001$.

The ANOVA for the accuracy percentages (Figure 1 and Table 2) revealed a significant interaction of group × facial emotion, $F(5, 270) = 4.16$, $p < .05$. A significant main effect of facial emotion, $F(5, 270) = 114.10$, $p < .001$, was also found. The main effect of group was not significant, $F(1, 54) = 1.14$. Follow-up analyses of the interaction revealed that the simple main effects of group, indicating less accurate recognition of emotional expressions in PDD subjects than in control group, were significant only for the fearful facial expressions, $F(1, 324) = 16.18$, $p < .005$.

Our preliminary analyses revealed that the normal distribution assumptions were not met for some conditions (Kolmogorov–Smirnov tests, $p < .05$ for the recognition of happy and surprised expressions in both control and PDD groups); thus, we reanalyzed the accuracy percentage data, using randomization tests. The results showed that, as in the case of the aforementioned parametric analyses, the main effect of facial emotion and the simple main effect of group in response to fearful expressions were significant ($p < .05$).

To investigate the possibility that impairment of fear recognition in the PDD group resulted from difficulty in recognizing cross-race faces (cf. Elfenbein & Ambady, 2002), we conducted a between-group comparison of fear recognition for each ethnicity. The results revealed that the recognition of fearful faces was less accurate in individuals with PDD than in typically developing controls irrespective of ethnicity— Caucasian: $t(54) = 2.06$, $p < .05$; Japanese: $t(54) = 3.15$, $p < .005$.

We further investigated whether PDD subtypes (Asperger’s disorder and PDD-NOS) affected fear recognition differently. The results revealed that fear recognition was not significantly different between the PDD subtypes, $t(26) = 0.25$, $p > .1$. Recognition of fearful faces was less accurate in both PDD subtype groups compared with typically developing controls— Asperger’s disorder: $t(41) = 2.51$, $p < .05$; PDD-NOS: $t(39) = 3.08$, $p < .01$.

No significant correlations between the accuracy of fearful expression recognition and IQ scores were found in the PDD group ($r = -.07$, $.02$, and $-.22$ for full-scale, verbal, and performance IQs, respectively; $ps > .1$). Even when the influence of chronological age was factored out, the results were identical ($r = -.07$, $.12$, and $-.21$ for full-scale, verbal, and performance IQs, respectively; ps > .1).

Face-perception Task

Benton Facial Recognition Task performance was less accurate in the PDD group than in the control group, $t(54) = 2.95$, $p < .05$ ($M \pm SE = 22.09 \pm 2.39$ and 23.57 ± 1.53 for PDD and control, respectively). The performance of all participants in both groups was above the cutoff score (18/27) (Benton et al., 1994) for impaired face perception, except for one participant in the PDD group.

We further analyzed whether PDD subtypes (Asperger's disorder and PDD-NOS) affected the performance of face perception. The results revealed that face perception was not significantly different between the PDD subtypes, $t(26) = 0.31$, $p > .1$. Both PDD groups showed less accurate face perception than typically developing controls—Asperger's disorder: $t(41) = 2.39$, $p < .05$; PDD-NOS: $t(39) = 2.82$, $p < .01$.

No significant correlations between face-perception scores and IQ scores were found in the PDD group ($r = -.10$, $-.02$, and $-.17$ for full-scale, verbal, and performance IQs, respectively; ps > .1). Even when the influence of chronological age was factored out, the results were identical ($r = -.11$, $-.07$, and $-.12$, for full-scale, verbal, and performance IQs, respectively; $ps > .1$).

Relationships among Fearful Expression Recognition, Age, and Face Perception

Fearful expression recognition showed a significant positive correlation with chronological age in the control group, $r = .51$, $p < .01$, but not in the PDD group, $r = .07$, $p > .1$ (Figure 2A). The correlation between face-perception performance and chronological age showed a nonsignificant trend in both the control, $r = .37$, $p < .1$, and PDD groups, $r = .33$, $p < .1$ (Figure 2B).

The correlation between fearful expression recognition and face-perception performance was significant in the control group, $r = .53$, $p < .005$, but showed a nonsignificant trend in the PDD group, $r = .35$, $p < .1$ (Figure 2C).

Differences between the control and PDD group correlation coefficients were tested by the chi-square test. The results revealed that the between-group difference was marginally significant for the Age–Fear relationship ($\chi2 = 3.03$, $p < .1$) but was not significant for the Age–Face ($\chi2 = 0.03$, $p > .1$) and Face–Fear ($\chi2 = 0.63$, $p > .1$) relationships.

Path analyses were conducted for each group to further examine the relationships among these variables. Based on the previous results in typically developing participants, the analyzed model assumed that age has positive effects on recognition of emotional expressions, both directly and indirectly via the development of face perception. The hypothesized model is presented in Figure 3.

For the control group, tests of path coefficients confirmed that all paths in the hypothesized model were significant (from age to expression recognition, from age to face perception, and from face perception to expression recognition; standardized coefficient = .37, .37, and .39, respectively; all $p < .05$).

The path coefficient tests revealed that no paths in the hypothesized model reached significance in the PDD group (from age to expression recognition, from age to face perception, and from face perception to expression recognition; standardized coefficient = .06, .33, and .31, respectively; $ps > .1$).

We conducted group comparisons in each path, using randomization tests. The results revealed that the control group path coefficients were significantly larger than those of PDD group in the Age–Fear path ($p < .05$) but not in the Age–Face and Face–Fear paths ($ps > .1$).

The Relationship between Impaired Fearful Expression Recognition and Symptom Severity

The average score of four items used as indices of social dysfunction ranged from 1.3 to 2.2. Correlation analyses revealed that fearful expression recognition in the PDD group was negatively and significantly correlated with social dysfunction, $r = -.51$, $p < .005$. Thus, individuals with PDD who showed worse recognition of fearful expressions had more severe symptoms in social domains (Figure 4). Even when the influence of chronological age, verbal IQ, and performance IQ was factored out, the correlation remained significant, $r = -.57$, $p < .005$.

Discussion

The present study revealed that individuals with PDD were less accurate in recognizing fearful facial expressions than were typically developing controls. Consistent with our data, recent studies have shown impaired facial expression recognition, particularly of fearful faces in subjects with PDD (Ashwin et al., 2006; Corden et al., 2008; Humphreys, Minshew, et al., 2007). Although some reports have documented general impairment of facial expression recognition, the impairment of fear recognition was found irrespective of face ethnicity and PDD subtype in the present study. Our findings suggest that individuals with PDD have a greater tendency to show impaired fearful expression recognition compared to other facial expressions.

Our results also show that the ability to recognize fearful facial expressions improves with age in typically developing controls, but not in PDD subjects; hence, the impairment of fearful face recognition in the PDD group manifested in adult subjects. Consistent with these data, recent studies have shown impaired fearful face recognition in adults (Ashwin et al., 2006; Corden et al., 2008; Humphreys, Minshew, et al., 2007), but not in children with PDD (Castelli, 2005; Grossman et al., 2000). However, these findings do not imply normal emotion processing in children with PDD. For example, Dawson, Webb, Carver, Panagiotides, and McPartland (2004) demonstrated that children with PDD aged 3–5 years show atypical brain responses to fearful faces, suggesting that individuals with PDD have impaired fearful face processing during childhood. Developmental psychology studies have shown that the accurate recognition of fearful expressions emerges later than that for other emotions, except for disgust, even in typically developing children (Holder & Kirkpatrick, 1991; Vicari, Reilly, Pasqualetti, Vizzotto, & Caltagirone, 2000). Based on these findings, the paradigm used here, that is, matching facial photographs with the appropriate verbal label, may be less sensitive to group differences in fearful expression recognition in childhood.

The path analysis revealed that face-perception ability improves with age in controls, but not in PDD subjects. Furthermore, typically developing controls, but not individuals with PDD, showed a significant positive relationship between face perception and fearful expression recognition. Hefter et al. (2005) showed that face-perception performance does not positively correlate with facial expression recognition in individuals with PDD, and previous studies have shown that face perception (for a review, see Maurer, Le Grand, & Mondloch, 2002) and facial expression recognition (Calder, Young, Keane, & Dean, 2000; Durand, Gallay, Seigneuric, Robichon, & Baudouin, 2007) rely on facial configuration processing in typically developing individuals. The detection of subtle changes in facial configuration (e.g., in the eye region) is required to discriminate between fearful and surprised faces (Ekman, 2003; Skuse, 2003). These findings suggest that the development of perceptual face processing facilitates fearful expression recognition in typically developing controls, but not in individuals with PDD.

The results revealed that ability to recognize fearful expressions did not improve with age in the PDD group independent of face-perception skill.

Othe components of facial expression processing may influence the performance of fear recognition in individuals with PDD. The finding of a group difference in the Age–Fear path, but not in the Age–Face and Face–Fear paths, suggests that deficits in emotion processing play an important role in impaired fearful expression recognition. Several researchers have proposed that emotional reactions in response to the facial expressions of others contribute to accurate facial expression recognition (e.g., Adolphs, 2002). Consistent with this theory, studies have suggested that a callous, unemotional trait (e.g., lack of empathy) specifically relates to impaired fearful face recognition (for a review, see Marsh & Blair, 2008). Minio-Paluello, Baron-Cohen, Avenanti, Walsh, and Aglioti (2009) found that individuals with PDD did not show empathetic bodily responses, and McIntosh, Reichmann-Decker, Winkielman, and Wilbarger (2006) reported that individuals with PDD did not exhibit spontaneous facial mimicry of other people's emotional expressions. Although individuals with PDD generally show high anxiety (e.g., Muris, Steerneman, Merckelbach, Holdrinet, & Meesters, 1998), an observational study suggested that their emotional response did not change in response to others' emotion (Corona, Dissanayake, Arbelle, Wellington, & Sigman, 1998). Taken together, these findings suggest that atypical emotional responses may explain poor fear recognition in individuals with PDD.

An alternative interpretation is that impaired face and emotion recognition is the result of reduced eye gaze fixation in individuals with PDD (for a review, see Senju & Johnson, 2009). For example, Corden et al. (2008) demonstrated that reduced fixation on others' gaze predicted the degree of impairment in fear recognition shown by individuals with PDD. Similarly, our study found that the averaged CARS score involving attention to other individuals ("relationship to people" and "visual response") was negatively correlated with the impairment of fear recognition ($r = -.40$, $p < .05$). However, other studies have reported that individuals with PDD did not show gaze avoidance while observing others' emotional (Rutherford & Towns, 2008) and non-emotional faces (van der Geest, Kemner, Verbaten, & van Engeland, 2002). Bal et al. (2010) showed that children with PDD were not less accurate in recognizing fearful facial expressions, though they show less fixation on eye gaze when they observe fearful faces. We did not track the participants' eye movements and cannot comment on this issue. The gaze-avoidance hypothesis of emotion recognition impairment is intriguing and warrants future investigation. The presence of confounding factors, such as chronological age and anxiety level, that may have contributed to inconsistent findings in previous studies make further studies necessary to clarify this issue.

Finally, we showed that impaired fearful expression recognition was related to social dysfunction in individuals with PDD. Consistent with this finding, previous studies have shown that accurate recognition of fearful faces is positively correlated with the theory of mind in typically developing individuals (Corden et al., 2006). Recognition of fearful faces is proposed to be important for the development of social cognitive function (such as theory of mind); fearful faces signal a threat and facilitate the interpretation of the other person’s thoughts (Skuse, 2003). These findings suggest that fearful face recognition may contribute to the development of several social cognitive functions. Furthermore, our results suggest that previous inconsistent findings can be partially accounted for by the severity of social dysfunction in individuals with PDD.

A potential neural substrate for impaired recognition of fearful expressions in individuals with PDD is the amygdala. Previous neuropsychological studies have demonstrated that the amygdala plays an important role in fearful expression recognition (e.g., Sato et al., 2002). A recent functional magnetic resonance imaging (fMRI) study reported that the amygdala showed less activation to fearful faces in individuals with PDD (Ashwin, Baron-Cohen, Wheelwright, O’Riordan, & Bullmore, 2007).

Furthermore, in line with the finding that fear recognition improved with age in controls, but not in individuals with PDD, structural MRI studies have found that the amygdala volume increased from childhood to adulthood in normal controls, but not in individuals with PDD (Nacewicz et al., 2006; Schumann et al., 2004). These data suggest that abnormal amygdala development may contribute to impaired fearful expression recognition in individuals with PDD.

The fusiform gyrus, a region that shows face specific responses (e.g., Kanwisher, McDermott, & Chun, 1997), is a possible candidate for the abnormal development of face-perception skills in PDD. Some neuroimaging studies have found less fusiform gyrus activation to face stimuli in adults and adolescents (11–14 years old) with PDD (Pierce, Müller, Ambrose, Allen, & Courchesne, 2001; Scherf, Luna, Minshew, & Behrmann, 2010; Schultz et al., 2000). Consistent with the finding that face-perception ability increases with age in normal subjects, studies have demonstrated that the fusiform gyrus shows increasing face-specific activity across development (Aylward et al., 2005; Golalrai et al., 2007). Furthermore, fMRI studies have suggested that the fusiform gyrus shows less activation to emotional facial expressions in individuals with PDD (Hall, Szechtman, & Nahmias, 2003;Wang, Dapretto, Hariri, Sigman, &

Bookheimer, 2004). These results indicate that abnormal development of the functional integrity of the fusiform gyrus may play an important role in not only face perception but also facial expression recognition in individuals with PDD.

Some limitations of the present study should be noted. First, no time limits for stimulus presentation and subject responses were set. In the real world, rapid understanding of other people's emotions is critical for undertaking appropriate behaviors. More rapid stimulus presentation in the facial expression recognition task might result in impaired recognition of other emotional facial expressions in individuals with PDD. Second, face perception and facial expression recognition in younger participants should be investigated further, as social dysfunction in PDD appears in the first year of life (Osterling, Dawson, & Munson, 2002; Ozonoff et al., 2010).

Third, we used only Caucasian faces in the face-perception task. Studies have suggested that typically developing individuals have difficulty in recognizing the faces of other races (other-race effect) (Elfenbein& Ambady, 2002). The other-race effect may explain the impairment in face perception and emotion recognition and the lack of a relationship with facial expression recognition in PDD. However, our results are not consistent with a race effect because the individuals with PDD had difficulty in recognizing fear in other- and same-race faces. A preliminary study has suggested that individuals with PDD show a reduced other-race effect in a face-memory task (Sasson, 2007). Given that the other-race effect appears at 6 months of age (Kelly et al., 2007), it is intriguing, considering the diagnosis, to ask whether individuals with PDD show the other-race effect.

Fourth, IQ and CARS scores were assessed only in individuals with PDD. The present data suggest that the impairment in fear recognition among individuals with PDD cannot be explained by general intellectual abilities alone, because the mean IQ of individuals in the PDD group was in the normal range, and IQ was not correlated with fear recognition. Furthermore, no differences were found between typically developing individuals and those with PDD in terms of the ability to recognize facial emotions depicting anger, disgust, and fear; and we also found no differences between those with PDD and typically developing individuals in the ability to recognize anger and disgust (Figure 1 and Table 2). However, Harms et al. (2010) reviewed previous studies and indicated that the IQ profiles of PDD and control groups may affect performance on emotion-recognition tasks. Thus, further studies are needed to investigate the effect of IQ profiles on emotion recognition by individuals with PDD. The CARS is not an appropriate test for the assessment of social functioning in typically developing individuals, because even individuals with Asperger's disorder and PDD-NOS showed relatively low social dysfunction scores. Scales that could assess social function in both groups would be useful to investigate individual differences in face- and emotion-recognition tasks.

In summary, our results show that the recognition of fearful faces was specifically impaired in individuals with PDD compared to controls. Fearful expression recognition improved with age in the control group, but not in the PDD group. Furthermore, fearful expression recognition was also facilitated by face-perception ability in the control, but not in the PDD group. These results reveal atypical development of facial expression recognition in PDD. In addition, impaired recognition of fearful expressions in the PDD group was related to symptom severity, suggesting a close relationship between impaired fearful expression recognition and social dysfunction in the real world.

References

Adolphs, R. (2002). Neural systems for recognizing emotion. Current Opinion in Neurobiology, 12, 169–177.

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

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

Anderson, M. J., & ter Braak, C. J. F. (2003). Permutation tests for multi-factorial analysis of variance. Journal of Statistical Computation and Simulation, 73, 85–113.

Ashwin, C., Baron-Cohen, S., Wheelwright, S., O'Riordan, M., & Bullmore, E.T. (2007). Differential activation of the amygdala and the 'social brain' during fearful faceprocessing in Asperger syndrome. Neuropsychologia, 45, 2–14.

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.

Aylward, E. H., Park, J. E., Field, K. M., Parsons, A. C., Richards, T. L., Cramer, S. C., et al. (2005). Brain activation during face perception: Evidence of a developmental change. Journal of Cognitive Neuroscience, 17, 308–319.

Bal, E., Harden, E., Lamb, D., Van Hecke, A. V., Denver, J. W., & Porges, S. W. (2010). Emotion recognition in children with autism spectrum disorders: Relations to eye gaze and autonomic state. Journal of Autism and Developmental Disorders, 40, 358–370.

Bentin, S., Deouell, L. Y., & Soroker, N. (1999). Selective visual streaming in face recognition: Evidence from developmental prosopagnosia. Neuroreport, 10, 823–827.

Benton, A. L., Sivan, A. B., Hamsher, K., Varney, N. R., & Spreen, O. (1994). Contributions to neuropsychological assessment. New York, NY: Oxford University Press.

Boucher, J., Lewis, V., & Collis, G. (1998). Familiar face and voice matching and recognition in children with autism. Journal of Child Psychology and Psychiatry, 39, 171–181.

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.

Bruce, V., Campbell, R. N., Doherty-Sneddon, G., Import, A. Langton, S., McAuley, S., et al. (2000). Testing face processing skills in children. British Journal of Developmental Psychology, 18, 319–333.

Bruce, V., & Young, A. (1986). Understanding face recognition. British Journal of Psychology, 77, 305–327.

Calder, A. J., Young, A. W., Keane, J., & Dean, M. (2000). Configural information in facial expression perception. Journal of Experimental Psychology: Human Perception and Performance, 26, 527–551.

Carey, S., Diamond, R., & Woods, B. (1980). The development of face recognition—a maturational component. Developmental Psychology, 16, 257–269.

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

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.

Chin, W. W., & Newsted, P. R. (1999). Structural equation modeling analysis with small samples using partial least squares. In R. E. Hoyle (Ed.), Statistical strategies for small sample research (pp. 307–341). Thousand Oaks, CA: Sage.

Corden, B., Chilvers, R., & Skuse, D. (2008). Avoidance of emotionally arousing stimuli predicts social-perceptual impairment in Asperger's syndrome. Neuropsychologia, 46, 137–147.

Corden, B., Critchley, H. D., Skuse, D., & Dolan, R. J. (2006). Fear recognition ability predicts differences in social cognitive and neural functioning in men. Journal of Cognitive Neuroscience, 18, 889–897.

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.

Dawson, G., Webb, S. J., Carver, L., Panagiotides, H., & McPartland, J. (2004). Young children with autism show atypical brain responses to fearful versus neutral facial expressions of emotion. Developmental Science, 7, 340–359.

de Gelder, B., Pourtois, G., Vroomen, J., Bachoud-Levi, A. C. (2000). Covert processing of faces in prosopagnosia is restricted to facial expressions: Evidence from crossmodal bias. Brain and Cognition, 44, 425–444.

DiLalla, D. L., & Rogers, S. J. (1994). Domains of the Childhood Autism Rating Scale:

Relevance for diagnosis and treatment. Journal of Autism and Developmental Disorders, 24, 115–128.

Durand, K., Gallay, M., Seigneuric, A., Robichon, F., & Baudouin, J. Y. (2007). The development of facial emotion recognition: The role of configural information. Journal of Experimental Child Psychology, 97, 14–27.

Edgington, O., & Onghena, P. (2007). Randomization tests (4th ed.). Boca Raton, FL: Chapman & Hall/CRC.

Efron, B., & Tibishirani, R. J. (1993). An introduction to the bootstrap. New York, NY: Chapman & Hall.

Ekman, P. (2003). Emotions revealed. NewYork, NY: Times Books.

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

Elfenbein, H. A., & Ambady, N. (2002). On the universality and cultural specificity of emotion recognition: A metaanalysis. Psychological Bulletin, 128, 203–235.

Falk, R. F., & Miller, N. B. (1992). A primer for soft modeling. Akron, OH: University of Akron Press.

Golarai, G., Ghahremani, D. G., Whitfield-Gabrieli, S., Reiss, A., Eberhardt, J. L., Gabrieli, J. D., et al. (2007). Differential development of high-level visual cortex correlates with category-specific recognition memory. Nature Neuroscience, 10, 512–522.

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.

Hall, G. B., Szechtman, H., & Nahmias, C. (2003). Enhanced salience and emotion recognition in autism: A PET study. American Journal of Psychiatry, 160, 1439–1441.

Harms, M. B., Martin, A., & Wallace, G. L. (2010). Facial emotion recognition in autism spectrum disorders: A review of behavioral and neuroimaging studies. Neuropsychology Review, 20, 290–322.

Hefter, R. L., Manoach, D. S., & Barton, J. J. (2005). Perception of facial expression and facial identity in subjects with social developmental disorders. Neurology, 65, 1620–1625.

Herba, C., & Phillips, M. (2004). Annotation: Development of facial expression recognition from childhood to adolescence: Behavioural and neurological perspectives. Journal of Child Psychology and Psychiatry, 45, 1185–1198.

Hobson, R. P. (1993). Autism and the development of mind. Hove, UK: Lawrence Erlbaum Associates Ltd.

Holder, H. B., & Kirkpatrick, S. W. (1991). Interpretation of emotion from facial expressions in children with and without learning disabilities. Journal of Learning Disabilities, 24, 170–177.

Howard, M. A., Cowell, P. E., Boucher, J., Broks, P., Mayes, A., Farrant, A., et al. (2000). Convergent neuroanatomical and behavioural evidence of an amygdala hypothesis of autism. Neuroreport, 11, 2931–2935.

Humphreys, K., Avidan, G., & Behrmann, M. (2007). A detailed investigation of facial expression processing in congenital prosopagnosia as compared to acquired prosopagnosia. Experimental Brain Research, 176, 356–373.

Humphreys, K., Minshew, N., Leonard, G. L., & Behrmann, M. (2007). A fine-grained analysis of facial expression processing in high-functioning adults with autism. Neuropsychologia, 45, 685–695.

Kanner, L. (1943). Autistic disturbances of affective contact. Nervous Child, 2, 217–250.

Kanwisher, N., McDermott, J., & Chun, M. M. (1997). The fusiform face area: A module in human extrastriate cortex specialized for face perception. Journal of Neuroscience, 17, 4302–4311.

Kelly, D. J., Quinn, P. C., Slater, A. M., Lee, K., Ge, L., & Pascalis, O. (2007). The other-race effect develops during infancy: Evidence of perceptual narrowing. Psychological Science, 18, 1084–1089.

Kirk, R. E. (1995). Experimental design: Procedures for the behavioral sciences. Pacific Grove, CA: Brooks-Cole.

Klin, A., Sparrow, S. S., de Bildt, A., Cicchetti, D. V., Cohen, D. J., & Volkmar, F. R. (1999). A normed study of face recognition in autism and related disorders. Journal of Autism and Developmental Disorders, 29, 499–508.

Kothari, C. R. (1990). Research methodology: Methods and techniques (2nd ed.). New Delhi India: Wiley Eastern.

Magyar, C. I., & Pandolfi, V. (2007). Factor structure evaluation of the Childhood Autism Rating Scale. Journal of Autism and Developmental Disorders, 37, 1787–1794.

Marsh, A. A., & Blair, R. J. (2008). Deficits in facial affect recognition among antisocial populations: A metaanalysis. Neuroscience and Biobehavioral Reviews, 32, 454–465.

Marsh, A. A., Kozak,M. N., & Ambady, N. (2007). Accurate identification of fear facial expressions predicts prosocial behavior. Emotion, 7, 239–251.

Matsumoto, D., & Ekman, P. (1988). Japanese and Caucasian facial expressions of emotion. San Francisco, CA: Intercultural and Emotion Research Laboratory, Department of Psychology, San Francisco State University.

Maurer, D., Le Grand, R., & Mondloch, C. J. (2002). The many faces of configural processing. Trends in Cognitive Sciences, 6, 255–260.

McIntosh, D. N., Reichmann-Decker, A., Winkielman, P., & Wilbarger, J. L. (2006). When the social mirror breaks: Deficits in automatic, but not voluntary, mimicry of emotional facial expressions in autism. Developmental Science, 9, 295–302.

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 Childhood and Adolescent Psychiatry, 28, 538–541.

Minio-Paluello, I., Baron-Cohen, S., Avenanti, A., Walsh, V., & Aglioti, S. M. (2009). Absence of embodied empathy during pain observation in Asperger syndrome. Biological Psychiatry, 65, 55–62.

Mondloch, C. J., Geldart, S., Maurer, D., & Le Grand, R. (2003). Developmental changes in face processing skills. Journal of Experimental Child Psychology, 86, 67–84.

Muris, P., Steerneman, P., Merckelbach, H., Holdrinet, I., & Meesters, C. (1998). Comorbid anxiety symptoms in children with pervasive developmental disorders. Journal of Anxiety Disorders, 12, 387–393.

Nacewicz, B. M., Dalton, K. M., Johnstone, T., Long, M. T., McAuliff, E. M., Oakes, T. R., et al. (2006). Amygdala volume and nonverbal social impairment in adolescent and adult males with autism. Archives of General Psychiatry, 63, 1417–1428.

Osterling, J. A., Dawson, G., & Munson, J. A. (2002). Early recognition of 1-year-old infants with autism spectrum disorder versus mental retardation. Development and Psychopathology, 14, 239–251.

Ozonoff, S., Iosif, A. M., Baguio, F., Cook, I. C., Hill, M. M., Hutman, T., et al. (2010). A prospective study of the emergence of early behavioral signs of autism. Journal of the American Academy of Child and Adolescent Psychiatry, 49, 256–266.

Pelphrey, K. A., Sasson, N. J., Reznick, J. S., Paul, G., Goldman, B. D., & Piven, J. (2002). Visual scanning of faces in autism. Journal of Autism and Developmental Disorders, 32, 249–261.

Pierce, K., Müller, R. A., Ambrose, J., Allen, G., & Courchesne, E. (2001). Face processing occurs outside the fusiform ‘face area’ in autism: Evidence from functional MRI. Brain, 124, 2059–2073.

Riby, D. M., Doherty-Sneddon, G., & Bruce, V. (2008). Exploring face perception in disorders of development: Evidence from Williams syndrome and autism. Journal of Neuropsychology, 2, 47–64.

Rutherford, M. D., & Towns, A. M. (2008). Scan path differences and similarities during emotion perception in those with and without autism spectrum disorders. Journal of Autism and Developmental Disorders, 38, 1371–1381.

Sasson, N. (2007). Face processing and the own-race bias: A study of typical development and autism. Saarbrücken, Germany: VDM Verlag Dr. Müller.

Sato, W., Kubota, Y., Okada, T., Murai, T., Yoshikawa, S., & Sengoku, A. (2002). Seeing happy emotion in fearful and angry faces: Qualitative analysis of the facial expression recognition in a bilateral amygdala damaged patient. Cortex, 38, 727–742.

Scherf, K. S., Luna, B., Minshew, N., & Behrmann, M. (2010). Location, location, location: Alterations in the functional topography of face- but not object- or place-related cortex in adolescents with autism. Frontiers in Human Neuroscience, 4, 2–16.

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

Schultz, R. T., Gauthier, I., Klin, A., Fulbright, R. K., Anderson, A. W., Volkmar, F., et al. (2000). Abnormal ventral temporal cortical activity during face discrimination among individuals with autism and Asperger syndrome. Archives of General Psychiatry, 57, 331–340.

Schumann, C. M., Hamstra, J., Goodlin-Jones, B. L., Lotspeich, L. J., Kwon, H., Buonocore, M. H., et al. (2004). The amygdala is enlarged in children but not adolescents with autism; the hippocampus is enlarged at all ages. Journal of Neuroscience, 24, 6392–6401.

Senju, A., & Johnson, M.H. (2009). Atypical eye contact in autism: Models, mechanisms and development. Neuroscience and Behavioral Reviews, 33, 1204–1214.

Skuse, D. (2003). Fear recognition and the neural basis of social cognition. Child and Adolescent Mental Health, 8, 50–60.

Stella, J., Mundy, P., & Tuchman, R. (1999). Social and nonsocial factors in the Childhood Autism Rating Scale. Journal of Autism and Developmental Disorders, 29, 307–317.

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.

van der Geest, J. N., Kemner, C., Verbaten, M. N., & van Engeland, H. (2002). Gaze behavior of children with pervasive developmental disorder toward human faces: A fixation time study. Journal of Child Psychology and Psychiatry, 43, 669–678.

Vicari, J., Reilly, J. S., Pasqualetti, P., Vizzotto, A., & Caltagirone, C. (2000). Recognition of facial expressions of emotions in school-age children: The intersection of perceptual and semantic categories. Acta Paediatrica, 89, 836–845.

Wang, A. T., Dapretto, M., Hariri, A. R., Sigman, M., & Bookheimer, S. Y. (2004). Neural correlates of facial affect processing in children and adolescents with autism spectrum disorder. Journal of the American Academy of Child and Adolescent Psychiatry, 43, 481–490.

Williams, K. R., Wishart, J. G., Pitcairn, T. K., & Willis, D. S., (2005). Emotion recognition by children with Down syndrome: Investigation of specific impairments and error patterns. American Journal on Mental Retardation, 110, 378–392.

Ziersch, A. M. (2005). Health implications of access to social capital: Findings from an Australian study. Social Science & Medicine, 61, 2119–2131.

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Table 1. Subjects demographics in PDD and control groups

	PDD (*N* = 28)	CON (*N* = 28)
Male : Female	23 : 5	24 : 4
Age range	9 - 30	9 - 28
Asperger : PDD-NOS	15 : 13	-
	Mean (*SD*)	Mean (*SD*)
Age	17.6 (5.2)	18.0 (4.0)
Verbal IQ	105.5 (14.7)	-
Performance IQ	100.1 (13.3)	-
Full-scale IQ	103.3 (13.1)	-
CARS	21.3 (2.7)	-

Table 2. Mean (with *SE*) scores of face perception task and mean (with *SE*) percentages of accurate emotion recognition

		Benton	Emotion Recognition						
Group			AN	DI	FE	HA	SA	SU	ALL
CON	Mean	23.6	53.8	46.4	51.8	98.2	76.3	94.2	70.1
	(*SE*)	(1.5)	(4.3)	(4.3)	(3.7)	(0.9)	(3.7)	(1.7)	(1.5)
PDD	Mean	22.1	60.7	39.3	32.1	98.7	79.9	95.3	67.7
	(*SE*)	(2.3)	(4.1)	(4.6)	(5.0)	(0.8)	(3.2)	(1.9)	(1.6)

AN = anger; DI = disgust; FE = fear; HA = happy; SA = sad: SU = surprise; ALL = the mean of all conditions

Figure Captions

Figure 1. Mean (with SE) percentages of accurate facial expression recognition in typically developing controls (CON) and in individuals with PDD. An asterisk indicates a significant difference between groups ($p < 0.05$). AN = anger; DI = disgust; FE = fear; HA = happiness; SA = sadness; SU = surprise.

Figure 2. The relationships between chronological age, fearful expression recognition, and face perception. (A) The percentage of accurate fearful expression recognition is plotted against the chronological age of each participant. (B) The face-perception task score is plotted against the chronological age of each participant. (C) The percentage of accurate fearful expression recognition is plotted against the score in the face-perception task. Black and white diamonds represent each participant in the control and PDD group, respectively. Solid and broken lines represent linear regressions in the control and PDD group, respectively.

Figure 3. The hypothesized model for the development of fearful face recognition. Face perception and fearful expression recognition improve

with age, and the development of face perception improves fearful face recognition. The hypothesized model shows better fits in typically developing controls (Right) but not in individuals with PDD (Left). Asterisks indicate significant path coefficients ($p < 0.05$).

Figure 4. The relationship between the percentage of accurate fearful expression recognition and the degree of social dysfunction evaluated using the CARS. Severe social dysfunction predicts the poor recognition of fearful expressions in individuals with PDD.

Figure 1.

top

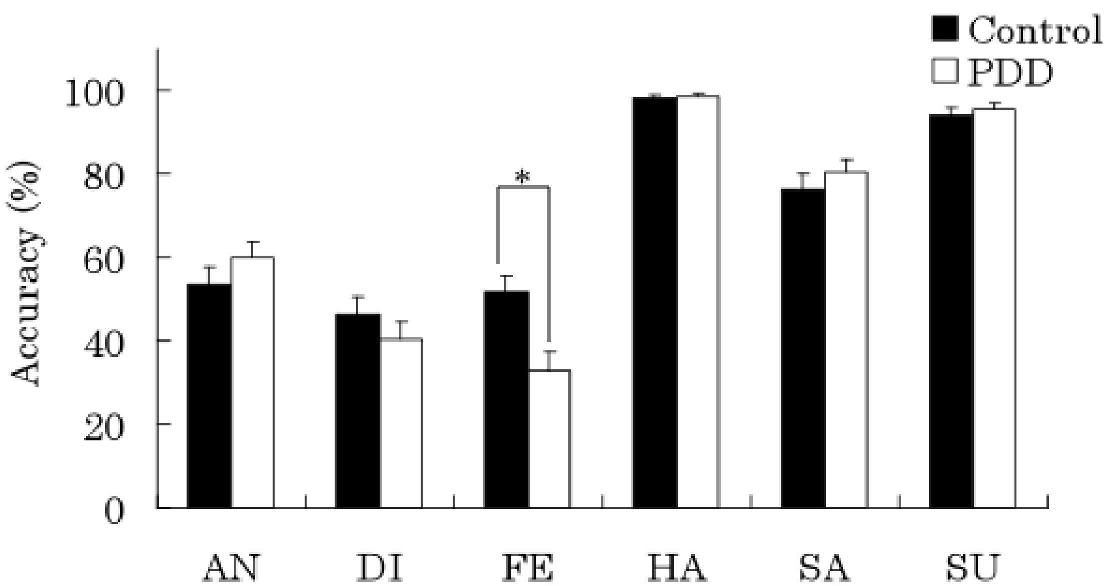

Figure 2a.

top

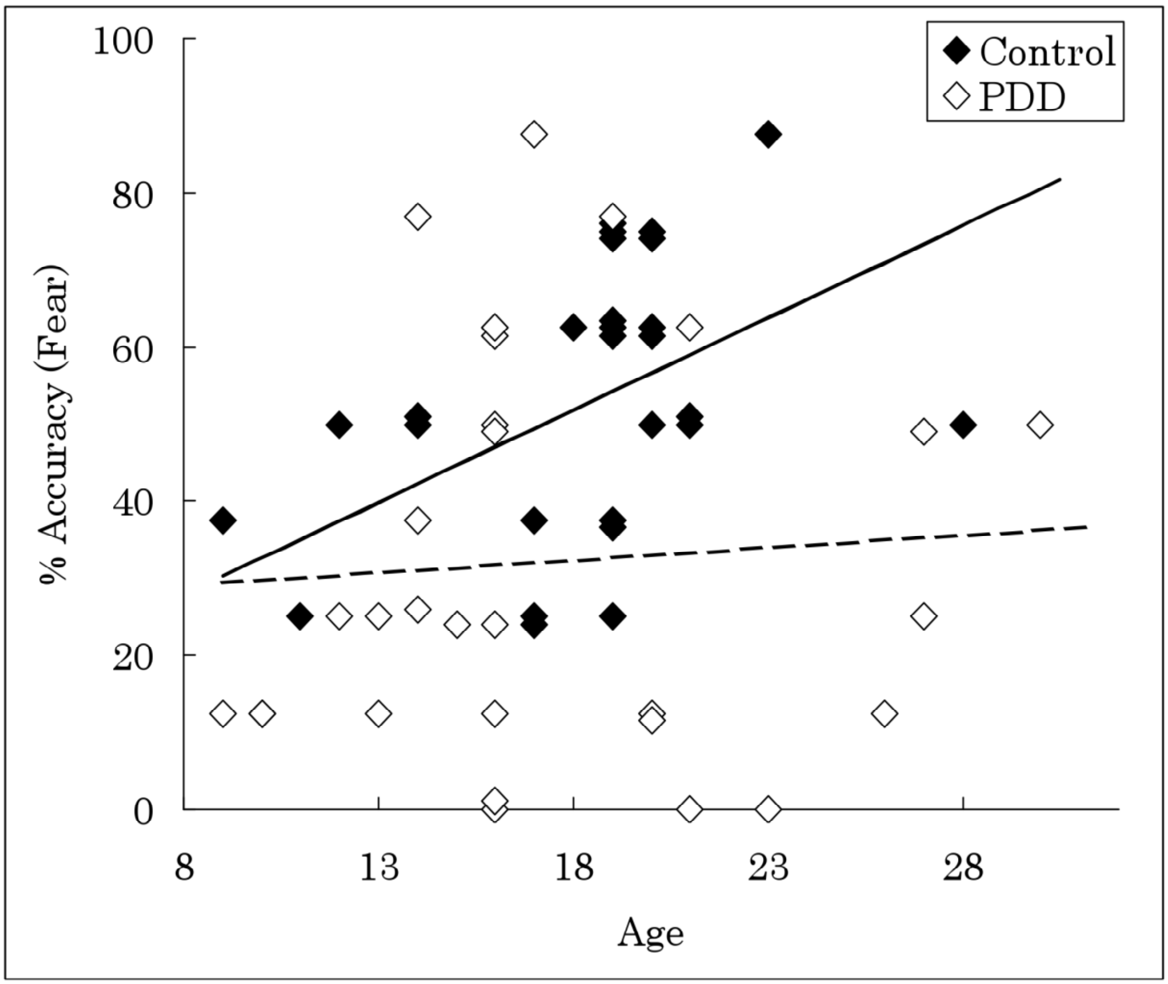

Figure 2b.

top

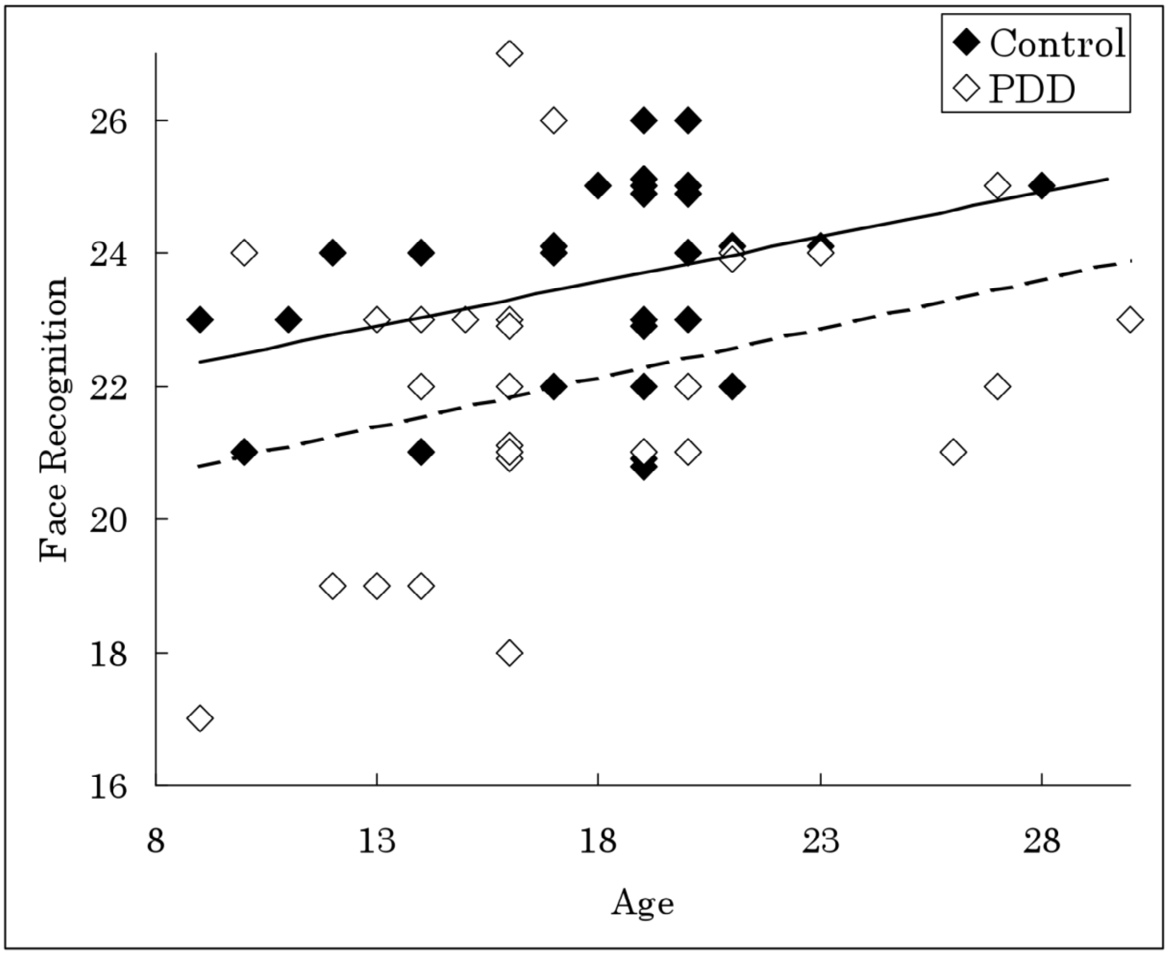

Figure 2c.

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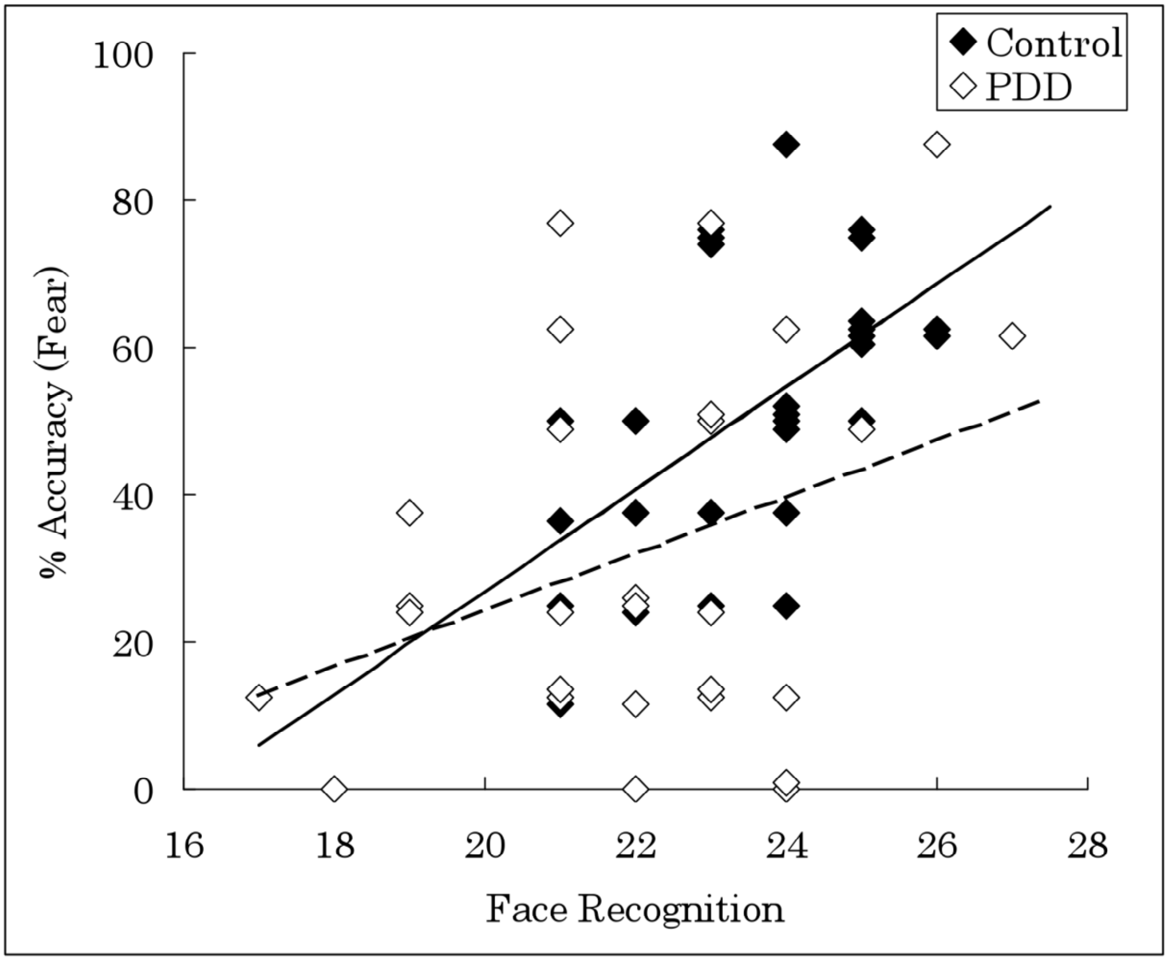

Figure 3.

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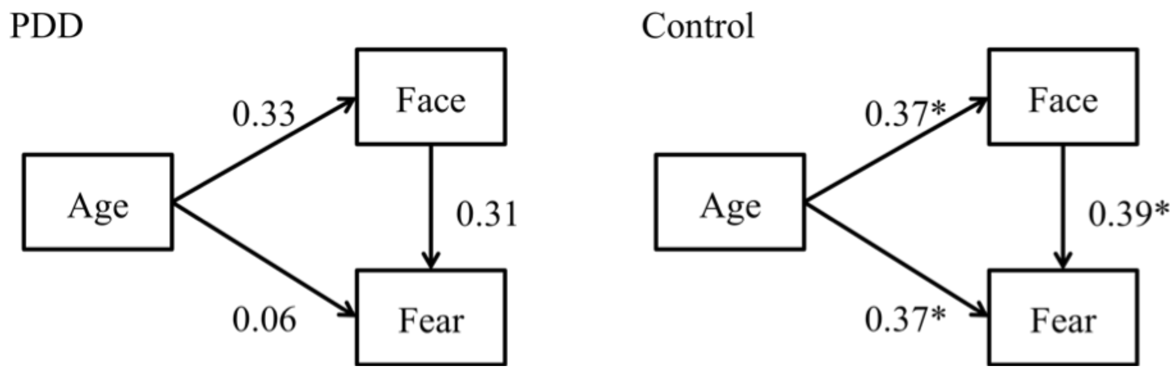
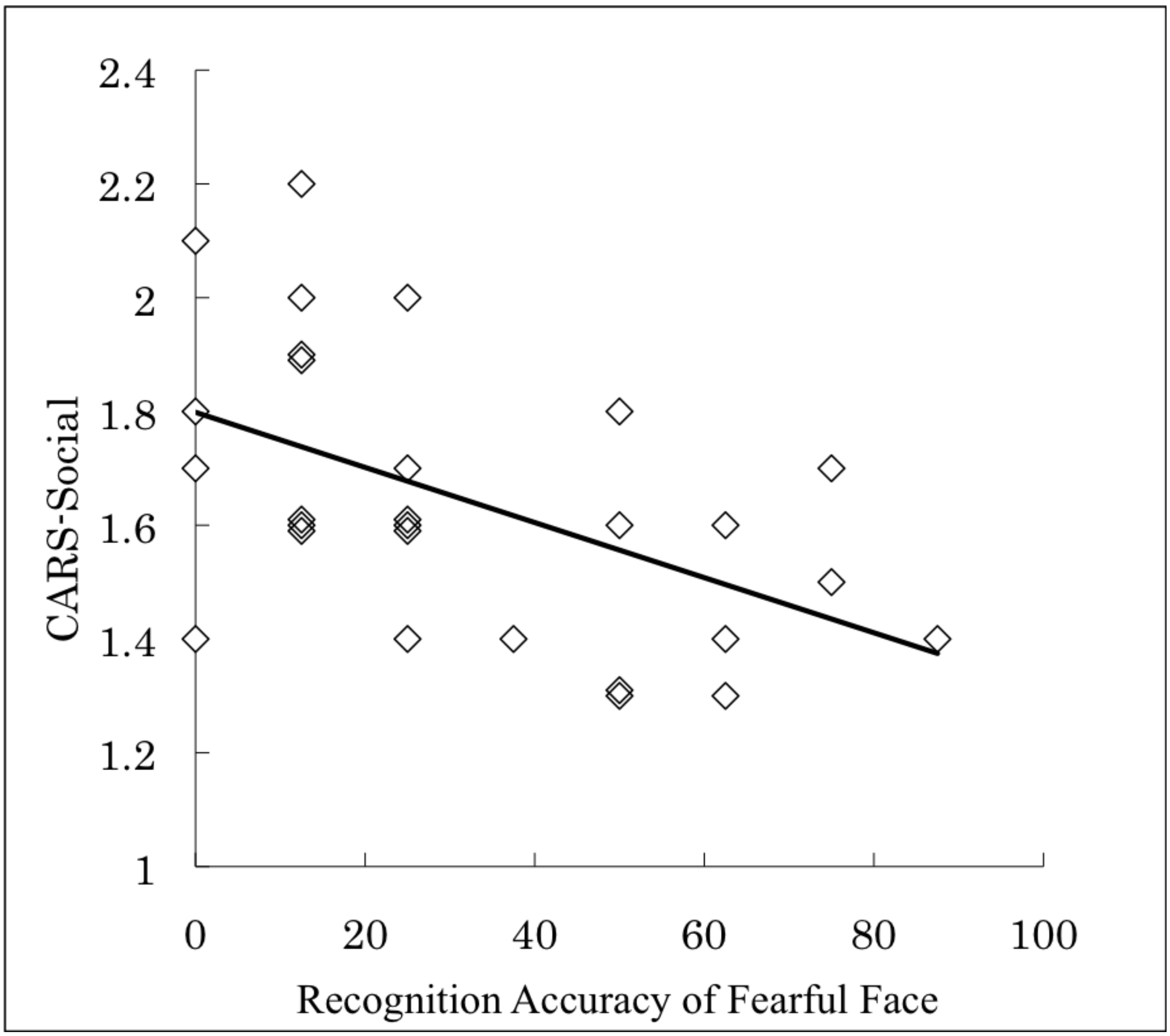

PDD
Age
Face
Fear
0.33
0.31
0.06
Control
Age
Face
Fear
0.37*
0.39*
0.37*

Figure 4.

top


2.4
2.2
2
1.8
1.6
1.4
1.2
1
CARS-Social
0
20
40
60
80
100
Recognition Accuracy of Fearful Face