RESEARCH ARTICLE

Sensory Processing Patterns and Fusiform Activity During Face Processing in Autism Spectrum Disorder

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A growing body of evidence has indicated that individuals with autism spectrum disorder (ASD) exhibit abnormal reactions to sensory stimuli and impaired face processing. Although behavioral studies have reported that individual differences in sensory processing patterns are correlated with performance in face processing tasks, the neural substrates underlying the association between sensory processing patterns and face processing remain unknown. Using functional magnetic resonance imaging, the present study examined the relationships between sensory processing patterns assessed with the Adolescent/Adult Sensory Profile (AASP) and brain activity during a one-back task with two types of stimuli (face or house pictures). We enrolled 18 Japanese adults with ASD and 19 age- and IQ-matched controls. Sensation Avoiding scores, which were assessed using the AASP, were positively correlated with right fusiform activity during the presentation of pictures of faces in the ASD group, but not in the control group. This suggests that abnormal sensory processing patterns in ASD are associated with abnormal face-related brain activity, possibly resulting in impaired face processing. ***Autism Res*** *2020, 13: 741–750.* © 2020 The Authors. *Autism Research published by International Society for Autism Research* published by Wiley Periodicals, Inc.

Lay Summary: Sensory abnormalities are one of the most common symptoms in people with autism spectrum disorder (ASD). This study shows that individuals with ASD who react abnormally to sensory stimuli also exhibit atypical brain activity when recognizing faces. Abnormal sensory processing may partly explain the difficulty that people diagnosed with ASD have in identifying others' faces.

Keywords: autism spectrum disorder; face processing; sensory processing; sensory profile; fMRI; fusiform gyrus

Introduction

Autism spectrum disorder (ASD) is a neurodevelopmental disorder characterized by social communication deficits, restricted interests, and repetitive behaviors, according to the fifth edition of the Diagnostic and Statistical Manual of Mental Disorders [DSM-5; American Psychiatric Association, 2013].

Growing behavioral evidence suggests that individuals with ASD often show difficulty in identifying others' faces (see Weigelt, Koldewyn, and Kanwisher [2012] for review). When human faces were presented simultaneously with geometrical patterns, compared to typically developing (TD) individuals, individuals with ASD focused on human faces for a shorter period and instead fixed their gaze for longer on geometrical patterns [Fujioka et al., 2016]. These findings suggest that individuals with ASD exhibit different visual processing patterns from those of their TD peers.

Functional magnetic resonance imaging (fMRI) studies have reported that the fusiform gyrus and amygdala exhibited lower activation during face processing in individuals with ASD than in TD individuals [Nomi & Uddin, 2015; Pierce, Muller, Ambrose, Allen, & Courchesne, 2001; Schultz et al., 2000]. An fMRI study reported that the activity in the fusiform face area increased with face-related working memory load [Druzgal & D'Esposito, 2001]. Moreover, abnormal face processing in ASD is particularly prominent during tasks involving face memory [Weigelt et al., 2012]; therefore, using a memory task may be effective for investigating functional abnormalities related to face processing in individuals with ASD.

Individuals with ASD also have abnormal sensory experiences. The DSM-5 added sensory abnormalities, such as

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hypersensitivity or hyposensitivity, to the diagnostic criteria of ASD [American Psychiatric Association, 2013]. Several studies have demonstrated that 90% or more of children with ASD exhibit some form of sensory abnormalities [Leekam, Nieto, Libby, Wing, & Gould, 2007; Tomchek & Dunn, 2007]. Sensory abnormalities, defined as atypical patterns of sensory processing, are assessed by measuring behavioral responses to sensory input in the field of occupational therapy [Brown, Tollefson, Dunn, Cromwell, & Filion, 2001]. The Adolescent/Adult Sensory Profile® (AASP) is a self-reported questionnaire used to evaluate such behavioral response patterns toward sensory stimuli in adults [Brown & Dunn, 2002; Hirashima et al., 2014]. It assesses sensory processing patterns according to four quadrants based on Dunn's [1997] model: "Low Registration," "Sensation Seeking," "Sensory Sensitivity," and "Sensation Avoiding." A previous study using AASP demonstrated that adults with ASD exhibited higher scores in the Low Registration and Sensation Avoiding quadrants than did TD adults, while Sensation Seeking scores were lower in the ASD adult group than in the TD adult group [Crane, Goddard, & Pring, 2009]. Similar patterns have also been observed in children with ASD [Jao Keehn et al., 2017; Stewart et al., 2016]

Previous research has suggested a link between abnormal face processing and sensory abnormalities in ASD. Regarding visual processing in ASD, it has been demonstrated that local information is processed preferentially over global information [Happé & Frith, 2006; Shah & Frith, 1983, 1993]. Several studies have reported an association between sensory processing patterns and global precedence [Stevenson et al., 2018] and another between global precedence and face processing [Gross, 2005], suggesting that abnormal face processing observed in ASD, which may be affected by weakened global processing of visual information [Behrmann et al., 2006], is associated with abnormal sensory processing patterns. However, the neural bases underscoring abnormal sensory processing patterns and face processing in ASD remain unknown.

The present study examined the neural substrates underlying the relationship between specific sensory traits and abnormal face processing in ASD. As mentioned previously, the fusiform gyrus and amygdala have been associated with abnormal face processing in individuals with ASD [Pierce et al., 2001; Schultz et al., 2000]. Therefore, we used fMRI to measure the brain activity in these areas during a face-processing task and used the AASP to assess sensory processing patterns in a sample of adults with ASD and their TD peers. To investigate the link between face-related activity and sensory processing patterns, we analyzed the correlations between brain activity and sensory profile scores.

Methods

Participants

Eighteen Japanese adults with ASD (15 males, three females; mean age $\pm$ *SD* = 31.17 $\pm$ 3.29 years; age range 27–39 years) and 19 TD controls (15 males, four females; mean age $\pm$ *SD* = 31.37 $\pm$ 3.19 years; age range 29–39 years) participated in this study. All participants were right-handed as assessed by the Edinburgh Handedness Inventory [Oldfield, 1971].

Participants in the ASD group were recruited from the Asperger Society Japan and diagnosed with Autistic Disorder, Asperger Disorder, or Pervasive Developmental Disorder based on the DSM-IV TR [4th edition, text revision; American Psychiatric Association, 2000] by a local psychiatrist. An independent, certified psychiatrist (K.J.T.) and psychologist (K.M.), who were qualified to administer the Autism Diagnostic Interview-Revised [Lord, Rutter, & Le Couteur, 1994] and Autism Diagnostic Observational Schedule [Lord et al., 1989] confirmed that all participants in the ASD group fulfilled ASD diagnostic criteria.

Full-scale intelligence quotient (IQ) was measured with the Wechsler Adult Intelligence Scale, third edition [Wechsler, 1997]. Although age did not significantly differ between the two groups, there was a marginally significant difference in the full-scale IQ (Table 1). Participants also completed the AASP, Social Responsiveness Scales-Second Edition (SRS-2: Constantino & Gruber, 2012], SRS-2 Adult Self-Report Form [Constantino & Gruber, 2012], and Autism-spectrum Quotient [Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001]. Written, informed consent was provided by each participant. This study was conducted in accordance with the Declaration of Helsinki and approved by the Clinical Research Ethics Committee at the Hamamatsu University School of Medicine.

Stimuli and Experimental Design

A one-back task with a block-design paradigm was performed in the magnetic resonance scanner. The experiment comprised six stimulus blocks of 30 sec each. Forty gray-scale faces (half male and half female) or house pictures were presented in each stimulus block. Face blocks and house blocks were alternately repeated (Fig. 1). All face pictures were full-face and trimmed to remove apparent features such as the neck, ears, and hair. Similarly, house pictures were edited to eliminate the background and extraneous objects. Photoshop CS4 (Adobe Systems Inc.) was used to edit pictures. The duration of the presentation of each picture was 500 msec, followed by a 250-msec inter-stimulus interval. The presentation order within each block was pseudo-randomized. During stimulus blocks, no fixation cross was presented, but participants were instructed to observe presented pictures

Table 1. Demographic Data and Behavioral Data in the One-Back Task

	ASD (n = 18)	TD (n = 19)	Comparison	
Mean age (range)	31.17 (27–39)	31.37 (29–39)	t = −0.17	P = 0.87
Intelligence quotient (mean ± SD)	87.12 ± 18.28	98.74 ± 8.83	t = −2.00	P = 0.054
Autism spectrum quotient (mean ± SD)	30.47 ± 8.00	15.42 ± 6.13	t = 6.51	P < 0.001
Social Response Scale Second Edition (SRS-2) (mean ± SD)	76.06 ± 23.01	30.05 ± 21.28	t = 6.35	P < 0.001
SRS-2 Adult Self-Report Form (mean ± SD)	88.41 ± 30.84	47.47 ± 21.46	t = 4.26	P < 0.001
Adolescent/adult sensory profile (mean ± SD)				
Low registration	32.06 ± 8.39	25.79 ± 8.67	t = 2.13	P = 0.04
Sensation seeking	36.88 ± 10.53	37.84 ± 5.52	t = −0.35	P = 0.73
Sensory sensitivity	32.59 ± 9.43	32.53 ± 7.99	t = 0.01	P = 0.99
Sensation avoiding	37.41 ± 8.58	33.00 ± 7.30	t = 1.47	P = 0.15
Autism diagnostic observation schedule (mean ± SD)				
Social reciprocity + communication	13.94 ± 3.15			
One-Back Task (mean ± SD)				
Reaction time (msec)				
Face	507.40 ± 85.41	512.24 ± 40.73	t = −0.22	P = 0.83
House	485.09 ± 86.76	489.73 ± 41.00	t = −0.21	P = 0.83
Correct answer rate				
Face	0.86 ± 0.09	0.89 ± 0.12	t = −0.93	P = 0.36
House	0.94 ± 0.10	0.91 ± 0.13	t = −0.92	P = 0.36
Head motion during scan acquisition (mean ± SD)				
x (mm)	−0.02 ± 0.08	0.00 ± 0.06	t = −0.73	P = 0.47
y (mm)	0.06 ± 0.07	0.03 ± 0.08	t = 1.46	P = 0.15
z (mm)	0.07 ± 0.26	0.13 ± 0.18	t = −0.58	P = 0.57
Pitch (radian)	0.00 ± 0.01	0.00 ± 0.01	t = 0.86	P = 0.40
Roll (radian)	0.00 ± 0.00	0.00 ± 0.00	t = −0.83	P = 0.41
Yaw (radian)	0.00 ± 0.00	0.00 ± 0.00	t = −1.00	P = 0.32

Abbreviations: ASD: individuals with autism spectrum disorder; TD: typically developing individuals.
For behavioral data in the one-back task, statistics on direct group comparisons in each picture type (face, house) are shown.

carefully and to memorize them temporarily. They were also required to press a button with their right index finger as quickly as possible when an identical picture was successively presented. Ten pictures served as target stimuli in each block. A fixation cross was presented for 20 sec before and after each stimulus block. In addition, a 25-sec fixation block was inserted at the beginning of the experiment, and a termination message was presented for 5 sec at the end of the experiment.

fMRI Data Acquisition

T2*-weighted images with blood oxygenation level-dependent contrast were collected with a 3-T MRI scanner (Signa HDxt, GE Healthcare) at the Kojin Hospital (Nagoya, Japan) using gradient-echo echo-planar imaging. The following parameters were used: repetition time (TR) = 2,500 msec, echo time (TE) = 30 msec, field of view = 210 × 210 mm^2, slice thickness = 3.0 mm with

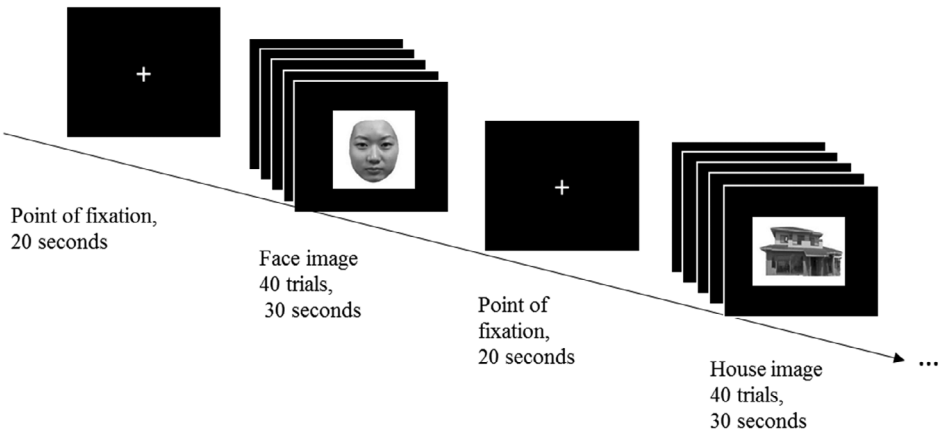

Figure 1. Schematic illustration of the stimuli and task.

0.5-mm gap, 42 transverse slices, flip angle (FA) = 80°, 64 × 64 matrix. In total, 140 scans were acquired per functional session. The first 10 and last two scans were discarded. Using a 3D SPGR sequence, T1-weighted anatomical images were also acquired with the following parameters: TR = 5.9 msec, TE = 1.9 msec, inversion time = 400 msec, FA = 15, voxel size = $1 \times 1 \times 1$ mm^3, 156 transverse slices.

Behavioral Data Analysis

For each participant, accuracy and mean reaction time for the one-back task were calculated. We then conducted a linear mixed-effects model analysis with Group (ASD, TD), Picture Type (face, house), and their interaction as fixed effects and a by-subject random intercept. Moreover, we included full-scale IQ as a covariate because we observed marginally significant group differences in full-scale IQ. Data fitting was performed with Stata MP 15.1 (StataCorp, College Station, TX).

fMRI Data Analysis

SPM12 software (http://www.fil.ion.ucl.ac.uk/spm/) was used for preprocessing and statistical whole-brain analysis of fMRI data. The applied preprocessing steps included the following: (a) the functional images were realigned to the mean image; (b) the difference of slice acquisition timing was corrected; (c) the functional images were co-registered to individuals' structural T1 images; (d) the spatial normalization parameters were estimated during the segmentation of structural images into gray matter, white matter, and cerebrospinal fluid; (e) all functional images were transformed into the Montreal Neurological Institute stereotaxic space using the estimated parameters, and resampled into $3 \times 3 \times 3$ mm^3 voxels; and (f) the normalized functional images were smoothed with a 6-mm full width at half maximum Gaussian kernel.

The preprocessed data were analyzed using a general linear model approach. The functional images were high-pass filtered to remove low-frequency noise with a cut-off period of 128 sec. The serial correlations in the fMRI time series were considered using the autoregressive AR(1) model, as implemented in the standard pipeline of SPM12. The face and house conditions were modeled as separate box-car regressors that were convolved with a canonical hemodynamic response function. Additionally, six head-motion parameters were included as confounding covariates.

The beta maps yielded by the individual-level analysis were submitted to a 2×2 full factorial analysis of variance for group-level random-effects statistical inference, with a between-subjects factor (Group [ASD or TD]) and within-subjects factor (Picture Type [face or house]). To identify group-level local maxima within the fusiform gyrus and amygdala associated with face processing, the main effect of Picture Type was tested by comparing the face condition to the house condition. The statistical threshold was set at $P = 0.05$ with family-wise error (FWE) correction for multiple comparisons at voxel-level. We did not apply an additional cluster-level correction, taking into account small cluster sizes. Anatomical labels of the peaks were defined using the Neuromorphometrics function in SPM12.

Region of Interest Analysis

To create individual regions of interest (ROIs) in the bilateral fusiform gyrus and amygdala, we localized activation peaks for each participant within mask images of the four target regions (i.e., the right fusiform gyrus, left fusiform gyrus, right amygdala, and left amygdala), comparing the face and house conditions with a significance threshold of $P = 0.05$ uncorrected for multiple comparisons. Those mask images were generated using the SPM Anatomy toolbox [Eickhoff et al., 2005]. Activated clusters in these anatomical masks were regarded as individual functional ROIs. For those who did not show any significant activation within a masked region, we used the activated clusters in the group-level analysis ($P < 0.05$ with FWE correction for multiple comparisons at voxel-level) within the same anatomical mask images (i.e., bilateral fusiform gyrus and amygdala) as functional ROIs. We created these ROIs from the group-level activated clusters by the contrast between the face condition and the house condition. We used Marsbar software [Brett, Anton, Valabregue, & Poline, 2002] to build all ROIs and to extract the beta values for the face condition from these ROIs.

To test the hypothesis that behavioral characteristics of sensory processing were correlated with altered brain activity during face processing in ASD, we calculated the partial correlations between AASP scores and beta values for the face condition within the ROIs with full-scale IQ as a covariate. We used Bonferroni correction for multiple comparisons.

Correlation Analysis Between Sensory Profile Scores and Symptom Severity

There may be associations between symptom severity in ASD and sensory processing patterns assessed by the AASP. These possible associations may result in spurious correlations between sensory processing patterns and brain activity. We calculated correlations between sensory profile scores and symptom severity assessed by the ADOS and ADI-R, to exclude this possibility.

Results

Behavioral Data

We observed that Picture Type had a significant effect on reaction time (β = 22.512, 95% confidence interval [CI] 6.922 to 38.101, P = 0.005), suggesting that the

Table 2. MNI Coordinates for Individual Activation Peaks for the Contrast of Face > House

	Fusiform gyrus (L)	Fusiform gyrus (R)	Amygdala (L)	Amygdala (R)
ASD1	[−50, −74, −8]	[44, −72, −10]	–	[16, −4, −16]
ASD2	[−44, −48, −26]	[40, −52, −20]	–	–
ASD3	[−44, −56, −22]	[42, −68, −18]	[−18, −2, −28]	–
ASD4	–	[46, −52, −18]	–	[26, 0, −30]
ASD5	–	[44, −50, −24]	–	[22, −6, −12]
ASD6	[−40, −50, −20]	[44, −52, −20]	[−20, −4, −26]	[24, −6, −12]
ASD7	–	–	–	[28, 4, −28]
ASD8	–	[44, −56, −18]	–	–
ASD9	[−44, −48, −26]	[46, −48, −22]	[−28, −2, −22]	[22, −4, −18]
ASD10	[−42, −50, −16]	[40, −58, −18]	[−22, −4, −14]	[24, 0, −14]
ASD11	[−46, −46, −28]	[46, −48, −26]	[−22, −8, −24]	[24, −6, −18]
ASD12	[−48, −60, −22]	[40, −54, −18]	[−18, −8, −14]	[16, −4, −16]
ASD13	[−46, −50, −24]	[44, −58, −14]	[−24, −6, −18]	[30, −6, −16]
ASD14	[−20, −62, −8]	[40, −72, −16]	[−16, −6, −16]	[22, −8, −12]
ASD15	[−40, −50, −14]	[42, −64, −12]	–	[16, −6, −20]
ASD16	[−44, −60, −14]	[46, −64, −18]	[−18, 2, −22]	[20, 0, −16]
ASD17	[−40, −42, −26]	[46, −50, −18]	–	[20, −4, −16]
ASD18	[−46, −44, −18]	–	[−18, 2, −22]	[34, −2, −24]
TD1	[−38, −66, −10]	[40, −52, −20]	[−20, −10, −12]	–
TD2	[−48, −60, −18]	[42, −56, −10]	[−16, −4, −18]	[20, −4, −16]
TD3	[−44, −52, −24]	[40, −56, −10]	[−16, −4, −16]	[22, −6, −12]
TD4	[−36, −60, −8]	[40, −48, −12]	[−22, 0, −16]	[22, −2, −16]
TD5	[−48, −64, −18]	[40, −56, −20]	[−22, −8, −14]	[26, −2, −18]
TD6	[−50, −60, −16]	[50, −46, −18]	[−18, −6, −20]	[18, −6, −22]
TD7	[−46, −58, −22]	[48, −48, −24]	–	[30, 2, −24]
TD8	–	–	–	–
TD9	[−40, −80, −14]	[38, −40, −18]	[−26, −4, −14]	[20, 0, −16]
TD10	[−46, −74, −14]	[40, −74, −12]	[−18, −8, −14]	[20, −6, −16]
TD11	[−42, −54, −22]	[44, −72, −18]	[−26, 0, −24]	[20, −2, −26]
TD12	[−42, −48, −16]	–	[−18, −4, −16]	[24, −8, −12]
TD13	[−40, −48, −16]	[46, −46, −20]	[−16, −2, −18]	[24, 4, −28]
TD14	[−38, −44, −24]	–	–	[20, −4, −16]
TD15	[−40, −60, −18]	[46, −46, −20]	[−18, −2, −18]	[26, 0, −18]
TD16	[−44, −52, −20]	[42, −50, −16]	[−22, −12, −14]	[16, −4, −18]
TD17	[−38, −54, −20]	[46, −60, −16]	[−20, −4, −14]	[24, −8, −14]
TD18	[−42, −72, −6]	[48, −56, −20]	–	–
TD19	[−48, −64, −20]	[48, −58, −20]	[−26, −4, −22]	[26, 0, −14]

Horizontal lines indicate no significant activation at the individual level.
Abbreviations: MNI: Montreal Neurological Institute; L, left; R, right.

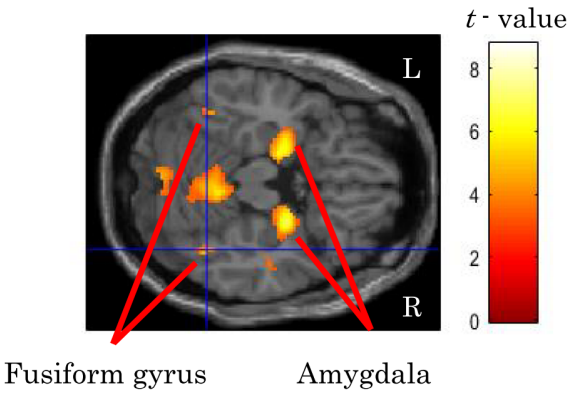

Figure 2. Group-level brain activation during the one-back task. The bilateral fusiform gyrus and amygdala showed increased activity for the face > house comparison when the two groups were combined. R: right, L: left.

Table 3. Brain Activation for the Contrast of Face Versus House

	MNI coordinate				
	x	*y*	*z*	*Z*-score	Cluster size
Right amygdala	24	−6	−14	7.18	653
Left amygdala	−20	−6	−14	5.77	664
Right cerebellum exterior	6	−44	−16	5.36	5731
Right superior frontal gyrus	28	44	40	5.08	1384
Right thalamus proper	26	−24	12	4.57	107
Right fusiform gyrus	44	−52	−18	4.52	33
Left supramarginal gyrus	−60	−56	30	4.49	389
Left fusiform gyrus	−42	−50	−20	4.47	16
Left parietal operculum	−32	−32	20	4.46	51

Abbreviation: MNI: Montreal Neurological Institute.

reaction to face pictures was significantly delayed compared to that of house pictures (Table 1). The effect of Group and the interaction of Group × Picture Type were not significant (β = −22.810, 95% CI −62.856 to 17.237, P = 0.26, and β = −0.201, 95% CI −22.552 to 22.151, P = 0.97, respectively). The effect of Group (β = 0.042, 95% CI −0.033 to 0.116, P = 0.27) and that of Picture Type (β = −0.016, 95% CI −0.052 to 0.021, P = 0.39) on accuracy were not significant. However, we observed a significant interaction of Group × Picture Type (β = −0.069, 95% CI −0.121 to −0.017, P = 0.009). We conducted post hoc pairwise comparisons using the "pwcompare" command in Stata, and found that the accuracy in the face condition was significantly lower than that in the house condition in the ASD group (contrast = −0.085, 95% CI −0.135 to −0.034, Bonferroni-corrected $q < 0.001$) but not in the TD group (contrast = −0.016, 95% CI −0.065 to 0.033, Bonferroni-corrected q = 1). Conversely, group differences were not significant for the face condition (contrast = −0.016, 95% CI −0.065 to 0.033, Bonferroni-corrected q = 1) or the house condition (contrast = −0.023, 95% CI −0.128 to 0.072, Bonferroni-corrected q = 1).

fMRI Data

Localizer analysis identified peak coordinates of each participant (Table 2). For participants whose peak was not identified in any ROI, we used local maxima revealed by the whole-brain group-level contrast of the face condition versus the house condition in the left fusiform gyrus, right fusiform gyrus, left amygdala, and right amygdala (x = −42, y = −50, z = −20 for the left fusiform gyrus; x = 44, y = −52, z = −18 for the right fusiform gyrus; x = −20, y = −6, z = −14 for the left amygdala; and x = 24, y = −4, z = −14 for the right amygdala) ($P < 0.05$, FWE corrected for multiple comparisons at voxel level; Fig. 2 and Table 3).

We calculated the partial correlations between scores in each quadrant of the AASP and beta value for the face condition in each ROI by controlling for full-scale IQ (Table 4). In the ASD group, right fusiform gyrus activity was positively correlated with Sensation Avoiding scores (r = 0.78, Bonferroni-corrected $q = P \times 48 = 0.009$; Fig. 3). Other correlations did not survive Bonferroni correction in the ASD group. In the TD group, no significant correlations were detected. For the bilateral amygdala, no significant correlation was observed in the ASD group, TD group, or a combination of the two groups.

We further tested the differences in correlation between right fusiform activity and Sensation Avoiding scores among groups. We observed that the correlation value was significantly higher in the ASD group than in the TD group (z = 2.56, P = 0.01). In addition, we divided each group into two subgroups on the basis of cut-off points for the Sensation Avoiding quadrant (42 for ages below 35 years, and 40 for ages 35 years and above), and compared right fusiform activity among these subgroups.

Table 4. Correlations Between AASP and Brain Activity

		Fusiform						Amygdala					
		All (n = 37)		ASD (n = 18)		TD (n = 19)		All (n = 37)		ASD (n = 18)		TD (n = 19)	
		Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Correlation coefficient (r)	Low registration	0.03	0.17	0.26	0.52	0.08	0.09	0.17	0.21	0.29	0.30	0.25	0.15
	Sensation seeking	0.18	0.32	0.27	0.48	0.01	0.11	0.16	−0.10	0.10	−0.24	0.19	0.13
	Sensory sensitivity	0.06	0.11	0.33	0.55	−0.23	−0.20	0.10	0.06	0.21	0.21	−0.04	−0.05
	Sensation avoiding	0.19	0.37	0.56	0.78	0.09	0.11	0.15	0.04	0.29	0.22	0.14	−0.01
Uncorrected P-value	Low registration	0.87	0.31	0.31	0.03*	0.75	0.72	0.32	0.21	0.27	0.24	0.31	0.54
	Sensation seeking	0.30	0.06	0.29	0.05	0.98	0.67	0.35	0.58	0.70	0.35	0.45	0.60
	Sensory sensitivity	0.74	0.51	0.19	0.02*	0.36	0.43	0.55	0.71	0.41	0.41	0.89	0.85
	Sensation avoiding	0.26	0.03*	0.02*	0.00**	0.73	0.66	0.38	0.83	0.26	0.40	0.58	0.96
Bonferroni corrected q-value	Low registration	1	1	1	1	1	1	1	1	1	1	1	1
	Sensation seeking	1	1	1	1	1	1	1	1	1	1	1	1
	Sensory sensitivity	1	1	1	1	1	1	1	1	1	1	1	1
	Sensation avoiding	1	1	0.97	0.009**	1	1	1	1	1	1	1	1

Abbreviation: AASP: Adolescent/Adult Sensory Profile.
*P < 0.05; **P < 0.01.

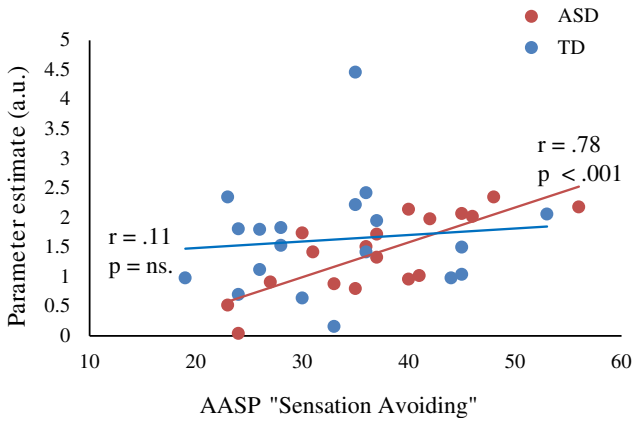

Figure 3. Relationships between sensory processing patterns assessed with AASP and brain activity in the face condition. Scatter plot of right fusiform gyrus activity and the Sensation Avoiding score. Parameter estimates show the beta values for the face condition in the individual right fusiform ROIs. The partial correlation coefficient and uncorrected *P*-value are shown. ASD, individuals with autism spectrum disorder; TD, typically developing individuals; AASP, Adolescent/Adult Sensory Profile; a.u., arbitrary unit.

No significant differences were observed between the high and low subgroups (4 for the high, 15 for the low) in the TD group. In the ASD group (5 for the high, 13 for the low), the high subgroup showed higher right fusiform activity than that in the low subgroup ($t = -5.68$, $P < 0.001$). We have to note, however, that there were very few participants in the high subgroups (five ASD, four TD), and these results should be interpreted cautiously. Moreover, we should also mention that there were marginally significant differences in age ($t = -1.71$, $P = 0.11$) and Sensory Sensitivity scores ($t = -1.94$, $P = 0.07$) when demographic, behavioral, and psychological measures were compared between the ASD subgroups. The results of the subgroup analysis could have been affected by some background factors.

Correlation Analysis Between Sensory Profile Scores and Symptom Severity

Sensation Avoiding scores, which were associated with right fusiform activity, showed no significant correlation with symptom severity (ADI-R social score, $r = 0.20$, $P = 0.4$; ADI-R communication score, $r = 0.37$, $P = 0.1$; ADI-R stereotype score, $r = 0.19$, $P = 0.45$; ADOS social reciprocity + communication score, $r = 0.05$, $P = 0.9$).

Discussion

In the present study, we examined the relationships between neural responses to pictures of faces and the sensory processing patterns in individuals with ASD. The results showed a positive correlation between Sensation Avoiding scores and right fusiform activity in the ASD group but not in the TD group. We also demonstrated that the correlation value was higher for the ASD group than for the TD group.

The magnitude of the Sensation Avoiding score, by definition, indicates a low threshold for sensory stimulation and engagement in behaviors to avoid sensory stimuli [Brown & Dunn, 2002; Dunn, 1997]. Therefore, the positive correlation between Sensation Avoiding scores and right fusiform activity implies that the greater the tendency to avoid sensory stimulation, the stronger the neural responses to face stimuli in ASD. Previous reports have indicated no significant differences between individuals with ASD and TD individuals in fusiform gyrus activity when both groups were subjected to a face recognition task and instructed to look into the eyes [Hadjikhani et al., 2004; Lassalle et al., 2017]. Although we did not provide explicit instructions to look into the eye region in pictures, we conjectured that individuals with ASD who had greater sensory abnormalities may have focused on the eyes more rigorously, given the positive correlations between fusiform gyrus activity and the Sensation Avoiding trait. Furthermore, in the present study, all participants were instructed to observe and memorize the presented faces carefully in the one-back task. For this reason, participants may have been unable to remove their gaze from face stimuli, although those with high "Sensation Avoiding" traits may have a tendency to look away from others' faces. This experimental manipulation may have influenced greater activity in the fusiform face area in ASD individuals with a greater Sensation Avoiding tendency.

In both the ASD and TD groups, we did not observe a relationship between sensory processing patterns and amygdala activity. However, Green et al. [2013] reported a relationship between sensory processing patterns and amygdala activity using an unpleasant auditory stimulation task. These contrasting results may be due to differences in the task modality. To date, research on face perception has recognized the fusiform gyrus and amygdala as key brain areas underscoring face perception. However, while we observed a significant correlation between sensory profile scores and right fusiform activity, no significant correlation was found for the amygdala. Therefore, it is conceivable that these two sites, namely fusiform gyrus and amygdala, play distinct roles in face perception. Furthermore, we used neutral expressions as the face stimuli, which may have contributed to the lack of increased brain activity in both groups.

In the Introduction, we described how individuals with ASD often exhibit local precedence over holistic processing, and this may be associated with abnormal face processing in ASD. The association between the Sensation Avoiding trait and right fusiform activity may be mediated by weakened global processing, but caution should be exercised when proposing such a causal

relationship. It is noteworthy that the ASD population exhibits considerable heterogeneity. Indeed, impaired global processing is not common across the entire ASD population [Simmons et al., 2009; Van der Hallen, Vanmarcke, Noens, & Wagemans, 2017]. Further studies are needed to investigate links between sensory processing patterns, local/global precedence in visual processing, and face processing in ASD.

Studies have reported that individuals with ASD show higher Sensation Avoiding scores than those of their TD counterparts [Crane et al., 2009]. It is thus possible that the association between abnormal sensory processing patterns and face-related brain activity is explained by the severity of ASD symptoms. However, Sensation Avoiding scores, which were associated with the right fusiform activity, showed no significant correlation with symptom severity. Moreover, the correlations of right fusiform activity with both ADI-R and ADOS scores were not significant, except for a marginal correlation with ADI-R social score ($r = 0.45$, $P = 0.06$). These results suggest that the Sensation Avoiding trait, rather than the overall severity of ASD symptoms, is associated with activity in the right fusiform face area in ASD.

Several studies have implicated abnormal face processing in ASD with social communication deficits, which is a core symptom of ASD [Schultz, 2005; Schultz et al., 2003; Webb, Neuhaus, & Faja, 2017]. The present study demonstrated that activity in the fusiform face area was increased as a function of the tendency to avoid sensory stimulation in ASD. This indicates that ASD individuals with high Sensation Avoiding trait display more "TD-like" brain activity during face processing, especially when instructed to look at other's faces carefully. It may be useful to explore treatment approaches focused on the Sensation Avoiding trait for social communication deficits, such as atypical eye contact.

Limitations

This study had several limitations. First, sensory processing patterns were evaluated based solely on a single subjective self-reported questionnaire in the present study. However, since the AASP is standardized and its reliability and validity have been confirmed [Crane et al., 2009; Hirashima et al., 2014], biases in the measurements were unlikely.

Second, the ASD group included four individuals with IQ scores in the 60s. Full-scale IQ could influence task performance in general, but the task accuracy of these four participants ranged between 85% and 90%, suggesting that they adequately understood the task requirements. Moreover, the correlation between right fusiform activity and Sensation Avoiding scores remained significant, even after adjusting for full-scale IQ.

Third, participants were recruited without considering sensory processing patterns. Previous research has identified significant differences between individuals with ASD and TD individuals regarding all quadrants in the AASP, but we only identified score differences for the Low Registration trait. For this reason, there were variations in the sensory processing patterns of participants, which may have made it difficult to observe a link between ASD and a specific brain function. Future research should refine recruitment by increasing the number of participants to reduce bias.

Finally, since our sample size was small, further studies with larger samples are needed. Despite these limitations, the present study contributes to our understanding of the neurobiological basis of ASD, as we provide the first evidence of an association between atypical sensory processing patterns and atypical fusiform activity during face processing, which may partly underlie abnormal face processing in ASD.

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Conflict of Interest

The authors declare no conflict of interest.

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