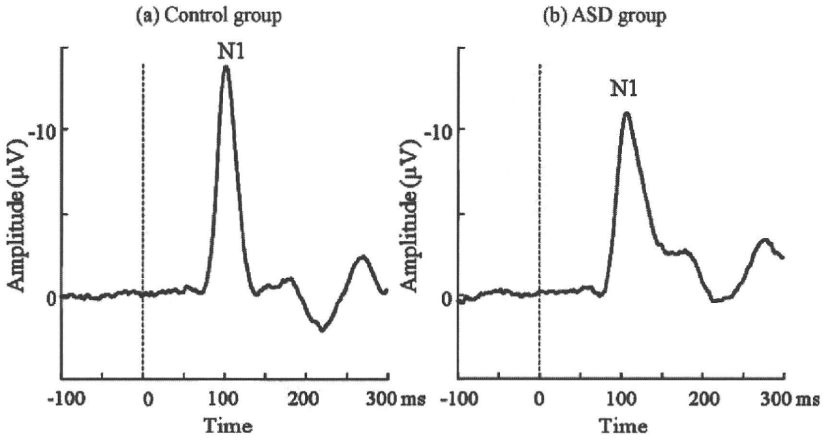

Fig. 2. Grand averaged waveforms of VEPs in response to chromatic stimuli at the Oz electrode in control (a) and ASD (b) groups. In both groups, a negative component around 100 ms (N1) was elicited, which is regarded as a major component.

3.2. Parvocellular function

In the trials designed to elicit P pathway activation, all participants correctly named the cartoon characters following VEP recording. This confirms that participants were attentive during the experiment. The numbers of trials rejected for α-activity were below five in both groups. There was no significant difference in the mean number of viable trials between groups (control group, 104.5 ± 10.3; ASD group, 100.7 ± 13.1, $p = 0.43$). These results suggest that differences in arousal and attention levels between groups did not affect VEP responses.

Grand-average VEP waveforms elicited by chromatic stimuli at Oz are shown in Fig. 2. In both groups, the negative component at approximately 100 ms (N1) was elicited as a major component. In terms of scalp topography, N1 was located at the occipital area (maximum at Oz), and there was no obvious difference in N1 distribution between the two groups (Fig. 3). The mean N1 latency in the ASD group (108.6 ± 7.7 ms) was significantly longer than in the control group (102.8 ± 5.3 ms) ($p = 0.04$). In contrast, there was no significant difference in mean N1 amplitude between control (15.5 ± 7.2 μV) and ASD groups (13.0 ± 6.3 μV) ($p = 0.47$).

Six ASD participants (50%) exhibited an N1 latency within the normal range (102.8 ± 5.3 ms). Thus, additional analyses (unpaired *t*-test) were performed to examine the characterization/phenotypic difference between the subgroups within or outside of the normal range. However, there was no significant difference between the two subgroups.

3.3. Magnocellular function

In the trials designed to elicit M pathway activation, all participants correctly named the cartoon characters following VEP recording. This confirms that participants were attentive during the experiment. The number of trials rejected for α-activity

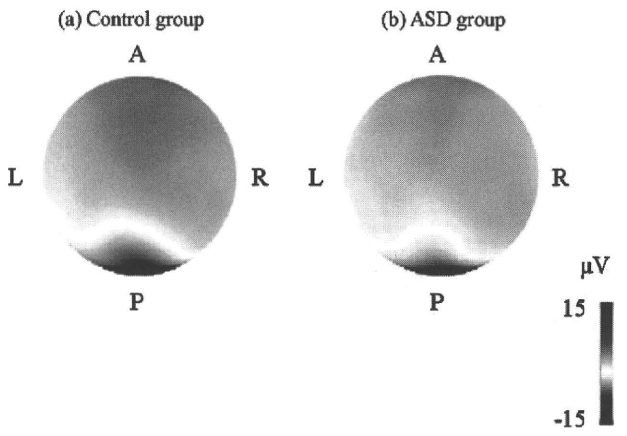

Fig. 3. Grand-averaged scalp topography of the N1 component in control (at 102 ms) (a) and ASD groups (at 108 ms) (b). In both groups, the N1 component is predominantly distributed at occipital areas (maximum at Oz). There was no obvious difference in N1 distribution between the two groups. L: left, R: right, A: anterior, P: posterior in this and Fig. 5.

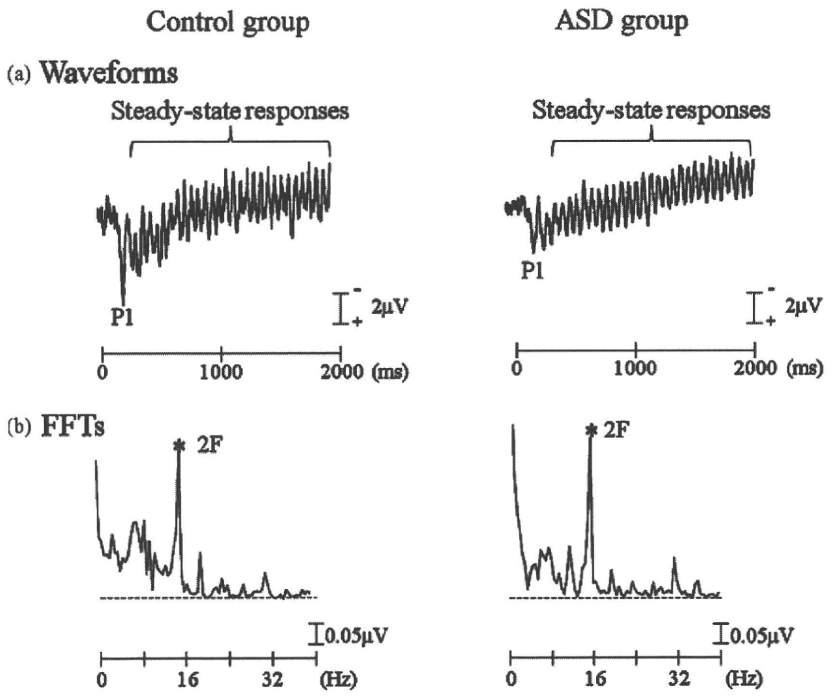

Fig. 4. Representative waveforms of VEPs (a) and fast Fourier transforms spectra (FFTs, b) in response to achromatic stimuli at the Oz electrode in control (left) and ASD (right) subjects. In both subjects, a positive component around 120 ms (P1) and quasi-sinusoidal waveforms correspond to the reversal frequency (16 Hz) (a). FFTs show that the second harmonic (2F) component is a major component in both groups (b).

in the trials designed to activate the M pathway was less than 15 in both groups. The mean number of viable trials in the ASD group was no different from the controls (control group, 105.3 ± 14.9; ASD group, 101.8 ± 11.8, $p = 0.53$). These results suggest that differences between arousal and attention levels did not affect the VEP responses.

In both groups, VEPs, in response to achromatic stimuli at Oz, exhibited a positive component (P1) at around 120 ms, as well as quasi-sinusoidal waveforms that corresponded to the reversal frequency (16 Hz; Fig. 4a). Scalp topography revealed that P1 and steady-state responses in the positive and negative phases were predominantly distributed over occipital areas (maximal at Oz). There was no obvious difference in the distribution of P1 and steady-state responses between the two groups (Fig. 5).

There was no significant difference in mean P1 latency between the control group (129.5 ± 5.3 ms) and the ASD group (132.0 ± 7.2 ms) ($p = 0.38$). In addition, no significant difference was detected in mean P1 amplitude between the control

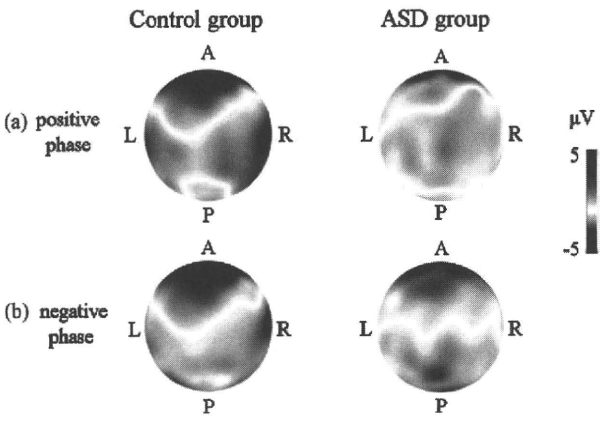

Fig. 5. Grand-averaged scalp topography of steady-state responses (positive (a) and negative (b) phases) in control (left) and ASD (right) groups. In the control group, scalp topography of positive phase at 787 ms (left, a) and negative phase at 755 ms (left, b) are mapped, while that of positive phase at 634 ms (right, a) and negative phase at 660 ms (right, b) are depicted in the ASD group. In both groups, steady-state responses are predominantly distributed at occipital areas (maximum at Oz). There is no obvious difference in the distribution of steady-state responses between the two groups.

(9.01 ± 3.34 μV) and ASD groups (7.73 ± 2.47 μV; $p = 0.43$). For the steady-state responses with FFTs, the second harmonic (2F) component was evident as a major component in both groups (Fig. 4b). As such, we analyzed the phase and amplitude of this component. In the control group, mean 2F amplitudes and phases were 0.57 ± 0.33 μV and 142.3 ± 62.9 (CSD) degrees, respectively. The *r*-value was 0.548 ($p < 0.05$). In the ASD groups, mean 2F amplitudes and phases were 0.51 ± 0.22 μV and 128.2 ± 53.6 (CSD) degrees, respectively. The measure of *r* was 0.646 ($p < 0.05$), suggesting narrow angle dispersion. There was no significant difference in mean 2F amplitudes and phases between the groups (amplitude, $p = 0.55$; phase, $p = 0.63$).

4. Discussion

4.1. Dysfunction of the parvocellular-color pathway in ASD

Chromatic stimuli with equal luminance do not stimulate M neurons. The mean N1 latency in response to chromatic stimuli in high-functioning adults with ASD was significantly longer than in the control group. The chromatic stimuli used in this study would be expected to preferentially activate the color pathway, but not the form pathway, since the form pathway preferentially responds to gratings with high spatial frequency and high contrast (Tobimatsu & Celesia, 2006). In accord with these previous findings, the present results indicate that dysfunctional activity in the P-color pathway at a relatively low level may be involved in ASD.

Although anecdotal evidence suggests that differences in color perception exist in children with autism and non-autistic children, few studies have directly examined this possibility. To the best of our knowledge, only one previous psychophysical study has investigated color perception in ASD, revealing color perception abnormalities (color memory, color search, and chromatic discrimination) in children with ASD, without color deficits in perceiving Ishihara color plates (Franklin, Sowden, Burley, Notman, & Alder, 2008). The authors concluded that abnormal color perception in ASD was due to differences in the anatomical and functional organization of the brain. In particular, disruption to one or more of the visual pathways was proposed to play a role in this color perception abnormality. Our present neurophysiological results are thus consistent with these previously described psychological findings in demonstrating that ASD is associated with dysfunctional activity in the visual pathway responsible for analyzing color information. The present study is the first to elucidate abnormal function within the P-color pathway in ASD.

The P-color pathway anatomically interacts with the P-form pathway (Yabuta & Callaway, 1998). Although the functioning of the P-form pathway itself was not assessed in the present study, the possibility of P-color dysfunction (color perception) and P-form biased function (detailed form perception) can be predicted based on the abundant evidence of superior fine form perception in ASD (Dakin & Frith, 2005). To test this hypothesis, further VEP studies are required to evaluate P-form pathway functioning using appropriate visual stimuli, such as high-contrast achromatic gratings with high spatial frequencies in children, as well as adults with ASD.

4.2. Normal function of the magnocellular pathway within V1 in individuals with ASD

P neurons respond poorly to achromatic low-contrast patterns with high temporal frequencies (Tobimatsu & Celesia, 2006). In the present study, there was no significant difference in VEP responses to achromatic stimuli between the groups. This indicates that lower-level M pathway functions are preserved in ASD adults.

Previous studies have demonstrated an elevated motion coherence threshold in ASD (Milne et al., 2002; Spencer et al., 2000). An additional psychophysical study (Bertone et al., 2003) revealed that motion sensitivity in ASD was similar to control groups for first-order (luminance-defined) motion stimuli related to V1 functioning. However, second-order (texture-defined) motion stimuli related to V2/3 activity elicited significantly decreased motion sensitivity in ASD patients compared to control groups. Moreover, relative to typical developing children (Pellicano, Maybery, & Durkin, 2005), children with ASD displayed an elevated global motion threshold, but equivalent flicker contrast sensitivity. These findings suggest abnormal functioning in the higher levels of the M pathway in ASD patients, but intact lower-level functioning, which further supports the present electrophysiological results showing normal lower-level M pathway activity.

The human visual system can detect a small percentage of coherently moving dots against a background of incoherently moving dots (Baker, Hess, & Zihl, 1991). This ability depends on V5/MT integration of local motion signals from V1 into global motion (Snowden, Treue, Erickson, & Andersen, 1991). Therefore, coherent motion stimuli are considered to be more useful than second-order motion for investigating higher-level functioning in the M pathway. Accordingly, replication of these studies is necessary for children with ASD, and further VEP studies using coherent motion stimuli are needed to confirm whether the higher-level activity in the M pathway is functionally impaired in children, as well as adults, with ASD.

4.3. Methodological limitations

Although special care was taken when creating the appropriate visual stimuli for P- and M pathways, our sample size was relatively small. Clinical diagnoses were performed based on extensive clinical interviews, and standard interview tools such as the ADI-R or ADOS-G were not used. Instead, we used a widely used scale (PARS) with high sensitivity and high specificity

in Japanese populations to distinguish individuals with PDD of all ages (Kamio et al., 2006). Intellectual function was not assessed in control participants, but since they were recruited from college students and faculties and reported no developmental problems, their intellectual functioning was very likely to be within the normal range.

5. Conclusion

The current study revealed that high-functioning adolescents and adults with ASD displayed a dysfunctional P pathway and a preserved M pathway at lower levels of visual processing within V1. These neurophysiological findings offer partial support to the 'complexity-specific' hypothesis, but not for the 'pathway-specific' hypothesis. Furthermore, our results indicated that color-processing abnormalities are also involved in high-functioning ASD. The P-form pathway within V1 as well as higher-level functioning in the P and M pathways, however, should be fully investigated to determine the various visual pathway functions in ASD from a developmental perspective.

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References

American Psychiatric Association. (1994). *DSM-IV: Diagnostic and statistic manual of mental disorders*(4th ed.). Washington, DC.
Baker, C. L., Jr., Hess, R. F., & Zihl, J. (1991). Residual motion perception in a "motion-blind" patient, assessed with limited-lifetime random dot stimuli. *Journal of Neuroscience, 11*, 454–461.
Batschelet, E. (1981). *Circular statistics in biology*. London: Academic Press.
Bertone, A., & Faubert, J. (2006). Demonstrations of decreased sensitivity to complex motion information not enough to propose an autism specific neural etiology. *Journal of Autism and Developmental Disorders, 36*, 55–64.
Bertone, A., Mottron, L., Jelenic, P., & Faubert, J. (2003). Motion perception in autism: A "complex" issue. *Journal of Cognitive Neuroscience, 15*, 218–225.
Bertone, A., Mottron, L., Jelenic, P., & Faubert, J. (2005). Enhanced and diminished visuo-spatial information processing in autism depends on stimulus complexity. *Brain, 128*, 2430–2441.
Dakin, S., & Frith, U. (2005). Vagaries of visual perception in autism. *Neuron, 48*, 497–507.
Ferree, T. C., Luu, P., Russell, G. S., & Tucker, D. M. (2001). Scalp electrode impedance, infection risk, and EEG data quality. *Clinical Neurophysiology, 112*, 536–544.
Franklin, A., Sowden, P., Burley, R., Notman, L., & Alder, E. (2008). Color perception in children with autism. *Journal of Autism and Developmental Disorders, 38*, 1837–1847.
Frith, U., & Happé, F. (2005). Autism spectrum disorder. *Current Biology, 15*, 786–790.
Gutschalk, A., Patterson, R. D., Rupp, A., Uppenkamp, S., & Scherg, M. (2002). Sustained magnetic fields reveal separate sites for sound level and temporal regularity in human auditory cortex. *Neuroimage, 15*, 207–216.
Happé, F. (1996). Studying weak central coherence at low levels: Children with autism do not succumb to visual illusions. A research note. *Journal of Child Psychology and Psychiatry, 37*, 873–877.
Happé, F., & Frith, U. (2006). The weak coherence account: Detailed-focused cognitive style in autism spectrum disorders. *Journal of Autism and Developmental Disorders, 36*, 5–25.
Ishida, R., Kamio, Y., & Nakamizo, S. (in press). Perceptual distortions in visual illusions in children with high-functioning autism spectrum disorder. *Psychologia*.
Ishihara, S. (1997). *Tests for colour-deficiency*. Tokyo: Kanehara.
Jolliffe, T., & Baron-Cohen, S. (1997). Are people with autism and Asperger syndrome faster than normal on the Embedded Figures Test? *Journal of Child Psychology and Psychiatry, 38*, 527–534.
Kamio, Y., Yukihiro, R., Adachi, J., Ichikawa, H., Inoue, M., Uchiyama, T., et al. (2006). Reliability and Validity of the Pervasive Developmental Disorder (PDD)—Autism Society Japan Rating Scale (PARS): A behavior checklist for adolescents and adults with PDDs. *Seishin Igaku, 48*, 495–508.
Landolt, E. (1905). Die Vereinheitlichung der Bestimmung der Sehschärfe. *Augenheilkunde, 13*, 519–541.
Livingstone, M., & Hubel, D. (1988). Segregation of form, color, movement, and depth: Anatomy, physiology, and perception. *Science, 240*, 740–749.
Mardia, K. V. (1972). *Statistics of directional data*. London, New York: Academic Press.
Milne, E., Swettenham, J., Hansen, P., Campbell, R., Jeffries, H., & Plaisted, K. (2002). High motion coherence thresholds in children with autism. *Journal of Child Psychology and Psychiatry, 43*, 255–263.
Nakashima, T., Goto, Y., Abe, T., Kaneko, K., Saito, T., Makinouchi, A., et al. (2008). Electrophysiological evidence for sequential discrimination of positive and negative facial expressions. *Clinical Neurophysiology, 119*, 1803–1811.
Pellicano, E., Maybery, M., & Durkin, K. (2005). Central coherence in typically developing preschoolers: Does it cohere and does it relate to mindreading and executive control? *Journal of Child Psychology and Psychiatry, 46*, 533–547.
Regan, D. (1989). *Human brain electrophysiology: Evoked potentials and evoked magnetic fields in science and medicine*. New York: Elsevier Science Publ Co.
Snowden, R. J., Treue, S., Erickson, R. G., & Andersen, R. A. (1991). The response of area MT and V1 neurons to transparent motion. *Journal of Neuroscience, 11*, 2768–2785.
Spencer, J., O'Brien, J., Riggs, K., Braddick, O., Atkinson, J., & Wattam-Bell, J. (2000). Motion processing in autism: Evidence for a dorsal stream deficiency. *Neuroreport, 11*, 2765–2767.
Tobimatsu, S., & Celesia, G. G. (2006). Studies of human visual pathophysiology with visual evoked potentials. *Clinical Neurophysiology, 117*, 1414–1433.
Tobimatsu, S., Goto, Y., Yamasaki, T., Tsurusawa, R., & Taniwaki, T. (2004). Non-invasive evaluation of face and motion perception in humans. *Journal of Physiological Anthropology and Applied Human Science, 23*, 273–276.
Tobimatsu, S., Goto, Y., Yamasaki, T., Tsurusawa, R., & Taniwaki, T. (2006). An integrated approach to face and motion perception in humans. *Clinical Neurophysiology, S59*, 43–48.
Tobimatsu, S., & Kato, M. (1998). Multimodality evoked potentials in evaluating visual dysfunction in optic neuritis. *Neurology, 50*, 715–718.
Tobimatsu, S., Shigeto, H., Arakawa, K., & Kato, M. (1999). Electrophysiological studies of parallel visual processing in humans. *Electroencephalography and Clinical Neurophysiology, S49*, 103–107.
Tobimatsu, S., Tomoda, H., & Kato, M. (1995). Parvocellular and magnocellular contributions to visual evoked potentials in humans: Stimulation with chromatic and achromatic gratings and apparent motion. *Journal of Neurological Sciences, 134*, 73–82.

Yabuta, N. H., & Callaway, E. M. (1998). Functional streams and local connections of layer 4C neurons in primary visual cortex of the macaque monkey. *The Journal of Neuroscience, 18*, 9489–9499.
Yamasaki, T., Goto, Y., Kinukawa, N., & Tobimatsu, S. (2008). Neural basis of photo/chromatic sensitivity in adolescence. *Epilepsia, 49*, 1611–1618.
Yamasaki, T., Taniwaki, T., Tobimatsu, S., Arakawa, K., Kuba, H., Maeda, Y., et al. (2004). Electrophysiological correlates of associative visual agnosia lesioned in the ventral pathway. *Journal of Neurological Sciences, 221*, 53–60.
Zar, J. H. (1999). *Biostatistical analysis* (4th ed.). Upper Saddle River, NJ: Prentice Hall.

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Top-down and bottom-up visual information processing of non-social stimuli in high-functioning autism spectrum disorder

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ABSTRACT

Individuals with high-functioning autism spectrum disorder (HF-ASD) often show superior performance in simple visual tasks, despite difficulties in the perception of socially important information such as facial expression. The neural basis of visual perception abnormalities associated with HF-ASD is currently unclear. We sought to elucidate the functioning of bottom-up and top-down visual information processing in HF-ASD using event-related potentials (ERPs). Eleven adults with HF-ASD and 11 age-matched normal controls (NC) participated in this study. Visual ERPs were recorded using 128-channel EEG. The P1 and P300 were recorded in response to target stimuli. Visual mismatch negativity (vMMN) potentials were obtained by subtracting responses to standard from those to deviant stimuli. Behaviorally, individuals with HF-ASD showed faster target detection than NCs. However, vMMN amplitude and latency were the same between the two groups. In contrast, P1 and P300 amplitudes were significantly decreased in HF-ASD compared with NCs. In addition, P300 latency was significantly delayed in HF-ASD. Individuals with HF-ASD exhibit altered visual information processing. Intact bottom-up attention (vMMN) may contribute to their superior simple visual task performance in spite of abnormal low-level (P1) and top-down (P300) visual information processing.

1. Introduction

Autism spectrum disorder (ASD) is a developmental neuropsychiatric disorder characterized by deficits in socialization, communication, and repetitive/stereotyped behaviors. Over the past several decades, extensive studies using various genetic, neurobiological, cognitive and behavioral approaches have sought a single explanation for the heterogeneous manifestations of ASD, but no consensus on the etiology of ASD has emerged (Happé & Frith, 2006). Although there are prominent symptoms of ASD within the social domain, several researchers have proposed that abnormalities also exist in basic (lower level) sensory processing as well as attention and cortical (higher level) processing (Dakin & Frith, 2005; Mottron & Burack, 2001; Tuchman & Rapin, 2006). Indeed, a number of studies have shown atypical performance of

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individuals with ASD in a wide range of perceptual tasks (e.g. for a review, Mottron, Dawson, & Soulières, 2009). In terms of research findings in the visual modality, evidence emerging over the past few decades has indicated that ASD is associated with both unique abilities and unique deficits in higher level visual processing (Dakin & Frith, 2005). For instance, individuals with ASD generally perform well on the Wechsler Intelligence Scale for Children (WISC) Block Design test (Shah & Frith, 1983; Shah & Frith, 1993), the embedded figures test (Jolliffe & Baron-Cohen, 1997), visual search (Plaisted, O'Riordan, & Baron-Cohen, 1998), and copying impossible figures (Mottron, Burack, Stauder, & Robaey, 1999). In contrast, their performance tends to be poor for detecting biological motion (Blake, Turner, Smoski, Pozdol, & Stone, 2003), integrating rapid visual motion (Gepner & Mastre, 2002), and perceiving coherent motion (Spencer, O'Brien, Riggs, Baraddick, Atkinson, & Wattam-Bell, 2002). These findings have often been interpreted from the viewpoint of local vs. global processing (Frith, 1989; Happé, 1999; Mottron & Burack, 2001; Plaisted, 2001). One persuasive theoretical account to explain the range of abilities and deficits characterizing ASD is "weak central coherence" (WCC). This theory proposes that the bias toward detail-focused, local processing over global processing results in a failure to extract global form/meaning (Happé & Frith, 2006). Alternatively, the concept of top-down and bottom-up attention may be related to the peculiar visual task performance of individuals with ASD. At present a conclusive explanation remains unclear due to the limited time resolution of the psychobehavioral techniques used so far.

Visual sensory information is first processed at a low level, with information flowing from the retina to the primary visual cortex (V1). The information then passes into a higher level of neural processing. It is well known that the P1 (i.e. the first positive peak from the stimulus onset) reflects the lower level visual information processing stage (i.e. V1 or earlier; for a review, Tobimatsu & Celesia, 2006). Previous studies have suggested that lower level visual information processing may be affected in ASD, because affected individuals exhibit a decreased and delayed P1 (Boeschoten, Kenemans, Engeland, & Kemner, 2007; Hoeksma, Kemner, Verbaten, & van Engeland, 2004; Hoeksma, Kemner, Kenemans, & van Engeland, 2006; Itier and Taylor, 2002, 2004; O'Conner, Hamm, & Krik, 2005; Taylor, Edmonds, McCarthy, & Allison, 2001; Webb et al., in press). Alternatively, selective attention may be involved. Selective attention is the process whereby a subset of the input is selected preferentially for further processing and has two major aspects: bottom-up attention and top-down attention. Bottom-up attention is elicited or driven by the properties of stimuli automatically whereas top-down attention refers to a volitional focusing of attention on a location and/or an object based on current behavioral goals (Ciaramelli, Grady, & Moscovitch, 2008). These streams can operate in parallel but bottom-up attention occurs more quickly than top-down attention (e.g. Treisman, Vieira, & Hayes, 1992). Event-related potentials (ERPs), which have the benefit of a very high-temporal resolution (in the order of milliseconds), are an appropriate technique for recording electrophysiological signals from the scalp. ERPs allow us to temporally characterize human sensory information processing. Two specific components of the ERP, the visual mismatch negativity (vMMN) and the visual P300, are candidates for biomarkers of bottom-up and top-down attention, respectively (Maekawa, Goto, Kinukawa, Taniwaki, Kanba, & Tobimatsu, 2005; Maekawa, Tobimatsu, Ogata, Onitsuka, & Kanba, 2009). To the best of our knowledge, there have been no ERP studies focusing on the bottom-up and top-down attention in ASD. Therefore, the aim of this study was to characterize visual information processing in high-functioning ASD (HF-ASD) individuals and to determine whether or not bottom-up and/or top-down attention is affected by the disorder. To this end, we measured early visual ERP components including the P1 and P300, as well as the vMMN.

2. Methods

2.1. Participants

Eleven individuals with HF-ASD (eight males and three females, aged 18–40 years, mean age 28.0), and 11 healthy controls (HCs) matched for chronological age (CA) and sex (four males and seven females, aged 20–38 years, mean age 28.9) participated in the study. The HF-ASD group included six individuals with Asperger's disorder, three individuals with autistic disorder, and three individuals with a pervasive developmental disorder not otherwise specified (PDD-NOS). The HF-ASD participants were diagnosed by a research team including a general psychiatrist experienced in the field (T.M.), an experienced child psychiatrist (Y.K.), and a licensed clinical psychologist (N.I.) according to the DSM-IV-TR criteria (APA, 2000) based on clinical interviews with participants and/or parents using semi-structured interviews validated for Japanese PDD populations (Kamio et al., 2006; Tani, Yukihiro, & Tsujii, 2009). Diagnostic agreement among the team was obtained for all participants. The NC participants (NC group) were recruited from the general public, and their NC status was confirmed by interviews. The intellectual function of HF-ASD participants was evaluated using the Japanese versions of the Wechsler Adult Intelligence Scale (WAIS-R or WAIS-III).

Informed consent was obtained from all participants. The experimental procedures were approved by the ethics committee of the Graduate School of Medical Sciences, Kyushu University.

2.2. Visual stimuli and procedures

Visual stimuli, apparatus, procedures, and EEG recordings except for the EEG machine were the same as in our earlier studies of healthy adults (Maekawa et al., 2005, 2009).

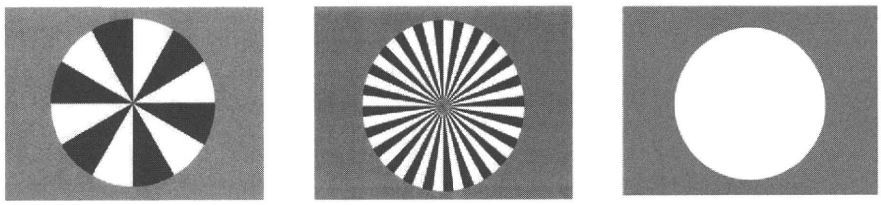

Fig. 1. Three stimulus types used in the present study; six-vane circular black–white windmill pattern stimulus (A), 24-vane stimulus (B), and unpatterned white circle stimulus (C). The two windmill pattern stimuli were adopted as standard or deviant stimuli (their probabilities were changed between sessions each other) and the white circle was always used as the target stimulus. Probabilities of standard, deviant, and target stimuli were 8:1:1, respectively.

Circular black–white windmill patterns with 90% contrast were presented on a 20-inch CRT monitor and controlled using a ViSaGe graphics board (Cambridge Research Systems, UK). The visual stimulus subtended 5.8° of visual angle in diameter at a viewing distance of 114 cm. Participants were seated comfortably in a semi-dark room. The participants were instructed to focus on a story delivered binaurally through earphones while looking at the center of the monitor and to press a button with their right thumb as soon as they recognized a target stimulus on the monitor. Between the stimulus runs, they were asked to fill out a questionnaire about the context of the story that they had heard.

Standard, deviant, and target stimuli were presented in a random order for 200 ms on the computer monitor (Fig. 1). The inter-stimulus interval (ISI) was 800 ms. Stimulus probabilities were 80% (standard), 10% (deviant), and 10% (target).

ERP recordings were composed of two sessions. One session had a windmill pattern with six vanes as the standard, 24 vanes as the deviant, and a non-patterned white circle as the target stimulus. In the other session, a six-vane windmill pattern was adopted as the deviant and a 24-vane pattern as the standard stimulus. The target stimulus was the same in both sessions.

2.3. ERP recordings

ERPs were recorded from 128 scalp sites referenced to Cz, using a high-density electroencephalography (EEG) system. EEG data were analyzed using a dense array EEG workstation (Net Station, Electrical Geodesics, Inc., USA). All 128 electrodes were attached with a sensor net (Net Station, Electrical Geodesics, Inc., USA). The impedances of all electrodes were maintained below 50 kΩ. EEG was continuously digitized at 500 Hz per channel and stored on a computer hard disk using a 0.05–200 Hz on-line filter. EEG data were filtered off-line with a bandpass of 0.5–30 Hz. Digital codes synchronized to the stimulus onset were also stored. At the end of the experiments, EEG epochs of 600-ms duration (100 ms pre-stimulus, 500 ms post-stimulus) associated with each stimulus type were extracted from the continuous record. Epochs contaminated by electro-oculograms, blinks, or muscle artifacts exceeding an artifact rejection threshold of ±70 μV were discarded automatically. Artifact-free epochs were then segregated by stimulus codes and averaged for each subject. The amplitudes of the ERPs were measured relative to a 100-ms pre-stimulus baseline. The grand average across all subjects in each stimulus condition was also computed. To compare our findings with those of previous studies (Maekawa et al., 2005, 2009), a re-reference was applied using the average of the two electrodes beside the nose (electrodes 126 and 127). Eye movements and blinks were measured from bipolar electrodes placed above and below the eyes (right, electrodes 14 and 126; left, electrodes 21 and 127).

2.4. Data analysis

2.4.1. Behavioral performance

To characterize degree of attention, the accuracy of participants' answers to questions about the story was evaluated. Questionnaires consisted of 40 questions, for example "What was the name of the hero?" or "How many persons participated in the operation?" In addition, reaction time (RT) and accuracy for the target stimuli were also measured as indices of participants' task performance.

2.4.2. ERP data

Difference waveforms were constructed by subtracting the waveforms in response to the standard stimuli from that to the deviants. Topographic distributions were inspected to verify that the vMMN was at its maximum at the Oz electrode, where the vMMN is typically largest. vMMN amplitude was calculated for each participant 150–350 ms from the stimulus onset. Lower level information processing was assessed using the P1, N1, P2, and N2 components at Oz. Top-down attention was evaluated by the P300 for the target stimulus at Pz. The amplitudes of major components for each stimulus were measured relative to baseline. Peak latencies and amplitudes were then compared between HF-ASD and NC groups using Student's *t*-tests.

3. Results

Although the behavioral performance of all participants was successfully measured, EEG data from two participants in each group were excluded from the ERP analyses because of excessive artifacts in their ERP recordings. Following these exclusions, there were nine participants in each group. Although the gender ratio appeared to be quite different between the two groups (i.e. female to male ratio in HF-ASD was 7:2 and that in NC was 4:5), there were no significant between-group differences in sex ratio (Fisher's exact test, $P = 0.33$), or CA (unpaired t-test, $P = 0.29$).

The HF-ASD participants exhibited IQ within the normal range (mean verbal IQ, 102.8 ± 14.3, range 90–125; mean performance IQ, 108.9 ± 13.9, range 91–136; mean full scale IQ, 107.0 ± 14.5, range 91–134). The information subscale of the WAIS-R or WAIS-III was adopted to estimate intellectual functioning. No significant difference was found between the two groups on this subscale (12 ± 3.7 vs. 13.6 ± 1.9, respectively).

3.1. Performance data

There was no significant difference in mean accuracy rate for questions related to the story context between the HF-ASD and NC groups (97.0% vs. 96.9%, respectively), confirming that both groups cooperated successfully and paid a high level of attention to the story. There was no significant difference in target stimulus detection accuracy between the two groups (92.5% ± 6.3% vs. 92.1% ± 4.7%, respectively). However, the HF-ASD group showed significantly shorter RTs than the NC group (374.2 ± 36.6 vs. 410.4 ± 40.6 ms, respectively. $P < 0.05$).

3.2. ERPs

Grand averaged waveforms of ERPs in response to each stimulus are shown in Fig. 2. A positive (P1)–negative (N1)–positive (P2) deflection was elicited equally by each stimulus type and was maximal at Oz (see Fig. 2A). Peak amplitudes and latencies of the P1, N1, P2, N2, and P300 in response to each stimulus type are summarized in Table 1. P1 amplitude in response to standard and deviant stimuli in the HF-ASD group was significantly smaller than in NCs (for standard, $t(16) = -2.47$, $P < 0.05$; for deviant stimuli, $t(16) = -2.79$, $P = 0.013$). However, there was no significant difference in P1

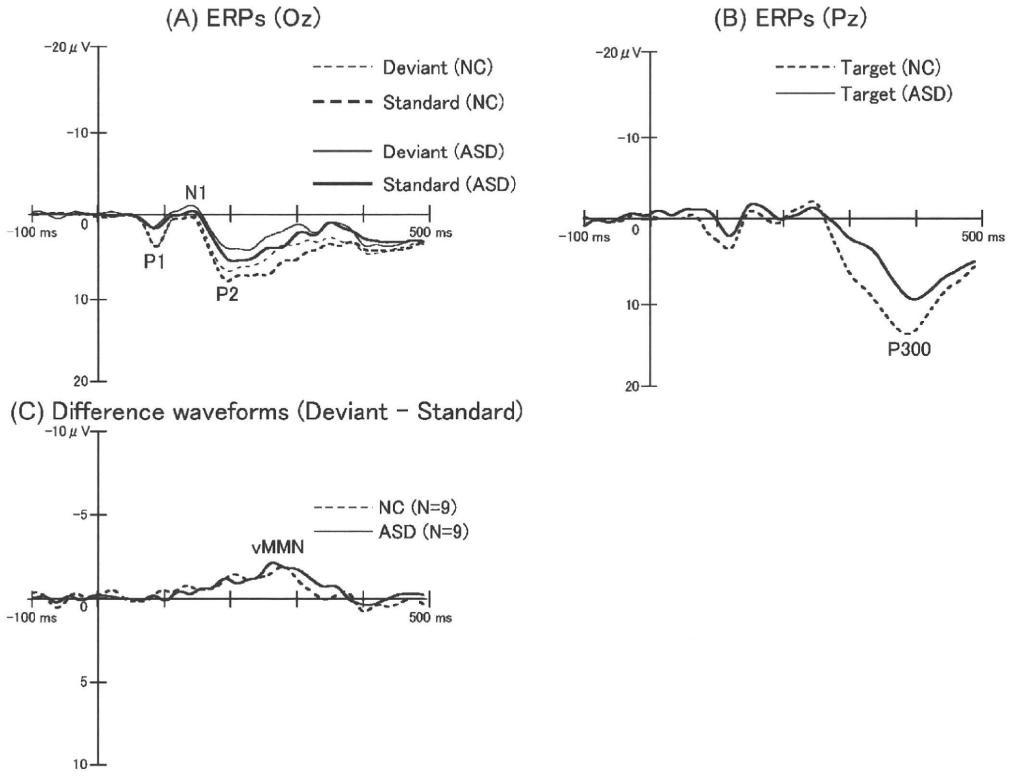

Fig. 2. Grand averaged waveforms of ERPs in each group. (A) Waveforms for standard stimuli (NC, thick dotted line; ASD, thick solid line) and for deviant stimuli (NC, thin dot line; ASD, thin solid line) at Oz. (B) Waveforms for target stimuli at Pz (NC, dotted line; ASD, solid line). While P300 latencies did not show any significant differences between the two groups, P300 amplitudes in ASD were significantly smaller than those of the NC group ($P < 0.05$). (C) Difference waveforms from responses to standard stimuli relative to responses to deviant stimuli at Oz (NC, dotted line; ASD, solid line). There were no statistically significant differences in the mean peak latency and amplitude of vMMN between the two groups.

Table 1
Mean latencies (ms) and amplitudes (μV) of the P1, N1, P2, N2, and P300 in NC and HF-ASD groups.

Stimuli	ERP peaks	Latency (SD)		Amplitude (SD)	
		NC	ASD	NC	ASD
Standard	P1	96.0 (11.9)	94.4 (12.8)	5.7 (2.8)	2.9 (1.8)*
	N1	140.2 (15.2)	137.6 (22.1)	−1.6 (3.7)	−2.6 (5.0)
	P2	224.9 (18.3)	218.4 (29.0)	8.5 (4.0)	7.5 (4.1)
Deviant	P1	97.1 (12.5)	95.1 (16.8)	6.1 (2.7)	3.0 (1.9)*
	N1	141.3 (16.9)	135.3 (26.0)	−2.2 (2.8)	−2.5 (4.9)
	P2	224.7 (16.2)	205.3 (21.9)	7.7 (3.9)	7.3 (5.2)
	N2	293.1 (18.8)	287.8 (33.7)	1.9 (2.4)	−0.1 (4.2)
Target	P1	118.4 (5.6)	121.8 (5.8)	8.5 (4.4)	6.3 (3.4)
	N1	162.5 (10.6)	167.3 (13.1)	−1.0 (2.4)	−3.0 (4.9)
	P2	191.0 (11.5)	200.0 (8.0)	1.6 (1.4)	0.8 (4.7)
	P300	392.0 (11.9)	412.4 (17.4)*	14.3 (1.9)	10.2 (4.1)*
Difference (deviant – standard)	vMMN	274.2 (27.9)	268.7 (28.1)	−2.4 (0.8)	−2.2 (1.4)

* $P < 0.05$.

amplitude for target stimulus between the two groups. There was also no statistical difference in P1 latency for each stimulus type between the two groups (see Table 1, Fig. 2A). There were no significant differences between the groups in the latencies and amplitudes of the N1 and P2. The mean peak amplitude of the P300 in the HF-ASD group was significantly smaller than that of NC group ($t(16) = -2.73$, $P = 0.015$). In addition, the mean peak latency of the P300 in HF-ASD group was significantly prolonged compared with that of the NC group ($t(16) = 2.91$, $P = 0.010$; Fig. 2B).

Although vMMN was clearly exhibited at the occipital and posteriotemporal electrodes in both groups, there was no statistical difference in either the peak latency or mean amplitude between the groups (Table 1, Figs. 2C and 3).

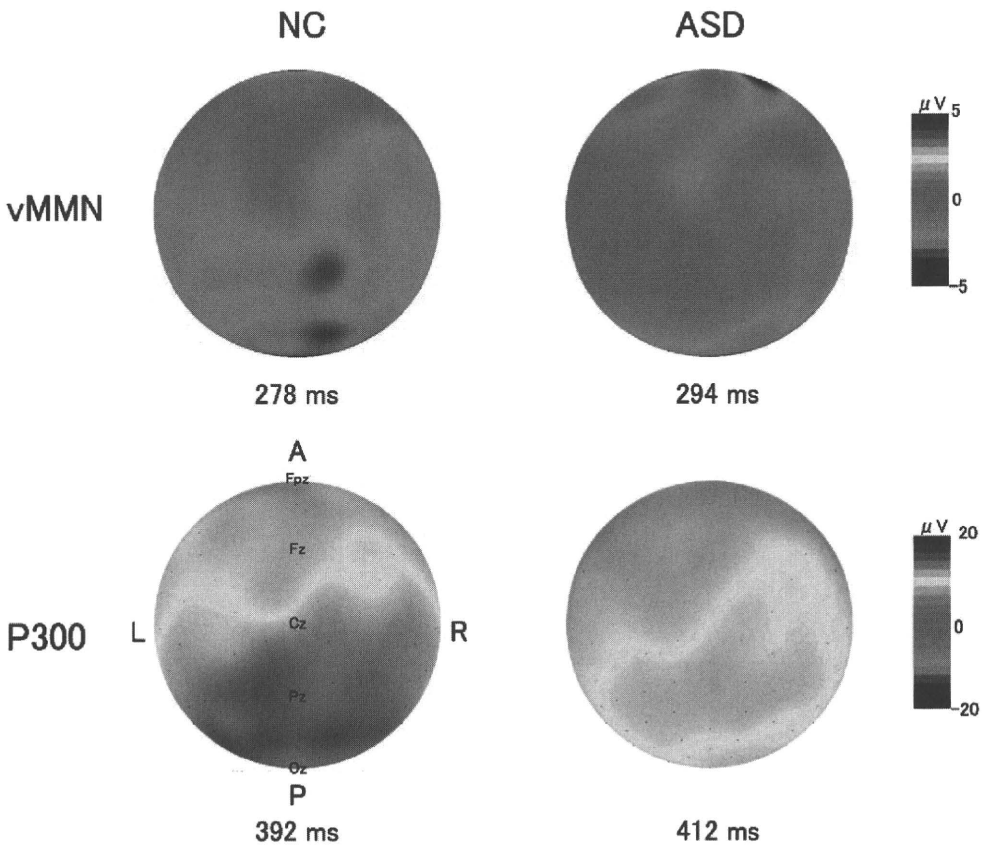

Fig. 3. Topographical maps of the vMMN (Oz) and P300 (Pz) in each group. Upper panel shows the topography of difference activity from standard to deviant stimuli of each group at vMMN peak latency. Although there was no statistically significant difference in the mean amplitude of the vMMN between the two groups, the amplitude gradient of the NC group appears to be steeper than in the ASD group. Lower panel shows the amplitude gradient of topography of response for target stimuli in each group at the P300 peak latency. The amplitude gradient of the NC group is steeper than that in the ASD group, which roughly corresponds to the statistically significant differences (Table 1).

4. Discussion

The major differences we found between the HF-ASD group and the NC group are summarized as follows. In HF-ASD individuals, (1) behavioral target detection was significantly faster, (2) the P1 response (80–120 ms) to standard and deviant stimuli was significantly smaller, (3) the P300 latency (300–500 ms) was significantly prolonged and its amplitude was decreased, and (4) both the mean amplitude and latency of vMMN (150–300 ms) were within the normal range. These findings suggest that individuals with HF-ASD exhibit differences in perceptual integration, with a unique electrophysiological processing pattern. Namely, this group exhibits abnormal lower level (P1) and top-down attentive processing (P300) while bottom-up processing (vMMN) appears to be intact. In the following section, we will discuss the pattern of unusual electrophysiological activity we observed in HF-ASD individuals in terms of bottom-up and top-down attention.

4.1. Abnormal lower visual level processing

The reduced P1 amplitude we observed in the HF-ASD group in our study suggests abnormalities in lower level visual processing, in accord with previous reports (Boeschoten et al., 2007; Hoeksma et al., 2004; Hoeksma et al., 2006; Itier and Taylor, 2002, 2004; O'Conner et al., 2005; Taylor et al., 2001; Webb et al., in press). Boeschoten et al. (2007) focused on the effect of spatial frequency (SF). They examined early visual sensory processing in HF-ASD children using two types of horizontal grating stimuli. They found that P1 responses evoked by both low- (0.75 cycles/deg or 4 bars) and high-SF (6 cycles/deg or 32 bars) gratings were significantly decreased in the HF-ASD group compared with control children. The authors suggested that atypical social perception and recognition (including deficits in face processing) in ASD may be caused by more fundamental lower level visual processes. In accord with this report, we also found that HF-ASD individuals exhibited a significantly smaller P1 in response to windmill patterns of both low (6-vane) and high (24-vane) SF, but not in response to unpatterned stimuli. Therefore, our findings are consistent with the results of Boeschoten et al. (2007), which suggested that abnormal lower level visual information processing was also exhibited by HF-ASD adolescents and adults.

Our interpretation is in accord with previous findings showing that hierarchical face processing is differentially influenced by the removal of high- and low-SF content, (Badcock, Whitworth, Badcock, & Lovegrove, 1990; Boeschoten, Kemner, Kenemans, & van Engeland, 2005; Goffax, Gauthier, & Rossion, 2003; Goffax, Hault, Michel, Vuong, & Rossion, 2005; LaGasse, 1993; Ruitz-Solar and Beltran, 2006). Thus, the local visual processing biases often found in ASD (e.g. Behrmann, Thomas, & Humphreys, 2006; Dakin & Frith, 2005; Happé & Frith, 2006; Mottron, Dawson, Soulières, Hubert, & Burack, 2006) may be related to abnormal early processing of SF. Furthermore, abnormal processing of low-SF stimuli was also found in our study. Namely, we found that HF-ASD individuals exhibited decreased P1 amplitude in response to six-vane windmill patterns. This could be related to the abnormal face and emotion recognition often reported in ASD (Baron-Cohen et al., 1999; Braverman, Fein, Lucci, & Waterhouse, 1989; Critchley et al., 2000; Dawson, Webb, Garver, Panagiotides, & McPartland, 2004; Hobson & Lee, 1989; Wang, Dapretto, Hariri, Sigman, & Bookheimer, 2004), because low-SF information is important for both face recognition and emotion perception (Pourtois, Dan, Grandjean, Sander, & Vuilleumier, 2005; Tanskanen, Näätänen, Montez, Päällysaho, & Hari, 2005; Vuilleumier, Armony, Driver, & Dolan, 2003).

4.2. Distinct electrophysiological features of HF-ASD

To our knowledge, this is the first report of vMMN in an HF-ASD group. However, there have been several previous MMN studies in the auditory modality (Ceponiene, Rinne, & Näätänen, 2002; Ceponiene et al., 2003; Dunn, Gomes, & Gravel, 2008; Kuhl, Coffey-Corina, Padden, & Dawson, 2005; Lepistö et al., 2005, 2006, 2008, 2009). Kuhl et al. (2005) found that the children with ASD showed a normal MMN to changes in non-speech sounds, but showed no MMN in response to changes in speech syllables. In general, the majority of autistic children preferred to listen to non-speech sounds, thus demonstrating an association between cortical processing of language and behavior (Kuhl et al., 2005). In the current study, we found that vMMN in response to a non-social stimulus (a windmill pattern) was preserved. This finding suggests that the pre-attentive visual information processing involved in detecting subtle changes in the visual environment is intact in HF-ASD.

On the other hand, the P300 in individuals with HF-ASD was significantly smaller than that of NCs in the present study. There have been a small number of studies examining the visual P300 in ASD (see for a review, Jeste & Nelson, 2009). In addition, there have been several reports showing a smaller auditory P300 in ASD, despite normal behavioral performance (e.g. Ciesielski, Courchensne, & Elmasian, 1990; Lincoln, Courchesne, Harms, & Allen, 1993). These findings for auditory tasks imply that individuals with ASD have altered cortical processing that may interfere specifically with speech sounds but not pitch sounds. In light of these previous findings, we expected that individuals with HF-ASD would show intact vMMN and smaller a P300 in response to a non-social stimulus such as a visual windmill pattern. Several previous studies demonstrated a smaller visual P300 in children with ASD (Gomarus, Wijers, Minderaa, & Althaus, 2009; Gunji, Inagaki, Inoue, Takeshima, & Kaga, 2009; Hoeksma et al., 2004; Hoeksma et al., 2006; Kemner, van der Gaag, Verbaten, & van Engeland, 1999; Pitchard, Raz, & August, 1987; Verbaten, Roelofs, van Engeland, Kenemans, & Slangen, 1991). However, there the P300 findings in adults with HF-ASD have not been consistent. Couchesne, Couchesne, Hicks, and Lincoln (1985), Courchesne, Lincoln, Kilman, and Galambos (1985), Courchesne, Lincoln, Yeung-Courchesne, Elmasian, and Grillon (1989), and Hoeksma et al. (2004, 2006) reported a normal P300 in HF-ASD adults, while Townsend et al. (2001) found a significantly reduced P300. In

addition, Hoeksma et al. (2006) found smaller P300 s in response to a rectangle discrimination task in children with HF-ASD, but a normal P300 in adults with HF-ASD in the same task. These findings suggest that an abnormal P300 in children with ASD may be accompanied by abnormal selective attention, but that normalization of P300 may occur by adulthood. Thus, Hoeksma et al. (2006) interpreted their results as showing that the P300 may be an index of a compensatory process. In the present study, the P300 was significantly decreased and delayed in an HF-ASD group, in direct contrast to the findings of Hoeksma et al. (2006). It is possible that windmill pattern stimuli are more sensitive in the detection of altered visual functioning than other visual stimuli such as the rectangle used in the earlier study.

4.3. Bottom-up attention may compensate top-down processing

Although a number of neuropsychological studies have investigated the neural mechanisms of both bottom-up and top-down attention, it is currently unclear whether aspects of these mechanisms are affected in HF-ASD. Our vMMN results suggest that bottom-up attention is relatively preserved in this condition, while the abnormal P300 we observed indicates that top-down attentional processing is impaired (Maekawa et al., 2005). Interestingly, individuals with HF-ASD showed faster behavioral target detection than NCs. Taking behavioral and neurophysiological findings into account, we assume that preserved bottom-up attention could cause faster target detection in our participants. There are several lines of evidence for atypical visual information processing in ASD from both neurophysiological and neuroimaging studies (see Jeste & Nelson, 2009 for a review; Müller, 2008). Superior visual performance has been more commonly observed in ASD than in other developmental cognitive disorders (see Mottron et al., 2009 for a review). Although several hypotheses (including WCC theory; Frith, 1989) have been proposed to explain this discrepancy, it remains unclear why autism is associated with superior visual task performance. Our findings may indicate that adolescents and adults with HF-ASD may exhibit involuntary or automatic processing in vMMN tasks. This idea provides a new hypothesis regarding altered visual information processing underlying the visual task performance advantage found in HF-ASD.

4.4. Methodological reservations

Although the difference in the gender ratio between the groups was not statistically significant, a possible effect of the trend towards a difference should still be considered. A number of studies have demonstrated mixed gender effects on visual and auditory oddball ERPs. Lower amplitudes in males and shorter latencies in females of early VEP components including the N50, P100, N100 and N200 have been previously reported (Ehlers, Wall, Garcia-Andrade, & Philips, 2001; Mitchell, Howe, & Spencer, 1987). Hoffman and Polich (1999) found that females exhibited a larger P300 component than males. However, other studies contradicted this finding, showing no significant gender difference in visual P300 (e.g. Steffensen et al., 2008; Rozenkrants & Polich, 2008). Thus, gender was unlikely to have significantly affected the results of the present study.

5. Conclusion

The present study is the first report focusing on bottom-up and top-down attention in HF-ASD using vMMN and the P300. Our results suggested that bottom-up involuntary attention is unaffected in HF-ASD, while lower level and top-down visual information processing are impaired in the condition.

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References

American Psychiatric Association. (2000). *Diagnostic and statistical manual of mental disorders. 4th edition text revised (DSM-IV-TR)*. Washington, DC: American Psychiatric Association.

Badcock, J. C., Whitworth, F. A., Badcock, D. R., & Lovegrove, W. J. (1990). Low-frequency filtering and the processing of local-global stimuli. *Perception, 19*, 617–629.

Baron-Cohen, S., Ring, H. A., Wheelwright, S., Bullmore, E. T., Brammer, M. J., Simmons, A., et al. (1999). Social intelligence in the normal and autistic brain: An fMRI study. *European Journal of Neurosciences, 11*, 1891–1898.

Behrmann, M., Thomas, C., & Humphreys, (2006). Seeing it differently: Visual processing in autism. *Trends in Cognitive Sciences, 10*, 258–264.

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

Boeschoten, M. A., Kemner, C., Kenemans, J. L., & van Engeland, H. (2005). The relationship between local and global processing and the processing of high and low spatial frequencies studied by event-related potentials and source modeling. *Cognitive Brain Research, 24*, 228–236.

Boeschoten, M. A., Kenemans, J. L., Engeland, H., & Kemner, C. (2007). Abnormal spatial frequency processing in high-functioning children with pervasive developmental disorder (PDD). *Clinical Neurophysiology, 118*, 2076–2088.

Braverman, M., Fein, D., Lucci, D., & Waterhouse, L. (1989). Affect comprehension in children with pervasive developmental disorders. *Journal of Autism and Developmental Disorders, 19*, 301–319.

Ceponiene, R., Lepistö, T., Shestakova, A., Vanhala, R., Alku, P., Näätänen, R., et al. (2003). Speech-sound-selective auditory impairment in children with autism: They can perceive but do not attend. *Proceedings of the National Academy of Sciences of the United States of America, 100*, 5567–5572.

Ceponiene, R., Rinne, T., & Näätänen, R. (2002). Maturation of cortical sound processing as indexed by event-related potentials. *Clinical Neurophysiology, 113*, 870–882.
Ciaramelli, E., Grady, C. L., & Moscovitch, M. (2008). Top-down and bottom-up attention to memory: A hypothesis (AtoM) on the role of the posterior parietal cortex in memory retrieval. *Neuropsychologia, 46*, 1828–1851.
Ciesielski, K. T., Courchensne, E., & Elmasian, R. (1990). Effects of focused selective attention tasks on event-related potentials in autistic and normal individuals. *Electroencephalography and Clinical Neurophysiology, 75*, 207–220.
Courchesne, E., Couchesne, R. Y., Hicks, G., & Lincoln, A. J. (1985). Functioning of the brain-stem auditory pathway in non-retarded autistic individuals. *Electroencephalography and Clinical Neurophysiology, 61*, 491–501.
Courchesne, E., Lincoln, A. J., Kilman, B. A., & Galambos, R. (1985). Event-related brain potential correlates of the processing of novel visual and auditory information in autism. *Journal of Autism and Developmental Disorders, 15*, 55–76.
Courchesne, E., Lincoln, A. J., Yeung-Courchesne, R., Elmasian, R., & Grillon, C. (1989). Pathophysiologic findings in nonretarded autism and receptive developmental language disorder. *Journal of Autism and Developmental Disorders, 19*, 1–17.
Critchley, H. D., Daly, E. M., Bullmore, E. T., Williams, S. C., van Amelsvoort, T., Robertson, D. M., et al. (2000). The functional neuroanatomy of social behavior: Changes in cerebral blood flow when people with autistic disorder process facial expressions. *Brain, 123*, 2203–2212.
Dakin, S., & Frith, U. (2005). Vagaries of visual perception in autism. *Neuron, 48*, 497–507.
Dawson, G., Webb, S. J., Garver, 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.
Dunn, M. A., Gomes, H., & Gravel, J. (2008). Mismatch negativity in children with autism and typical development. *Journal of Autism and Developmental Disorders, 38*, 52–71.
Ehlers, C. L., Wall, T. L., Garcia-Andrade, C., & Philips, E. (2001). Auditory P3 findings in mission Indian youth. *Journal of Studies on Alcohol., 62*, 562–570.
Frith, U. (1989). *Autism: Explaining the enigma*. Oxford, UK: Basil Blackwell.
Gepner, B., & Mastre, D. R. (2002). Brief report: Postural reactivity to fast visual motion differentiates autistic from children with asperger syndrome. *Journal of Autism and Developmental Disorders, 32*, 231–238.
Goffax, V., Gauthier, I., & Rossion, B. (2003). Spatial scale contribution to early visual differences between face and object processing. *Cognitive Brain Research, 16*, 416–424.
Goffax, V., Hault, B., Michel, C., Vuong, Q. C., & Rossion, B. (2005). The respective role of low and high spatial frequencies in supporting configural and featural processing of faces. *Perception, 34*, 77–84.
Gomarus, H. K., Wijers, A. A., Minderaa, R. B., & Althaus, M. (2009). ERP correlates of selective attention and working memory capacities in children with ADHD and/or PDD-NOS. *Clinical Neurophysiology, 120*, 60–72.
Gunji, A., Inagaki, M., Inoue, Y., Takeshima, Y., & Kaga, M. (2009). Event-related potentials of self-face recognition in children with pervasive developmental disorders. *Brain and Development, 31*, 139–147.
Happé, F. (1999). Autism: Cognitive deficit or cognitive style? *Trends in Cognitive Sciences, 3*, 216–222.
Happé, F., & Frith, U. (2006). The weak coherence account: Detail-focused cognitive style in autism spectrum disorders. *Journal of Autism and Developmental Disorders, 36*, 5–25.
Hobson, R. P., & Lee, A. (1989). Emotion-related and abstract concepts in autistic people: Evidence from the British Picture Vocabulary Scale. *Journal of Autism and Developmental Disorders, 19*, 601–623.
Hoeksma, M. R., Kemner, C., Kenemans, J. L., & van Engeland, H. (2006). Abnormal selective attention normalizes P3 amplitudes in PDD. *Journal of Autism and Developmental Disorders, 36*, 643–654.
Hoeksma, M. R., Kemner, C., Verbaten, M. N., & van Engeland, H. (2004). Processing capacity in children and adolescents with pervasive developmental disorders. *Journal of Autism and Developmental Disorders, 34*, 341–354.
Hoffman, L. D., & Polich, J. (1999). P300, handedness, and corpus callosal size: Gender, modality, and task. *International Journal of Psychophysiology, 3*, 163–174.
Itier, R. J., & Taylor, M. J. (2002). Inversion and contrast polarity reversal affect both encoding and recognition processes of unfamiliar faces: A repetition study using ERPs. *NeuroImage, 15*, 353–372.
Itier, R. J., & Taylor, M. J. (2004). N170 or N1? Spatiotemporal differences between object and face processing using ERPs. *Cerebral Cortex, 14*, 132–142.
Jeste, S. S., & Nelson, C. A. (2009). Event related potentials in the understanding of autism spectrum disorders: An analytical review. *Journal of Autism and Developmental Disorders, 39*, 495–510.
Jolliffe, T., & Baron-Cohen, S. (1997). Are people with autism and Asperger syndrome faster than normal on the embedded figures test? *Journal of Child Psychology and Psychiatry, 38*, 527–534.
Kamio, Y., Yukihiro, R., Adachi, J., Ichikawa, H., Inoue, M., Uchiyama, T., et al. (2006). Reliability and validity of the pervasive developmental disorder (PDD)—Autism society Japan rating scale (PARS): A behavior checklist for adolescent and adults with PDDs. *Clinical Psychiatry (Seishin Igaku), 48*, 495–505 (in Japanese).
Kemner, C., van der Gaag, R. J., Verbaten, M., & van Engeland, H. (1999). ERP difference among subtypes of pervasive developmental disorders. *Biological Psychiatry, 46*, 781–789.
Kuhl, P. K., Coffey-Corina, S., Padden, D., & Dawson, G. (2005). Links between social and linguistic processing of speech in preschool children with autism: Behavior and electrophysiological measures. *Developmental Science, 8*, F1–F12.
LaGasse, L. L. (1993). Effects of good form and spatial frequency on global precedence. *Perception and Psychophysics, 53*, 89–105.
Lepistö, T., Kuitunen, A., Sussman, E., Saalasti, S., Jansson-Verkasalo, E., Wendt, T. N., & Kujala, T. (2009). Auditory stream segregate in children with Asperger syndrome. *Biological Psychology, 82*, 301–307.
Lepistö, T., Kujala, T., Vanhara, R., Alku, P., Huotilainen, M., & Näätänen, R. (2005). The discrimination of and orienting to speech and non-speech sounds in children with autism. *Brain Research, 1066*, 147–157.
Lepistö, T., Kujala, T., Vanhala, R., Alku, P., Huotilainen, M., Näätänen, R., et al. (2008). The perception of invariant speech features in children with autism. *Biological Psychology, 77*, 25–31.
Lepistö, T., Silokallio, S., Nieminen, -von Wendt, T., Alku, P., Näätänen, R., & Kujala, T. (2006). Auditory perception and attention as reflected by the brain event-related potentials in children with Asperger syndrome. *Clinical Neurophysiology, 117*, 2161–2171.
Lincoln, A. J., Courchesne, E., Harms, L., & Allen, M. (1993). Contextual probability evaluation in autistic, receptive developmental language disorder, and control children: Event-related brain potential evidence. *Journal of Autism and Developmental Disorders, 23*, 37–58.
Maekawa, T., Goto, Y., Kinukawa, N., Taniwaki, T., Kanba, S., & Tobimatsu, S. (2005). Functional characterization of mismatch negativity to a visual stimulus. *Clinical Neurophysiology, 116*, 2392–2402.
Maekawa, T., Tobimatsu, S., Ogata, K., Onitsuka, T., & Kanba, S. (2009). Preattentive visual change detection as reflected by mismatch negativity (MMN)—Evidence for a memory-based process. *Neuroscience Research, 65*, 107–112.
Mitchell, K. W., Howe, J. W., & Spencer, S. R. (1987). Visual evoked potentials in the older population: Age and gender effects. *Clinical Physics and Physiological Measurement, 8*, 317–324.
Mottron, L., & Burack, J. A. (2001). Enhanced perceptual functioning in the development of autism. In Burack, J. A., Chaman, T., Yirmiya, N., & Zelazo, P. R. (Eds.), *Developmental psychopathology*. Vol. 1 (pp.357–391). New York: Wiley.
Mottron, L., Burack, J. A., Stauder, J. E., & Robaey, P. (1999). Perceptual processing among high-functioning persons with autism. *Journal of Child Psychology and Psychiatry, and allied disciplines, 40*, 203–211.
Mottron, L., Dawson, M., & Soulières, I. (2009). Enhanced perception in savant syndrome: Patterns, structure and creativity. *Philosophical Transactions the Royal Society B, 364*, 1385–1391.
Mottron, L., Dawson, M., Soulières, I., Hubert, B., & Burack, J. (2006). Enhanced perceptual functioning in autism: An update, and eight principles of autistic functioning. *Journal of Autism and Developmental Disorders, 36*, 27–43.

Müller, R. A. (2008). From loci to network and back again: Anomalies in the study in autism. *Annals of the New York Academy of Sciences, 1145*, 300–315.
O'Conner, K., Hamm, J. P., & Krik, I. J. (2005). The neurophysiological correlates of face processing in adults and children with Asperger's syndrome. *Brain and Cognition, 59*, 82–95.
Pitchard, W. S., Raz, N., & August, G. J. (1987). Visual augmenting/reducing and P300 in autistic children. *Journal of Autism and Developmental Disorders, 17*, 231–242.
Plaisted, K. (2001). Reduced generalization in autism: An alternative to weak central coherence. In J. A. Bruck, T. Charman, N. Yirmiya, & P. R. Zerazo (Eds.), *The development of autism: Perspectives from theory and research* (pp. 149–169). Hillsdale, NJ: Erlbaum.
Plaisted, K., O'Riordan, M., & Baron-Cohen, S. (1998). Enhanced visual search for a conjunctive target in autism: A research note. *Journal of Child Psychology and Psychiatry Allied Disciplines, 39*, 777–783.
Pourtois, G., Dan, E. S., Grandjean, D., Sander, D., & Vuilleumier, P. (2005). Enhanced extrastriate visual response to bandpass spatial frequency filtered fearful faces: Time course and topographic evoked-potentials mapping. *Human Brain Mapping, 26*, 65–79.
Rozenkrants, B., & Polich, J. (2008). Affective ERP processing in a visual oddball task: Arousal, valence, and gender. *Clinical Neurophysiology, 119*, 2260–2265.
Ruitz-Solar, M., & Beltran, F. S. (2006). Face perception: An integrative review of the role of spatial frequencies. *Psychological Research, 70*, 273–292.
Shah, A., & Frith, U. (1983). A islet of ability in autistic children: A research note. *Journal of Child Psychology and Psychiatry Allied Disciplines, 24*, 613–620.
Shah, A., & Frith, U. (1993). Why do autistic individuals show superior task performance on the block design task? *Journal of child psychology and psychiatry, and allied disciplines, 34*, 1351–1364.
Spencer, J., O'Brien, J., Riggs, K., Baraddick, O., Atkinson, J., & Wattam-Bell, J. (2000). Motion processing in autism: Evidence for a dorsal stream deficiency. *Neuroreport, 11*, 2765–2767.
Steffensen, S. C., Ohrans, A. J., Shipp, D. N., Hales, K., Stobbs, S. H., & Fleming, D. E. (2008). Gender-selective effects of the P300 and N400 components of the visual evoked potential. *Vision Research, 48*, 917–925.
Tani, I., Yukihiro, R., & Tsujii, M. (2009). Reliability and validity of the pervasive developmental disorder (PDD). *Autism society Japan rating scale (PARS). Proceedings of Asia Pacific autism conference* (pp. 31–).
Tanskanen, T., Näätänen, R., Montez, T., Päällysaho, J., & Hari, R. (2005). Face recognition and cortical responses show similar sensitivity to noise spatial frequency and orientation. *Cerebral Cortex, 15*, 526–534.
Taylor, M., Edmonds, G., McCarthy, G., & Allison, T. (2001). Eyes first! Eye processing develops before face processing in children *Neuroreport, 12*, 1671–1676.
Tobimatsu, S., & Celesia, G. G. (2006). Studies of human pathophysiology with visual evoked potentials. *Clinical Neurophysiology, 117*, 1414–1433.
Townsend, J., Westerfield, M., Leaver, E., Makeig, S., Jung, T., Pierce, K., & Courchesne, E. (2001). Event-related brain response abnormalities in autism: Evidence for impaired cerebello-frontal spatial attention networks. *Brain Research. Cognitive Brain Research, 11*, 127–145.
Treisman, A., Vieira, A., & Hayes, A. (1992). Automatically and preattentive processing. *American Journal of Psychology, 105*, 341–362.
Tuchman, R., & Rapin, I. (2006). *Autism: A neurological disorder of early brain development*. London, England: International Review of Child Neurology Series, Mac Keith Press.
Verbaten, M. N., Roelofs, J. W., van Engeland, H., Kenemans, J. K., & Slangen, J. L. (1991). Abnormal visual event-related potentials of autistics children. *Journal of Autism and Developmental Disorders, 21*, 449–470.
Vuilleumier, P., Armony, J. L., Driver, J., & Dolan, R. J. (2003). Distinct spatial frequency sensitivities for processing faces and emotional expressions. *Nature Neuroscience, 6*, 624–631.
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.
Webb, S. J., Merkle, K., Murias, M., Richards, T., Aylward, E., & Dawson, G. (in press). ERP response differentiate inverted but not upright face processing in adults with ASD. *Social Cognitive and Affective Neuroscience*.

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Electrophysiological evidence for selective impairment of optic flow perception in autism spectrum disorder

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ABSTRACT

People with autism spectrum disorder (ASD) often show inferior global motion performance with superior performance in detail form perception, suggesting dysfunction of the dorsal visual stream. To elucidate the neural basis of impaired global motion perception in ASD, we measured psychophysical threshold and visual event-related potentials (ERPs) with a 128-channel system in 12 ASD and 12 healthy control adults. Radial optic flow (OF) and horizontal motion (HO) were used as the visual stimuli. The former was related to the ventro-dorsal stream formed by the inferior parietal lobule, while the latter was conveyed from the dorso-dorsal stream formed by the superior parietal lobule. No significant group differences were observed in the motion thresholds for both OF and HO. N170 and P200 were elicited as major components of ERPs in both groups. However, the latencies of both components for OF but not HO were significantly prolonged in ASD compared with the control group. Our ERP results suggest that ASD has a selective impairment for OF processing even though the psychophysical thresholds are preserved. Therefore, we provide the first electrophysiological evidence for altered function of the higher-level dorsal visual stream in ASD, specifically the ventro-dorsal stream closely related to OF perception.

1. Introduction

Autism spectrum disorder (ASD) is a neurodevelopmental disorder characterized by social interaction and communication impairments, as well as restricted and repetitive behaviors and interests (Frith & Happé, 2005; Kamio et al., in press). Individuals with ASD show superior performance in processing fine details (Happé & Frith, 2006; Happé, 1996; Jolliffe & Baron-Cohen, 1997), while even those with high IQ are poor at processing global structure and motion perception (Bertone, Mottron, Jelenic, & Faubert, 2003; Milne et al., 2002; Spencer et al., 2000). This unusual cognitive style of reduced global bias coupled with enhanced local bias may be related to abnormal integration of perceptual information and may affect cognitive operations. Thus, low-level perception is considered to contribute to higher-level impairments of social

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cognition in ASD (Dakin & Frith, 2005; Mottron & Burack, 2001). Consequently, to elucidate the neural basis of impaired social interaction and communication in ASD, it is important to investigate visual motion perceptual function.

Fine-form perception is mainly processed in the parvocellular (P) pathway. In contrast, global motion is processed in the magnocellular (M) pathway on a basis of parallel visual information processing (Livingstone & Hubel, 1988; Tobimatsu & Celesia, 2006). After the primary visual cortex (V1), the M pathway projects to the dorsal stream that includes V1–3, V3a, V5/MT, MST, V6, and the posterior parietal lobule. Recently, the dorsal stream has been divided into two functional streams in primates: the dorso-dorsal (d-d) and ventro-dorsal (v-d) streams (Rizzolatti & Matelli, 2003). The former consists of V6 and the superior parietal lobule (SPL), whereas the latter is formed by V5/MT and the inferior parietal lobule (IPL). Given this background, we hypothesized that the atypical visual findings seen in ASD might derive from abnormalities at higher-level processing in the M pathway.

It is well known that the higher-level dorsal pathway including V5/MT integrates local motion signals from V1 into global motion (Snowden, Treue, Erickson, & Andersen, 1991). Therefore, coherent motion stimuli have been widely used to investigate global motion processing in psychophysical, electrophysiological, and neuroimaging studies (Morrone et al., 2000; Newsome & Paré, 1988; Niedeggen & Wist, 1999). There are several types of global motion including radial optic flow (OF) and horizontal motion (HO). Radial OF is the visual motion seen during observer self-movement and is known to be important for daily life because it provides cues about the heading direction and the three-dimensional structure of the visual environment (Gibson, 1950; Warren & Hannon, 1988). Using functional magnetic resonance imaging (fMRI), we recently reported that OF is mainly processed in the v-d (IPL) stream, while HO is mostly related to the d-d (SPL) stream in healthy humans (Yamasaki & Tobimatsu, in press). Thus, the use of both stimuli can reveal the function of two distinct higher-level dorsal pathways in ASD in detail.

Many psychophysical studies have been conducted to investigate motion perception in ASD. Motion coherence thresholds for HO (Milne et al., 2002; Spencer et al., 2000), OF (Del Viva, Igliozzi, Tancredi, & Brizzolara, 2006; Tsermentseli, O'Brien, & Spencer, 2008), and plaid motion (Vandenbroucke, Steven Scholte, van Engeland, Lamme, & Kemner, 2008) were measured to evaluate the function of the dorsal stream. Conversely, several studies evaluated the function of the lower and higher levels of the dorsal streams separately. One study examined motion sensitivity to the lower level of first-order (luminance-defined) and higher level of second-order (texture-defined) motion (Bertone et al., 2003). Other studies assessed dorsal stream functioning at both lower (sensitivity to flicker contrast) and higher (sensitivity to coherent HO) levels (Pellicano & Gibson, 2008; Pellicano, Gibson, Maybery, Durkin, & Badcock, 2005). However, it is still controversial whether impaired motion perception exists, and if it exists, it remains unclear how the M (or dorsal) pathway is functionally impaired in ASD.

Visual event-related potentials (ERPs) can detect abnormalities not only in patients with visual complaints but also in patients with no visual symptoms on examination (Tobimatsu & Celesia, 2006). Therefore, ERPs are considered to be useful for resolving the psychophysical controversy about motion perception (function of the dorsal pathway) in ASD; however, to date, there have been no such ERP studies on ASD. Therefore, in the present study, the psychophysical threshold of coherent motion (OF and HO) and ERP responses to these stimuli were measured to evaluate the function of the two distinct higher-level dorsal pathways in ASD.

2. Methods

2.1. Experiment 1: psychophysical threshold measurements

2.1.1. Subjects

Twelve ASD adults (nine males and three females, aged 20–39 years) and 12 control adults with similar chronological age and sex ratios (nine males and three females, aged 20–39 years) participated in this experiment. The ASD patients comprised six patients with Asperger's syndrome and six patients with pervasive developmental disorder not otherwise specified (PDD-NOS). These patients were diagnosed by a research team, including an experienced child psychiatrist (Y.K.), according to DSM-IV criteria (American Psychiatric Association, 1994) based on clinical interviews with patients and/or parents using semi-structured interviews that were validated for the Japanese PDD population (Pervasive Developmental Disorders Autism Society Japan Rating Scale; Kamio et al., 2006). Diagnostic agreement among the team was obtained for all subjects. Control subjects were recruited from the college student and faculty population and were confirmed as having no developmental problems by interviews.

Intellectual function of the ASD patients was evaluated using WAIS-R. ASD participants with full-scale IQ scores below 70 were not included in the study. All subjects exhibited normal or corrected-to-normal visual acuity (>1.0), evaluated using the Landolt's ring (Landolt, 1905). Autism-Spectrum Quotient (AQ) (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001; Wakabayashi, Baron-Cohen, Wheelwright, & Tojo, 2006) was also examined.

Informed consent was obtained after the nature of the experiment had been fully explained. The experimental procedures were approved by the ethics committee of the Graduate School of Medical Sciences, Kyushu University.

2.1.2. Visual stimuli

The visual stimuli were generated by the software Presentation (Neurobehavioral Systems, Inc., San Francisco, CA, USA), which was run on a personal computer and displayed on a gamma-corrected color monitor with a frame rate of 60 Hz

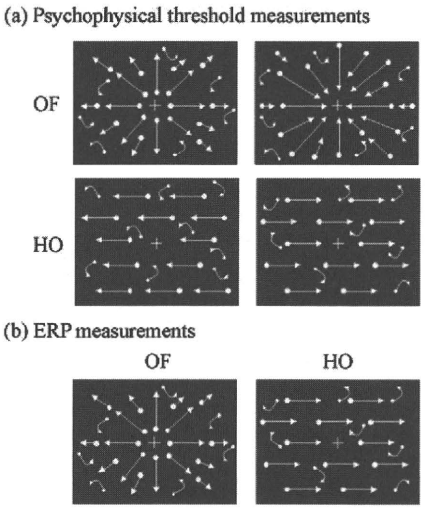

Fig. 1. Visual motion stimuli used in this study. Four hundred white square dots (visual angle, 0.2° × 0.2°; luminance, 48 cd/m^2) are randomly presented on a black background (visual angle, 50° × 48°; luminance, 0.1 cd/m^2). The contrast level is 99.6%. The white dots move at a velocity of 5.0°/s. (a) Shows two types of motion stimuli, OF and HO, for psychophysical threshold of coherent motion measurements. HO contains dots that move leftward or rightward. OF contains dots that move in a radial outward or inward pattern on the center of the screen. (b) Depicts visual motion stimuli for ERP measurements. When the white dots move incoherently, RM stimulation is created. When the white dots move coherently, OF and HO are perceived. *Abbreviations*: RM, random motion; HO, horizontal motion; OF, optic flow.

(Electron22blue IV, LaCie, Tokyo, Japan). We used coherent motion stimuli as the visual stimuli (Fig. 1). They consisted of 400 white square dots randomly presented on a black background. The white dots moved at a velocity of 5.0°/s. Two types of motion stimuli, namely OF and HO, were used (Fig. 1a). OF contained dots that moved in a radial outward or inward pattern on the center of the screen. HO contained dots that moved leftward or rightward. These coherent motion patterns were intermixed with random motion (RM), and the percentage of coherently and randomly moving dots varied between trials for the determination of motion coherent thresholds. After central fixation was established, these visual stimuli were shown for 750 ms with an interstimulus interval of 1500 ms. Both stimuli had the same dot density, luminance, contrast, and average dot speed.

2.1.3. Psychophysical testing

Participants sat on a chair in front of a monitor in a dark room and fixated on a fixation point (visual angle 0.2° × 0.2°) in the center of the monitor. In the OF condition, participants indicated whether the coherent motion was expansion or contraction. In the HO condition, participants indicated whether the coherent motion was to the left or right. Participants were instructed to press the computer mouse buttons with either thumb as soon as possible. The ratio of dots with coherent movement varied at 14 steps from 5% to 70% in a random order. Each step consisted of 40 trials (20 trials × 2); therefore, one session was 40 trials × 14 steps. Perceptual thresholds were defined as the percentage of coherent motion in stimuli (([coherently moving dots]/[coherently moving dots + random dots]) × 100) yielding 82.0% correct responses, reflecting Weibull fits to psychophysical responses (Harvey, 1986). The order of motion stimulation was counterbalanced across participants.

2.1.4. Data analysis

We performed two-way analysis of variance (ANOVA) with repeated measures to determine the effects of the participant groups and stimulus types on the coherent motion perceptual threshold. Multiple comparisons with Bonferroni correction were also conducted for paired comparisons.

2.2. Experiment 2: ERP measurements

2.2.1. Participants

Twelve ASD adults and 12 control adults participated in this experiment. The participants were the same as those in experiment 1.

2.2.2. Visual stimuli

Two types of motion stimuli, namely OF and HO, were used (Fig. 1b). OF contained dots that moved in a radial outward pattern. HO contained dots that moved leftward or rightward. The coherence level was 90% in both stimuli. The stimulus characteristics, such as visual angle, dot density, luminance, contrast, and average dot speed, were the same as the stimuli in

experiment 1. An image of RM-containing dots that moved incoherently was used as the baseline condition. In each session, the motion stimulus was fixed to one of the two stimuli, namely OF and HO, and the stimulus was presented 25 times for 750 ms with presentation of the RM for 1500–3000 ms alternating with the motion stimuli. Thus, one session lasted for about 60–90 s. In each motion stimulation, six sessions were performed, such that each motion stimulation was presented a total of 150 (25 × 6) times. The order of motion stimulation was counterbalanced among the subjects.

2.2.3. ERP recording

ERPs were recorded using a Geodesic electroencephalogram (EEG) system, NetAmps 200 (Electrical Geodesics Inc. [EGI], Eugene, OR, USA). A high-density 128-channel HydroCel Geodesic Sensor net (EGI) was applied over the scalp of the subject. This net holds each electrode in place and distributes electrodes from the nasion to the inion and from left to right mastoids at uniform intervals. Each electrode consisted of a silver-chloride carbon-fiber pellet, a lead wire, a gold-plated pin, and a potassium-chloride-soaked sponge. This electrode configuration effectively blocked out electrochemical noise and minimized triboelectric noise. Signals were amplified via an AC-coupled, 128-channel high-input impedance amplifier (NetAmps 200, EGI). Amplified analog voltages were hardware band-pass filtered at 0.1–200 Hz. All sensors were individually adjusted by the experimenter until the impedance of each electrode was less than 50 kΩ (Ferree, Luu, Russell, & Tucker, 2001). The impedance levels were comparable between the ASD and control groups. EEG data were collected using the vertex (Cz) electrode reference.

The subjects sat on a chair in front of a monitor in a dark room and fixated on a fixation point (visual angle, 0.2° × 0.2°) at the center of the monitor. The subjects were instructed to remain relaxed and as motionless as possible and to fixate on the center of the screen with both eyes. The arousal level was carefully monitored visually by the observer within the room, by the video camera outside of the room, and by EEG. If the subjects were getting drowsy, we alerted them and gave them a brief rest.

2.2.4. Data analysis

EEG data were collected using the vertex (Cz) electrode reference. Epochs that contained blinks, horizontal or non-blink eye movements, A/D saturation, or obvious occipital α-activity were rejected in offline analysis to obtain averaged waveforms. The electrodes surrounding the eyes were used to identify the artifacts of blinks and horizontal or non-blink eye movements. Then, they were re-referenced offline to the average of two channels on the cheeks. The analog data, hardware band-pass filtered at 0.1–200 Hz, were digitized at a sampling rate of 500 Hz/channel and were filtered using a 1–30 Hz band-pass filter and a 60-Hz notch filter before averaging. And then, 150 samples of 800-ms (from −100 to 700 ms) epochs were averaged using the software (EMSE Suite, Source Signal Imaging, Inc., San Diego, CA, USA).

To reveal the characteristic difference among the stimuli, the global field powers (GFP; Brandeis & Lehmann, 1986; Lehmann & Skrandies, 1980) of the major components were calculated for each stimulus for each participant as well as in averaged data for these individuals. Then, referring to the GFP peak in each grand-averaged waveform, we created the scalp topography and evaluated the difference of the scalp topography of the major components among the visual stimuli. Two-way ANOVA with repeated measures was performed to determine the effects of the subject groups and stimulus types on the GFP peak amplitudes and peak latencies of the major components. Multiple comparisons with the Bonferroni correction were also conducted for paired comparisons.

3. Results

3.1. Intellectual function

ASD patients exhibited normal IQ (verbal IQ, 103.8 ± 10.4 [mean ± SD]; performance IQ, 96.3 ± 21.5; full-scale IQ, 100.3 ± 15.7). AQ in these patients was 27.8 ± 6.4 (mean ± SD). There were no significant differences in chronological age (*t*-test) and sex ratio (χ^2-test) between the two groups.

3.2. The psychophysical thresholds for coherent motion

The motion thresholds for OF and HO in both groups are summarized in Table 1. Within the participant groups, no significant difference in the mean motion threshold between the two stimuli was found. When compared between the two groups, there were no significant differences in the mean motion threshold for both OF and HO. In sum, ASD adults showed no decline in discrimination of both OF and HO.

Table 1
The thresholds for coherent motion in control and ASD adults.

Stimuli	Control adults	ASD adults
OF	17.3 ± 3.4	22.9 ± 11.0
HO	16.7 ± 3.4	20.1 ± 5.0

Data are expressed as mean ± SD (%).

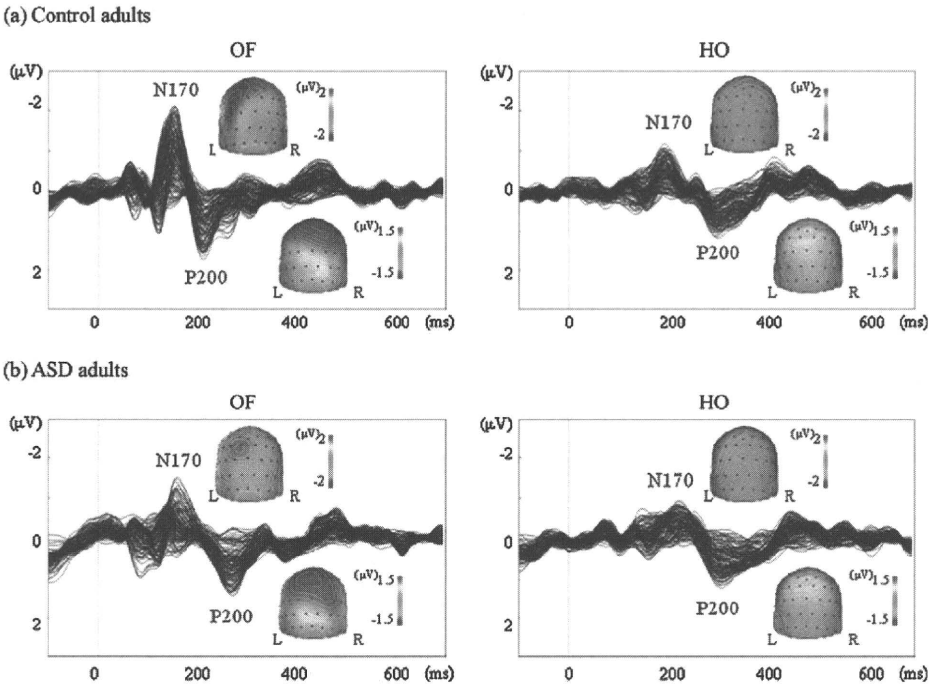

Fig. 2. The superimposed waveforms and the scalp topography of grand-averaged ERPs in response to each motion stimulus in control (a) and ASD (b) groups. In both groups, N170 and P200 are evoked by both motion stimuli. ASD adults show an apparent prolongation of P200 latency for OF compared with control adults.

3.3. ERP responses

In the control group, two major components (N170 and P200) were obtained by both motion stimuli (Fig. 2a). N170 was predominant at the occipito-temporal regions for both stimuli. P200 for OF was distributed at parietal regions, whereas P200 for HO was located at central regions (Fig. 2a). ASD adults exhibited similar patterns of ERP responses and scalp topography as observed in control adults. However, ASD adults displayed the prolongation of P200 latency for OF compared with controls (Fig. 2b).

Regarding the N170 GFP peak amplitude, there was no main effect of the participant groups or an interaction effect of the subject groups × stimulus types (Table 2). For the N170 GFP peak latency, an interaction effect of the subject groups × stimulus types was found ($F(1,22) = 13.435$, $p < 0.001$). The mean N170 latency for OF in ASD adults was significantly prolonged compared with that of controls ($p < 0.001$), while there was no difference in the mean N170 latency for HO between the two groups (Table 2). For the P200 GFP peak amplitude, there was no main effect of participant groups or interaction effect of subject groups × stimulus types (Table 2). However, for the P200 GFP peak latency, a significant main effect of the subject groups ($F(1,22) = 15.578$, $p < 0.001$) and an interaction effect of the subject groups × stimulus types ($F(1,22) = 9.749$, $p < 0.01$) were found. The mean P200 latency for OF in ASD adults was significantly prolonged compared with the controls ($p < 0.001$). In contrast, there was no difference in the mean P200 latency for HO between the two groups (Table 2).

Table 2
GFP peak amplitudes and latencies of the N170 and P200 components in control and ASD adults.

Stimuli	N170 amplitude (μV)		N170 latency (ms)	
	Control adults	ASD adults	Control adults	ASD adults
OF	8.1 ± 5.5	9.9 ± 5.7	158.5 ± 11.8*	194.5 ± 28.4*
HO	4.1 ± 1.2	5.6 ± 1.9	225.0 ± 28.2	201.5 ± 37.1
Stimuli	P200 amplitude (μV)		P200 latency (ms)	
	Control adults	ASD adults	Control adults	ASD adults
OF	8.1 ± 3.6	10.2 ± 4.7	210.1 ± 16.3*	262.3 ± 36.5*
HO	5.1 ± 1.8	6.7 ± 2.8	284.5 ± 19.3	293.5 ± 24.9

Data are expressed as mean ± SD.
* $p < 0.001$, control adults vs. ASD adults.

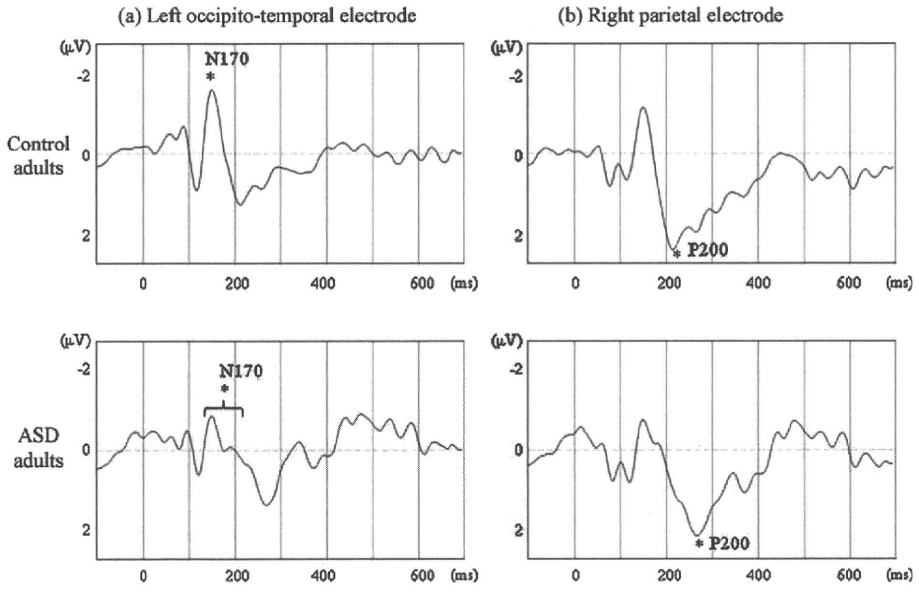

Fig. 3. Grand average of ERPs in response to OF stimulation at the left occipito-temporal electrode (a) and at the right parietal electrode (b) in control and ASD groups. ASD adults exhibit small and ill-defined N170 response (a) and prolonged P200 latency (b) compared with control adults.

Fig. 3 shows the maximal N170 response for OF at the left occipito-temporal electrode and the maximal P200 response for OF at the right parietal electrode on the basis of the scalp topography in both groups. ASD adults exhibited a small and ill-defined N170 response, which may be because of the large variability of N170 latency of ASD adults compared with control adults (Fig. 3a, Table 2). A marked prolongation of P200 latency was observed in ASD adults (Fig. 3b, Table 2). Overall, ASD adults manifested significant prolongation of both N170 and P200 latencies for OF but not HO compared with control adults.

4. Discussion

4.1. Selective impairment of OF perception in ASD adults

In the psychophysical experiment, there were no significant differences in the motion threshold for both OF and HO between the two groups. However, ERPs provided objective evidence for the decline of motion perception in ASD. We found significant prolongations of N170 and P200 latencies for OF but not HO in ASD adults, indicating the selective impairment of OF perception in ASD even though the psychophysical thresholds were preserved.

Which portion of the dorsal stream is impaired? In control adults, N170 and P200 were the two distinct major ERP components. N170 was evoked by both motion stimuli, while the parietal-distributed P200 was only elicited by OF. This suggests that N170 is a nonspecific motion component but the parietal-distributed P200 is an OF-specific component. Previous ERP studies with unidirectional coherent motion stimuli (Kuba & Kubová, 1992; Niedeggen & Wist, 1999) detected an occipito-temporal-distributed N2 component (latency, 150–200 ms) originating from in or around V5/MT (Probst, Plendel, Paulus, Wist, & Scherg, 1993). It is likely that our N170 corresponds to N2; therefore, our N170 reflects chiefly V5/MT function. In contrast, our recent fMRI study on healthy humans has revealed that the v-d (IPL) stream is significantly activated by OF compared with HO (Yamasaki & Tobimatsu, in press), which implies that P200 may represent the function of IPL. Therefore, impaired OF perception may result from the dysfunction of the higher level of the v-d (IPL) stream after V5/MT in ASD adults.

What is the meaning of selective impairment of OF perception but not HO perception in ASD adults? OF includes information about heading direction, orientation, and visual navigation in three-dimensional space, which controls posture and locomotion, as well as perception of moving objects and selection of motor actions that allow appropriate interactions with these objects (Gibson, 1950; Koenderink, 1986; Warren & Hannon, 1988). In contrast, HO has unidirectional motion information, and therefore, HO is a relatively low-level motion compared with OF. It is likely that OF information is more important for perception of the external world, including other people, compared with HO information and that impaired communication is closely related to the impaired OF perception in ASD. Gepner and Mestre (2002) demonstrated that autistic children are posturally hyporeactive to visually perceived environmental motion (visuo-postural tuning) in comparison with control children, which may support in part our OF-specific impairment in ASD.

4.2. "Pathway-specific" vs. "complexity-specific" hypotheses

Based on the atypical visual perceptual abnormalities in ASD, "pathway-specific" (Spencer et al., 2000) and "complexity-specific" (Bertone & Faubert, 2006; Bertone et al., 2003; Bertone, Mottron, Jelenic, & Faubert, 2005) hypotheses have been