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Sakihara, Kotoe

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Original article

Modulation effects of the intact motor skills on the relationship between social skills and motion perceptions in children with autism spectrum disorder: A pilot study

Kotoe Sakihara ^{a,b,*}, Yosuke Kita ^{c,d}, Kota Suzuki ^e, Masumi Inagaki ^{b,f}

^a Department of Clinical Laboratory Science, Faculty of Medical Technology, Teikyo University, Japan

^b Department of Developmental Disorders, National Institute of Mental Health, National Center of Neurology and Psychiatry (NCNP), Japan

^c Department of Psychology, Faculty of Letters, Keio University, Tokyo, Japan

^d Cognitive Brain Research Unit (CBRU), Faculty of Medicine, University of Helsinki, Helsinki, Finland

^e Faculty of Education, Shitennoji University, Japan

^f Tottori Prefectural Tottori Rehabilitation Center, Japan

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Abstract

Background: An individual with autism spectrum disorder (ASD) has social skill, motor skill, and motion perception deficits. However, the relationship among them was not clarified. Therefore, this study aimed to evaluate the effects of motor skills on social skills and motion perception.

Methods: Five typically developed children and fourteen children with ASD participated in our study. The N200 component, a brain activity indicating motion perception, was induced in mid-temporal (MT/V5) brain area by watching a random dot kinematograph, and was recorded using a scalp electroencephalogram. Furthermore, the social responsiveness scale (SRS) indicating the social skill deficit, the developmental coordination disorder questionnaire (DCDQ) estimating the developmental coordination disorder (DCD), and the movement assessment battery for children second edition (MABC-2) indicating motor skills were recorded in the children with ASD. A hierarchical multiple regression analysis was conducted to examine the modulation effects of motor skills on the relationship between social skills and motion perception. The dependent variable was the N200 latency, and the independent variables were SRS, MABC-2, and combined MABC-2 and SRS.

Results: The N200 latency was more delayed in children with ASD relative that in typically developed children. Intact balance ability modulated the relationship between social skills and N200 latency in children with ASD. Within the high balance ability, when the social skills worsened, the N200 latency was shortened.

Conclusions: This is the first report that intact motor skills could modulate the relationship between social skills and motion perception.

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Keywords: Autism spectrum disorder; Motor skill; Social skill; Motion perception; N200 latency; Random dot kinematograph; Social responsiveness scale; Movement assessment battery for children second edition; Developmental coordination disorder

1. Introduction

A core feature of autism spectrum disorder (ASD) indicates social communication and social interaction

* Corresponding author at: Department of Clinical Laboratory Science, Faculty of Medical Technology, Teikyo University 2-11-1 kaga, Itabashi, Tokyo, 173-8605, Japan.

E-mail address: sakihara@med.teikyo-u.ac.jp (K. Sakihara).

deficits and encompasses restricted, repetitive behavioral, interest, or activity patterns [1]. However, clinicians and researchers have reported motor deficits in children with ASD in the early days [2,3]. Robust meta-analysis has revealed that motor deficits are a potential core symptom of ASD [4], and the prevalence of motor deficits in ASD is well-known. Children with ASD and developmental coordination disorder (DCD) generally overlapped [5–7].

Motor deficits are characterized by clumsiness and lack of coordination in children with ASD [8] and are divided into fine and gross motor deficits. The gross motor is based on balance ability kept by integrating three information on visual, vestibular, and somatosensory inputs. Of these three inputs, the visual input is dominant for balance to maintain posture [9]. Adults with ASD do not use visual inputs [10] and rely on the somatosensory input to control posture [11]. Children with ASD are also less dominant in vision to keep posture [11] due to declined motion perception in ASD. Gepner *et al.* (1995) reported the motion perception abnormality in children with ASD for the first time [12], and the visual dorsal pathway deficit in children with ASD could be the source of abnormality [13]. Meta-analysis of adults and children with ASD indicated that the mid-temporal (MT/V5) area in the dorsal visual pathway was declined in ASD [14]. MT/V5 is associated with motion perception and declined MT/V5 is suggested to result in motion perception abnormality.

The MT/V5 was electrophysiologically investigated in children with ASD by an event-related potential (ERP) [15], which was analyzed using an electroencephalogram (EEG) recorded from the scalp surface. ERP represents transient changes in the brain's electrical activity in response to a stimulus or an event. In ERP studies, researchers have gained insights into perceptual and cognitive functions [16,17]. The early component of ERP reflects basic sensory processing, whereas the late component reflects higher perceptual and cognitive processing. The ERP after 200 ms is included in the late component [18]. The N200 is a negative component at approximately 200 ms. N200 component induced by a visual coherent motion task in MT/V5 reflects the global motion perception [15]. The motor perception abnormality is associated with a motor deficit and causes motor deficiencies in children with DCD [19,20]. They exhibit a declined right parietal region and indicate that the MT/V5 dysfunction is related to the gross motor deficit.

The motor skill impairment is also correlated with social skill impairments in children with ASD [21]. However, to date, the relationship between motor skills, social skills, and motion perception was not clarified. We hypothesized that the motor skills have effects on the social skills and motion perception. Our finding

was unexpected because not only the motor skill deficit but also intact motor skill modulated the relationship between social skill and motion perception in children with ASD. It clarified that intact motor skills could predict the relationship between social skills and motion perception. In other words, the behavioral test pattern for motor skills may estimate the relationship between social skills and motion perception in children with ASD.

2. Subjects and methods

2.1. Subjects

Five children with typical development (TD) (10 years \pm 5 months, 7 years and 9 months to 12 years and 2 months, 2 boys and 3 girls) and twelve children with ASD (11 years \pm 7 months, 5 years 6 months to 16 years and 9 months, 10 boys and 2 girls) (Table 1) participated in this study. Children with ASD were diagnosed with pervasive developmental disorder by an experienced pediatric neurologist concerning the Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition (DSM-IV) criteria because our study was conducted before the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-V) was released. We used the smallest number of children with TD because our study was a pilot one. With the small number of typically developed children and the wide age range of children with ASD, we did not determine that they were completely age-matched; however, with some help, no statistical difference was observed between them. We described it in the Limitation section. Furthermore, more boys were included than girls in the ASD group. We tested the handedness of subjects using Edinburgh's handedness inventory. Four children with TD were right-handed and one was left-handed. Then, children with ASD were all right-handed.

None of the subjects received any medications and suffered from any neurophysiological or neuropsychiatric disease. All had normal eyesight. Raven's colored progressive matrices were used for children with TD, and Wechsler Intelligence Scale for Children Fourth (WISC-IV) was used for children with ASD to examine intellectual capacity. The total Raven's colored progressive matrix scores were above the cut-off value [22] in all children with TD, and the full score of WISC-IV was higher than the cut-off value in all children with ASD. All subjects had sufficient intellectual capacity to perform our task. This study was approved by the ethics committee of Teikyo University (protocol 14-025-2) and the National Center of Neurology and Psychiatry (protocol A2012-007). The study was performed following the Declaration of Helsinki. All subjects were informed in detail regarding the aim and experimental procedures in the study. Their written informed assents

Table 1
Subjects lists of ASD.

ASD subject	s1	s2	s3	s4	s5	s6	s7	s8	s9	s10	s11	s12
Age	5y1m	6y0m	8y3m	9y11m	10y7m	10y11m	11y3m	11y11m	12y9m	13y10m	14y3m	16y9m
Sex	boy	boy	girl	boy	boy	boy	boy	boy	boy	boy	girl	boy
WISC-IV(FSIQ)	98	129	82	105	92	75	96	109	87	97	107	93
SRS total	89***	73**	84***	51	83***	64*	88***	72**	63*	92***	71**	94***
DCDQ total	30#	41#	26#	47#	32#	47#	28#	44#	55#	37#	46#	19#

It includes age, sex, diagnose, full IQ (WISC-IV), total T score of SRS and total row score of DCDQ.

s1: subject1, ASD: Autism Spectrum Disorder, WISC: Wechsler Intelligence Scale for Children, SRS: Social Responsiveness Scale, DCDQ: Developmental Coordination Disorder Questionnaire, DCD: Developmental Coordination Disorder, PDD: Pervasive Developmental Disorder.

***: severe risk, **: mid risk, *: mild risk of ASD, #indication or suspected DCD.

were obtained. The written informed permissions were also obtained by at least one parent after being informed about the study aim and protocol.

2.2. Psychiatric tests

The social responsiveness scale (SRS) was used to assess the ASD severity. Developmental Coordination Disorder Questionnaire (DCDQ) was used to examine motor skills and estimate DCD. Both tests were questionnaires answered by parents. Movement Assessment Battery for Children Second Edition (MABC-2) was used to analyze motor skills. SRS, DCDQ, and MABC-2 were tested in the children with ASD. The Japanese versions of SRS [23] and DCDQ [24–26] were applied. The Japanese DCDQ was a useful tool and has been well used. We translated MABC-2 from English to Japanese. Five examiners verified the precision and reliability of translated instructions before conducting the study. We confirmed the applicability of the Japanese version of MABC-2 [27]. T-score of SRS, a total raw score of DCDQ, and a standard score of MABC-2 were recorded in the children with ASD. The Japanese versions of SRS, DCDQ, and MABC-2 were not standardized in Japan. We used the cut-off of the English version for SRS, DCDQ [28], and MABC-2.

2.3. Experimental procedure

2.3.1. Visual stimuli

The visual motion stimuli were presented on a liquid crystal monitor. The stimulus included five phases as follows: (1) the fixation phase of 500 ms, (2) the static phase of 500 ms, (3) the random motion phase of 500 ms, (4) the coherent motion phase of 250 ms, and (5) the black background phase of 4000–4500 ms (Fig. 1). Furthermore, the stimulus onset asynchrony was 5750–6250 ms. In the fixation phase, a white cross was center positioned on a black background, whereas in the static, random, and coherent motion phases, 500 white dots were presented at the vertical 5 deg × horizontal 5 deg square, the center positioned on a black background. Each white dot is comprised

of 5 pixels. The monitor was vertical 23 degree × horizontal 33 degree, and the viewing distance between the subjects and the monitor was 50 cm. The dot speed and lifetime of dots were 5 degrees/s and unlimited, respectively [29]. White dots were made by the MATLAB (Matrix Laboratory) software (Mathworks, Inc., version R2012a). The stimuli were generated and run using the E-Prime2.0 software (Psychology Software Tools, Inc.).

The random motion phase was presented following the coherent motion phase to distinguish the responses between the general motion onset and coherent motion onsets. A longer random motion phase was used rather than a coherent motion phase for two reasons: (1) to finish the response evoked by the general motion onset before the coherent motion onset and (2) to avoid motion adaptation. Motion adaptation caused a lower amplitude of the evoked response. Furthermore, to evoke a larger amplitude of the N200 response, a short duty cycle has been used [30]. A duty cycle is a rate of (coherent motion time)/(total time) [30]. A short duty cycle means that the coherent motion phase is shorter than that of the total phases. About 10% of the duty cycle was applied in previous studies [30], and 5% of the duty cycle was used in the present study.

In the coherent motion phase, some white dots moved upward or downward vertically. The subjects sat on a comfortable chair and watched the motion stimuli. They put their right index finger on the number “8” of the numeric keypad and then put their left index finger on the number “2” of the numeric keypad beforehand. When they knew the direction of the coherent motion, they pressed the number “8” or “2” immediately. The coherent motion phase had two coherent conditions: 80% and 100%. An easy condition was used so that all subjects could conduct all tasks. In 80% of coherent conditions, 80% of white dots vertically moved upward or downward and 20% of white dots moved in random directions. In 100% coherent conditions, all-white dots moved upward or downward vertically. There were four conditions: upward direction in 80%, downward direction in 80%, upward direction in 100%, and downward direction in 100%. Subjects under-

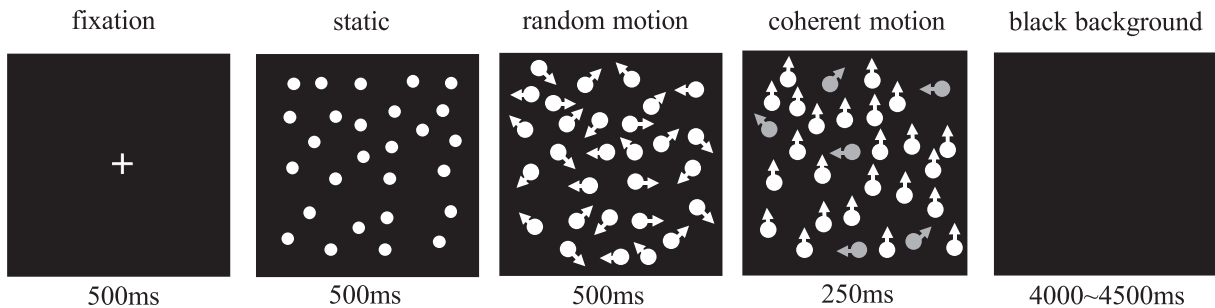


Fig. 1. Schematic illustration of visual motion stimulus and duration of each phase, which was presented at vertical 5 degree and horizontal 5 degree in the center of the monitor.

went four sessions and took a rest for several minutes between each session. Each session included 20 stimuli as follows: 5 stimuli of upward directions in 80%, 5 stimuli of downward directions in 80%, 5 stimuli of upward directions in 100%, and 5 stimuli of downward directions in 100%. In each session, all stimuli were randomly presented. The total number for each respective condition was 20. One session lasted approximately 2 (115–125) min.

2.3.2. EEG recording

Scalp EEGs and electrooculograms (EOGs) were recorded using the Active Two System (Biosemi, Inc., Amsterdam). All electrodes were Ag-AgCl and active electrodes. A total of 32 electrodes were placed on the scalp for EEGs (Fp1, Fpz, F7, F3, FC3, CP3, T7, C3, PO7, POz, P7, P3, Pz, PO3, O1, Oz, O2, PO4, P4, P8, PO8, CP4, C4, T8, CPz, FC4, F4, F8, FCz, Fp2, Fz, and Cz) using the 10–10 system. Two electrodes were placed at the lower and lateral sides of the left eye for EOGs. Impedances were maintained at <2 k Ω for each electrode. EEGs were recorded with a sampling rate of 2048 Hz/electrode.

2.4. Data analysis

2.4.1. EEG and ERP analyses

The EEG and ERP were analyzed using the EEGLAB application [31] on the MATLAB (Mathworks Inc. R2012a) application. In the off-line mode, EEGs and EOGs were re-referenced to a common average of 32 electrode EEGs. Data were down-sampled at 500 Hz and were bandpass-filtered at 1–30 Hz. Independent component analysis and a second-order blind identification algorithm were used to remove artifacts [32] on the EEGLAB toolbox. Trials were averaged to obtain the N200 component. The N200 was used to test the motion perception in this study. Trials on subjects who answered in the correct direction were used to calculate the average values. Trials of upward and downward directions in 80% of conditions were averaged, and trials of upward and downward directions in 100% of conditions were also averaged. The baseline

was set to 100 ms before the coherent motion phase for averaging. The N200 component was identified as a negative peak amplitude in the 150–300 ms range after the coherent motion onset. The peak amplitudes and latencies of the N200 component were analyzed. A two-way analysis of variance was performed about the peak amplitudes and latencies in children with TD and ASD at 80% and 100% condition.

2.4.2. Statistical analysis

A hierarchical multiple regression analysis was conducted to examine the modulation effects of MABC-2 on the relationship between SRS and N200 latency [33] using the IBM SPSS Statics 22.0 software. The data of the children with ASD only were used for the undertaking of the hierarchical multiple regression analysis. The dependent variable (outcome) was the N200 latency at 100% condition, whereas independent variables (predictor) were subset of MABC-2 and SRS, and combined MABC-2 and SRS subsets. MABC-2 had three subsets: “manual dexterity,” “aiming and catching,” and “balance.” SRS had five subsets: “social awareness,” “social cognition,” “social communication,” “social motivation,” and “autistic mannerisms.” Before conducting the hierarchical multiple regression analysis, independent variables were centered to reduce multicollinearity between the main effects and interaction terms [34]. During the first step of the model, the centered SRS subset served as a predictor. In the second step, the SRS and MABC-2 centered subsets served as predictors. In the third step, a centered subset of SRS and MABC-2 centered subsets and the interaction term of combined MABC-2 and SRS subset served as predictors. At each step of the model, when the F value to the ΔR^2 between steps was significant, the predictor was significant. After ΔR^2 between steps was significant, a simple slope analysis [35] was performed to examine the sub-effect. For simple slope analysis, multiple regression analysis was conducted. The outcome was N200 latency at 100% condition. Predictors were the subset of SRS at high (+1SD) and low (-1SD) level, and subset of MABC-2 at high (+1SD) and low (-1SD) level, and interaction terms combining MABC-2 and SRS subset.

3. Results

3.1. Psychiatric tests and behaviors

SRS showed that six children had a severe risk of ASD, three had a moderate risk, and two had a mild risk (Table 1). Subject #4 showed normal SRS. DCDQ revealed that all ASD showed indications or were suspected of DCD, showing variations between them. DCDQ has three subsets: “control during movement,” “fine motor/handwriting,” and “general coordination.” The average ratio of each score for each subset was 54 ± 16 , 57 ± 20 , and $30\% \pm 11\%$. Paired *t*-test showed that general coordination was significantly lower when comparing the “control during movement” and “fine motor/handwriting” ($p < .001$). MABC-2 revealed that three children with ASD showed a probable risk or severity of “manual dexterity,” and six children with ASD showed a probable risk or severity at “aiming and catching.” Meanwhile, all children with ASD were good at “balance.” The reaction time and accuracy of the random dot kinematogram (RDK) task showed no differences between children with TD and ASD. No differences were observed between the two dominant hands. They also showed no differences between 80% and 100% conditions.

3.2. ERP

The N200 component was evoked at the right parietotemporal area (P8, MT/V5) in 80% and 100% conditions in both children with TD and ASD. However, it was not constantly evoked in the left hemisphere (P7). The total averaged amplitude was mapped on a head model, and the peak latency is located in P8 (Fig. 2). The N200 amplitude was -4.5 ± 3.1 ms and -4.2 ± 2.4 ms in 80% and 100% conditions of children with TD, and -3.7 ± 2.1 ms and -4.2 ± 2.9 ms in 80% and 100% conditions of children with ASD. The amplitude showed no differences between children with TD and ASD, showing no differences between 80% and 100% conditions (two-way analysis of variance, $F(1,15) = 0.087$, $p = .772$). The N200 latency was significantly more delayed in children with ASD than in those with TD (Fig. 3) in 80% and 100% conditions (two-way analysis of variance, $F(1,15) = 6.14$, $p < .05$). The N200 latency was 230.8 ± 42.9 ms and 228.8 ± 52.7 ms in 80% and 100% conditions of children with TD, and 299.8 ± 54.8 ms and 299.8 ± 67.1 ms in 80% and 100% conditions of children with ASD.

3.3. Psychiatric and ERP data

Hierarchical multiple regression analyses revealed that no main effects were found at both steps 1 and 2. Significant two-way interactions were found in step 3

(Table 2). The significant ΔR^2 was found in step 3 when the following interaction was entered: (1) SRS (social awareness) \times MABC-2 (balance) ($\Delta R^2 = 0.42$, $F(1,8) = 7.36$, $p < .05$), (2) SRS (social cognition) \times MABC-2 (balance) ($\Delta R^2 = 0.40$, $F(1,8) = 5.95$, $p < .05$), and (3) SRS (autistic mannerisms) \times MABC-2 (balance) ($\Delta R^2 = 0.45$, $F(1,8) = 7.10$, $p < .05$) (Table 2).

The simple slope analyses revealed three significant negative associations between the N200 latency and SRS when MABC-2 (balance) was high (Fig. 4): (1) Significant negative associations were observed between the N200 latency and SRS (social awareness) when the MABC-2 (balance) was high ($B = -4.40$, $p < .05$). However, no significant association was observed when MABC-2 (balance) was low ($B = 3.17$, $p = .17$). (2) Significant negative associations were noted between the N200 latency and SRS (social cognition) when the MABC-2 (balance) was high ($B = -4.67$, $p < .05$). However, no significant association was noted when the MABC-2 (balance) was low ($B = 1.65$, $p = .29$). (3) Furthermore, significant negative associations were observed between the N200 latency and SRS (autistic mannerisms) when the MABC-2 (balance) was high ($B = -4.48$, $p < .05$). However, no significant association was observed when MABC-2 (balance) was low ($B = 2.24$, $p = .16$).

4. Discussion

4.1. ASD with motor disability

Results of DCDQ revealed that all children with ASD displayed motor disabilities in this study. The European Academy for Childhood Disability recommended using DCDQ for criteria B of DCD [36]. An overlap between ASD and DCD is observed in children [5,7]. We estimated that children with ASD might have DCD, although they could not be determined retrospectively. Motor difficulties in children with ASD start at a preschool age and continue through adolescence [21]. The DCDQ score indicated that children with ASD in this study, especially, had a deficit in a subset of “general coordination,” which tested the following parameters: “like sports,” “learning new skills,” “quick and competent,” “bull in a shop,” and “does not fatigue.” Meanwhile, MABC-2 revealed that children with ASD had an intact “balance” subset that tested the static and dynamic balance abilities, such as “balance on Board,” “walking heel to toe forward/backward,” and “hopping on mats/zig-zag hopping.” These results suggested that the motor deficiency was mild, and the inconsistency implied that children with ASD might not apply the intact balance ability to the general coordinated movement. We were the first to report the chil-

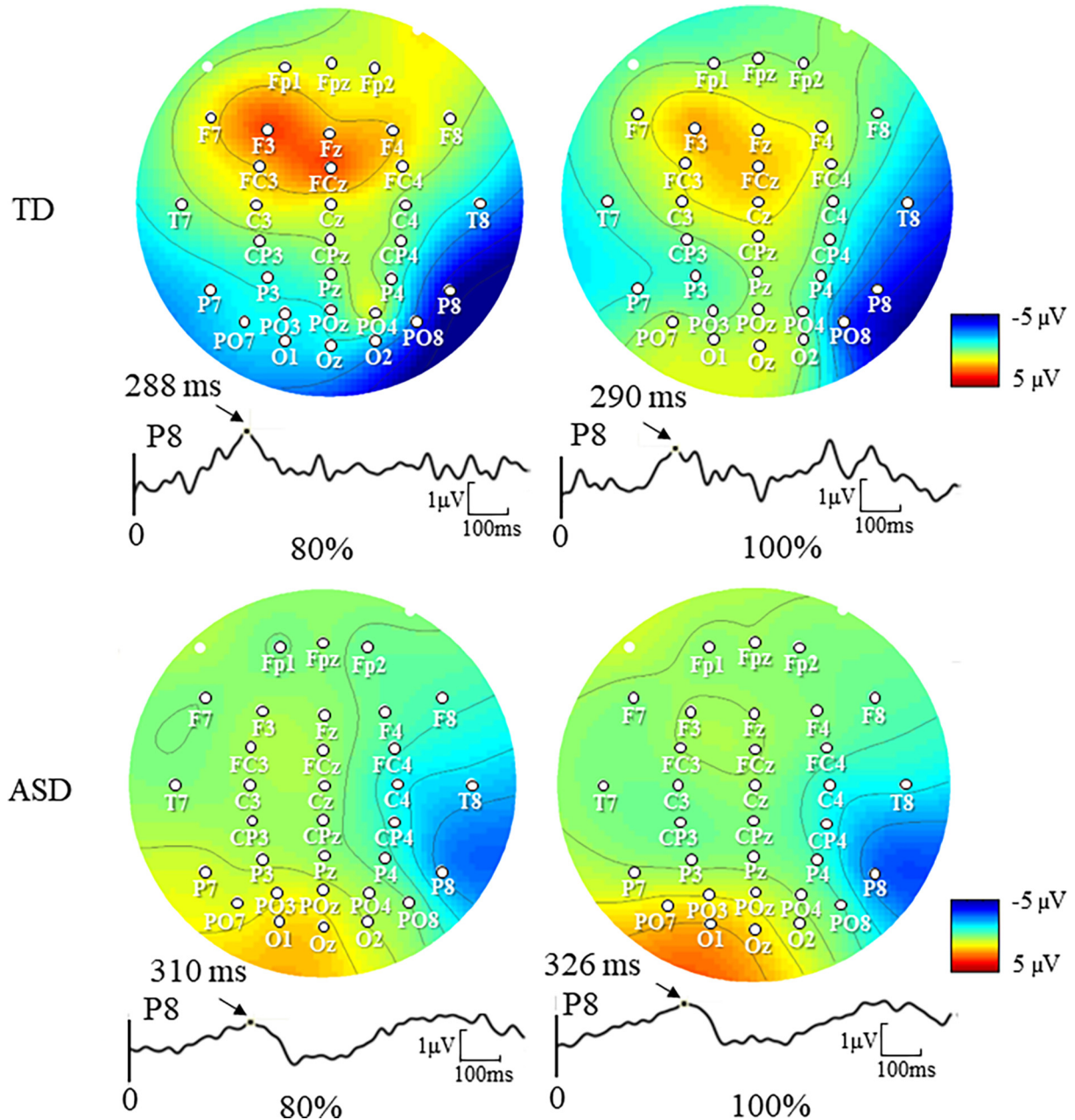


Fig. 2. A map of the amplitude of the grand averaged N200 component and the waveforms located in P8 in children with TD and ASD. The N200 at the right parietotemporal area (P8) was evoked in 80% and 100% stimulus conditions. TD: typical development, ASD: autism spectrum disorder.

dren with ASD who had motor disability but were intact in balance ability.

Motor skill deficits in children with ASD have been well-known. The role of motor skills is important in social communication [37]. Motor difficulty in children reduces peer participation during play and sports and reduces opportunities to explore and interact with the environment. It also hampers their social interaction and communication with others [37], which in turn prevents cognitive and social developments [4,37]. The degree of motor skills can provide the social skill effects.

4.2. N200 component

The N200 component was consistently evoked at the right parietotemporal area (P8) consisting of MT/V5 [38] in this study. The MT/V5 processes motion segregation, one of the higher motion perceptions applied to determine global motion patterns with a random noise [14]. Several studies have reported that children with ASD exhibit a dorsal visual pathway deficit [13,14] where MT/V5 is placed, and they have motion perception abnormality. Children with ASD show reduced N200 amplitude in the dorsal visual pathway compared to the

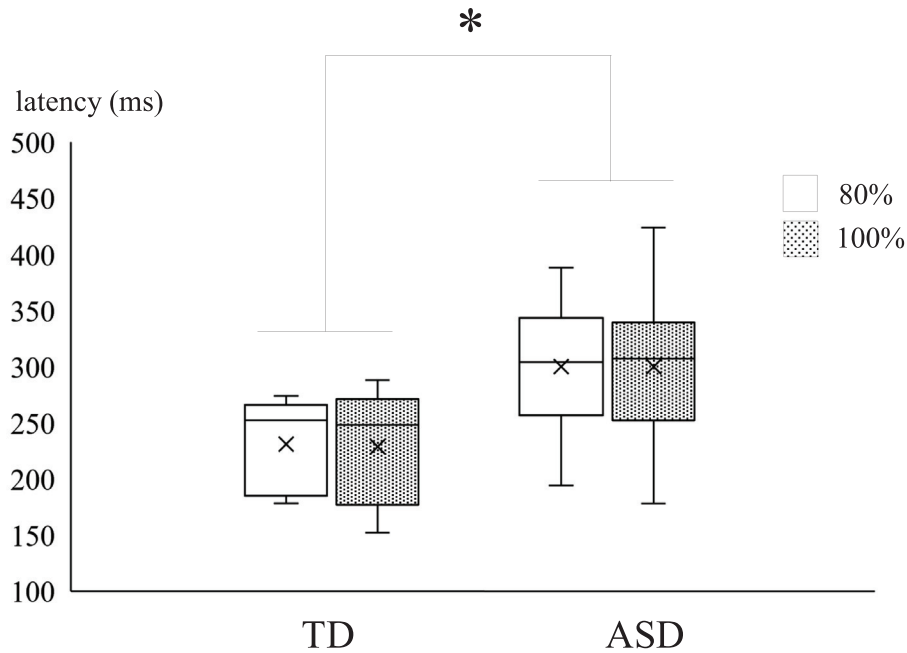


Fig. 3. Box-and-whisker plot of the N200 latency at P8 in children with TD and ASD at 80% and 100% stimulus conditions. The lower whisker is minimum, and the upper whisker is maximum, × is average, the horizontal line in the box is median, the lower hem of the box is the first quartile (25 percentile), and the upper hem of the box is the third quartile (75 percentiles). A two-way analysis of variance was performed (* $p < 0.05$). The N200 latency of ASD was significantly delayed rather than that of TD. TD: typical development, ASD: autism spectrum disorder.

Table 2
Hierarchical multiple regression analysis among three factors.

(a)	Variable	Step1		Step2		Step3	
		<i>b</i>	<i>bSE</i>	<i>b</i>	<i>bSE</i>	<i>b</i>	<i>bSE</i>
	SRS (social awareness)	-1.57	1.49	-1.55	1.56	-0.61	1.24
	MABC2 (balance)			-3.62	8.65	-2.33	6.64
	SRS (social awareness) × MABC2 (balance)					-1.56*	0.57
	ΔR^2	0.10		0.02		0.42	
	Adj ΔR^2	0.01		-0.08		0.37	
(b)	Variable	Step1		Step2		Step3	
		<i>b</i>	<i>bSE</i>	<i>b</i>	<i>bSE</i>	<i>b</i>	<i>bSE</i>
	SRS (social cognition)	-0.81	1.21	-0.91	1.27	-1.51	1.05
	MABC2 (balance)			-4.82	8.96	-4.14	7.20
	SRS (social cognition) × MABC2 (balance)					-1.30*	0.53
	ΔR^2	0.04		0.03		0.40	
	Adj ΔR^2	-0.05		-0.13		0.27	
(c)	Variable	Step1		Step2		Step3	
		<i>b</i>	<i>bSE</i>	<i>b</i>	<i>bSE</i>	<i>b</i>	<i>bSE</i>
	SRS (autistic mannerisms)	-0.65	1.17	-0.60	1.23	-1.12	0.97
	MABC2 (balance)			-3.45	9.04	0.60	7.14
	SRS (autistic mannerisms) × MABC2 (balance)					-1.38*	0.52
	ΔR^2	0.03		0.02		0.45	
	Adj ΔR^2	-0.07		-0.17		0.30	

The dependent variable was the N200 latency. Independent variables were the subset of SRS (i.e., social awareness, social cognition, and autistic mannerisms), the subset of MABC-2 (balance), and the interaction of SRS × MABC-2. There was a significant interaction effect (SRS × MABC-2). The subset of SRS was social awareness (a), social cognition (b), and autistic mannerisms (c). * $p < .05$.

SRS: Social Responsiveness Scale. MABC-2: Movement Assessment Battery for Children Second Edition.

ΔR^2 : delta determination coefficient, Adj ΔR^2 : adjusted delta determination coefficient, *b*: estimate, *bSE*: standard error of estimate.

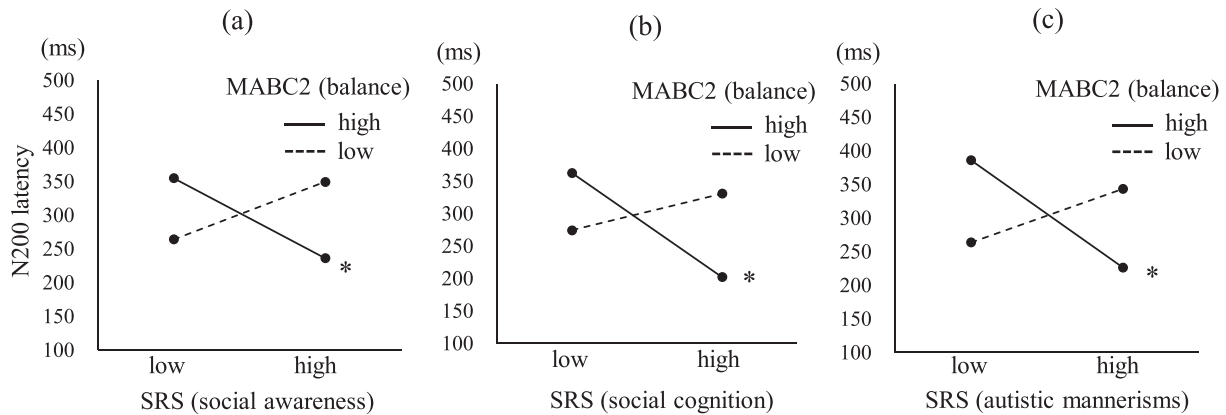


Fig. 4. Interaction effects (SRS \times MABC-2) predicting the N200 latency ($B = -1.56$, $p < .05$). Subset of SRS was at high (+1SD) or low (-1SD) level, and subset of MABC-2 was at high (+1SD) or low (-1SD) level. Simple slope analyses revealed that the N200 latency was significantly negatively associated with SRS among subjects with a relatively high MABC-2 (social awareness: $B = -4.40$, $*p < .05$, social cognition: $B = -4.67$, $*p < .05$, autistic mannerisms: $B = -4.48$, $*p < .05$). No significant association was observed between the N200 latency and SRS among subjects with a relatively low MABC-2.

control [15], and the findings provide support for dorsal visual pathway deficiency in ASD. The N200 latency is associated with stimulus difficulty. The N200 induced by RDK shows shortened latency when the number of moving elements increases [39], and the N200 latency is shortened when the task is easier to detect optic flow coherence [40]. These findings mean that the N200 latency was delayed in difficult tasks and in times of the motion perception process. In this study, the N200 amplitude showed no differences, but the N200 latency was delayed in children with ASD. As the balance ability was speculated to be intact and the motor deficit was mild, the deficiency in MT/V5 reflects on delayed N200 latency. N200 is a sensitive index of the visual dorsal pathway deficiency than behavior [41]. The N200 latency was delayed though the response time in children with ASD showed no differences compared with children with TD. We could detect the motion perception deficit as delayed N200 latency.

4.3. Modulation effects of balance ability

Intact balance ability modulated the relationship between social skills (social awareness and cognition) and N200 latency in this study, an unexpected finding. Several researchers have reported that the motor deficit in children with ASD is strongly correlated with ASD severity [42], and then, the modulation effects of intact motor skills on social skills and motion perception might appear to be odd. Balance ability is essential for gross motor movement. In early childhood, gross motor actions (such as lying to sitting upright, crawling, and walking) are associated with social referencing and interaction [43]. An individual with ASD displays a significant relationship between poor motor skills and social cognitive difficulties [44]; hence, motor skills can help predict the social function of ASD [45]. Based on our

literature review, this is the first report indicating that not only abnormal but also intact gross motor can modulate the relationship between social skills and motion perception.

Within high balance ability, in a more impaired social skill, the N200 latency was shortened. The shortened ERP in individuals with ASD has been recorded by visual stimuli [16,46] and it was interpreted as the impaired processing in low-level visual processing [16]. Therefore, the present study is the first report of the shortened ERP in higher visual processing in children with ASD. The shortened ERP suggested neural overconnectivity and skipped motor integration processes. Some studies have suggested the abnormal neural connection in individuals with ASD. An overconnected neural system with noise and crosstalk causes abnormal top-down attentional control, including deficits in the information integration processes [47]. Furthermore, an increased localized white matter volume can cause structural and functional abnormalities in neural connections [48]. As the brain grows, short-range association fibers increase, which works as intracortical connections because modules with short-range interconnections reduce the conduction time [49]. A functional MRI study revealed that posterior region overconnectivity is associated with higher ASD symptom severity (i.e., social reciprocity and repetitive behavior) [50]. Further studies are needed to clarify these mechanisms in detail.

5. Limitation

This study was conducted as a pilot one, with a small number of typically developed children, and a wide age range in children with ASD. We did not determine that subjects are completely age-matched though there were

no statistical significance between them. Children with ASD were diagnosed using the DSM-IV scale and were not determined whether they had DCD; however, we believed that the subjects might have DCD. We used the Japanese version of MABC-2 translated from English to Japanese by us. The Japanese versions of SRS, DCDQ, and MABC-2 were not standardized in Japan; thus, the cut-off of English versions for SRS, DCDQ, and MABC2 was used. The further studies were needed to precisely confirm that the cut-off of English-version could be applied to Japanese children.

6. Conclusions

The intact motor skills might modulate the relationship between social skills and the N200 latency in children with ASD. With high motor skills, when the social skills were worse, the N200 latency was probably shortened. Intact motor skills can predict the relationship between social skills and motion perception.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Author contributions

Kotoe Sakihara was responsible for the organization and coordination of the trial, and was the chief investigator. Kotoe Sakihara, Yosuke Kita, Kota Suzuki and Masumi Inagaki were responsible for the data analysis. Kotoe Sakihara developed the trial design. All authors contributed to the management or administration of the trial. All authors contributed to the writing of the final manuscript. All authors meet the ICMJE authorship criteria.

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