kana sentences on the Token Test by children with specific reading disorders and by normal children, in order to identify characteristics of fundamental reading deficits. They found that the following parameters significantly discriminated children with specific reading disorders from normal children: total time taken to read sentences, frequency of overall errors, total recovery time after disruptions, and frequency of disruption. In their study, the comparison group was second- through fourth-grade normal children without reading disabilities. Further studies on the typical standard scores of reading performance in each grade of elementary school are needed to elucidate the problems of children with specific reading disorders in comparison to those with a typical normal level of reading development.

Zoccolotti, De Luca, Di Pace, Gasperini, Judica, and Spinelli (2005) examined vocal reaction times to different word lengths among Italian normal children without disorders in the first, second, and third grades of elementary school, and compared them to the vocal reaction times of third-grade Italian children who were dyslexic. They found that vocal reaction times increased as the number of letters in the words increased. They also found that the size of the increase in reaction time decreased remarkably from the first to the third graders. They indicated that the effect of word length on the third-grade children who were dyslexic was very similar to that observed in the first-grade children.

The Dual Route Cascaded model (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001) of the effect of word length on reading has been confirmed. In that model, two reading processes are distinguished: the lexical and the non-lexical, both of which are activated at the same time. In the non-lexical process, the graphemes of a word are decoded one by one, in a serial manner. In the lexical process, all the letters of a word are activated in parallel, and these letters enable a word entry into the orthographic lexicon. This word entry, in turn, activates the corresponding word entry in the phonological lexicon that produces the word's phonemes (Coltheart et al., 2001; Martens & de Jong, 2006). With the development of reading skill, an increasing number of words become represented in the orthographic lexicon. For such words, the lexical process can then be used (Jackson & Coltheart, 2001). Zoccolotti et al. (2005) have discussed their results in relation to the Dual Route Cascaded model; they found that Italian third-grade children who were dyslexic failed to make the transition from a non-lexical to a lexical process.

In a regular orthographic language, such as Italian, German, or Dutch, learning to read starts with a rather brief phase of alphabetic decoding, after which children rapidly start to develop a lexical process (Zoccolotti et al., 2005). As Japanese kana syllables have a shallow grapheme-phoneme correspondence, it is expected that Japanese children will usually start to develop that ability in the early grades of elementary school, whereas Japanese children with specific reading disorders, like the Italian children who were dyslexic, have difficulty in making the transition from a non-lexical to a lexical process.

Based on the above, the present study aimed to investigate properties of the lexical process of Japanese children with specific reading disorders in relation to the typical development of children without specific reading disorders, by measuring vocal reaction times to meaningful kana words compared to pseudo kana words. We selected children with specific reading disabilities using four parameters that have been found to be effective in identifying children with specific reading disorders (Kasai et al., 2006). The procedure involved briefly presenting a one- to three-syllable kana word. Effects of the meaningfulness of the words were examined.

Method

Participants

Participants in the present study were children with LD ($N=42$), children without LD ($N=163$), and adults ($N=10$). Children with LD were operationally defined as follows: (1) those with scores of more than 85 on any scale of the WISC-III, FIQ, PIQ, or VIQ and indices of grouping factors, (2) FIQ of WISC-III greater than 70, (3) scores on a Japanese-language achievement test two years below the child's registered grade, showing an incomplete level of attainment (a test at one grade below registered grade for children in the second grade), (4) no evidence or medical history of brain disorder, and (5) a report by their teacher that the child's delay of achievement in reading Japanese exceeded one year for elementary school students in the second and third grade, or two years for those in the fourth, fifth, and sixth grade.

Participants in the present study were recruited as follows. Children with LD ($N=52$) who received training in three elementary school resource classrooms, and children with LD ($N=13$) who attended teaching sessions held in a university were asked to take a Japanese-language achievement test (Kyoken-shiki Standardized Achievement Test CRT-II of the Japanese language; Tatsuno & Kitao, 2005). The children with LD took a test at two grades below their class level, or one year below for children in the second grade. FIQs of WISC-III of all children were greater than 70. After evaluating the achievement test scores, 42 children who showed an incomplete attainment of a lower grade level in Japanese were selected as participants for the present study. The "reading words" sub-test of the K-ABC was administered in order to assess the children's reading skills.

The developmental standard of performance by the normal children without LD in reading kana sentences was then measured. Developmental standards included four parameters: frequency of overall errors, total recovery time after disruptions, and frequency of disruption, in addition to the total time taken to read sentences on the Token Test (Kasai et al., 2006). On the basis of the developmental standards, those children with LD who had specific reading disorders (SRD) and those without specific reading disorders (NSRD) were identified. Of those children, nineteen whose scores were greater than mean +2SD values in all the developmental standards made up the group of children with specific reading disorders. The other 23 children were placed in the group of children without specific reading disorders. All participants were able to read and write individual kana syllables. Their classroom teacher reported that they had difficulty writing words in kanji (Chinese characters). In the

TABLE 1 Mean Chronological Age (CA), SD, and Number of Children (N) Without Learning Disabilities for Participants in Each Grade of Elementary School and Adults

Group	*CA* (year : months)	*SD* (months)	*N*
Grade 1	7 : 00	3.53	31
Grade 2	8 : 00	3.30	30
Grade 3	8 : 11	3.86	30
Grade 4	10 : 00	2.92	28
Grade 5	11 : 00	3.00	26
Grade 6	12 : 10	2.94	18
Adults	21 : 10	19.69	10

present study, none of the children had difficulty maintaining attention during the reading task.

The children who participated in the standardization of the task of reading words in kana included 163 children without LD (76 boys, 87 girls). Teachers of the children without LD reported that those children had no delay in achievement in either Japanese language or arithmetic. 42 children with LD (33 boys and 9 girls) were in regular elementary school classrooms (second grade, 4 children; third grade, 14; fourth grade, 8; fifth grade, 9; sixth grade, 7).

In order to elucidate the period of developmental change in reading, university students (5 males, 5 females) were included as participants in the study.

The means and SDs of the CAs of the participants in each grade are shown in Table 1.

All participants were informed of the aim and design of this study, and permission for the children's participation was obtained from their parents, and for the university students, from themselves.

Materials and Tasks

Reading kana sentences. Reading levels were examined using three kana sentences from the Token Test, the same sentences that were used in Kasai et al. (2006). The participants were instructed to read a sentence that appeared on a computer monitor. Their voice was recorded by a digital audio recorder. Total reading times were measured. Reading errors were classified according to the criteria for error types used by Kasai et al. (2006), i.e., slips, omissions, stutters, mistakes in reading particles, repetitions, word mistakes, arbitrary readings, uncorrected errors, and reading disruptions.

Reading single words. One-, two-, and three-syllable words were used (15 one-syllable words, and 30 two- and three-syllable words). The two- and three-syllable words consisted of 15 words with meaning and 15 pseudo words of corresponding length. The words used are shown in Appendix 1.

TABLE 2 Mean Scores on WISC-III and K-ABC Scores on the "Reading Words" Subtest

		SRD	NSRD	*t*	*df*	
WISC-III	VIQ	89.31 (12.87)	91.52 (13.83)	−0.53	40	n.s
	PIQ	89.05 (17.55)	87.13 (14.06)	0.39	40	n.s
	FIQ	88.05 (12.96)	88.17 (11.54)	−0.3	40	n.s
Verbal Comprehension		90.89 (12.32)	92.83 (12.45)	−0.5	40	n.s
Perception Organization		92.05 (18.24)	88.39 (14.68)	0.72	40	n.s
Freedom from Distractivity		84.42 (16.22)	88.17 (13.16)	−0.8	40	n.s
Processing Speed		88.21 (14.47)	85.61 (10.76)	0.69	40	n.s
K-ABC Reading Words		72.89 (17.60)	101.26 (18.89)	−5.0	40	$p<.05$

Notes. SRD = LD children with specific reading disorders; NSRD = LD children without specific reading disorders.

The selection of words was based on Japanese word association lists (Umemoto, 1955; Chihara & Tsujimura, 1985). Meaningfulness values for the two-syllable words ranged from 220 to 229 for meaningful words, and 30 to 59 for pseudo words (Umemoto, 1955). Association values for the meaningful three-syllable words ranged from 4.25 to 5.00; those for pseudo words, from 1.00 to 2.00 (Chihara & Tsujimura, 1985).

Words were presented on a computer monitor after display of a fixation point (3000 ms) and a blank screen (1500 ms). The duration of word presentation was 140 ms (Higuchi, 2005). Each syllable was subtended 2.0 cm horizontally (1.0° visual angle at a distance of about 60 cm).

After the tester confirmed the participant's attention, the next fixation point was presented. One block of five stimuli was administered for practice and to confirm the participant's understanding of the instructions.

Experimental blocks of 15 words were used. Five word blocks were used, namely, one-syllable words, meaningful two- and three-syllable words, and two- and three-syllable pseudo words.

The participant's task was to read the words aloud as quickly as possible. Performance was recorded by a digital audio recorder. The vocal reaction time was measured for correctly read words by a voice data analyzing program.

Results

Information Processing Scores in Children With and Without Specific Reading Disorders

Table 2 shows the mean scores on the WISC-III and the K-ABC sub-test, "reading words", for participants in each group. The LD children with specific reading disorders had significantly lower scores on "reading words" than did the LD children without specific reading disorders ($t(40)=-5.0$, $p<.01$).

Performance on Reading Kana Sentences

The total time taken to read sentences is shown in Fig. 1. For normal children without LD, the total reading time means (bars) and 2SDs (lines) are displayed for each grade and for the university students. In Fig. 1, mean total reading time values are displayed for each child with a specific reading disorders (filled circles) and each child without a specific reading disorders (open circles). The mean reading times (and, in parentheses, SD) were 21.5 s (11.5) for the first grade students, 16.3 s (6.5) for second graders, 14.2 s (3.5) for third graders, 11.6 s (2.8) for fourth graders, 11.1 s (1.7) for fifth graders, and 11.0 s (1.3) for sixth graders.

Erroneous reading by the children with LD was examined, based on standardized values of error occurrence. The standardized values were calculated from the mean and SD of errors by the children without LD in the same grade as the children with LD. Fig. 2 shows the mean of the standardized values for each type of error. In comparison to the children without specific reading disorders, the children with specific reading disorders showed significantly greater standardized values for errors in particles (Fisher test, $p<.05$) and for disruption of reading (Fisher test, $p<.01$).

Performance When Reading Single Words

Figure 3 shows the mean vocal reaction times on the task of reading a single-word (see Appendix 2). The panels on the left side report the data for the performance when reading meaningful words; those on the right, that when reading pseudo words. For comparison, the vocal reaction time of one syllable is described. The

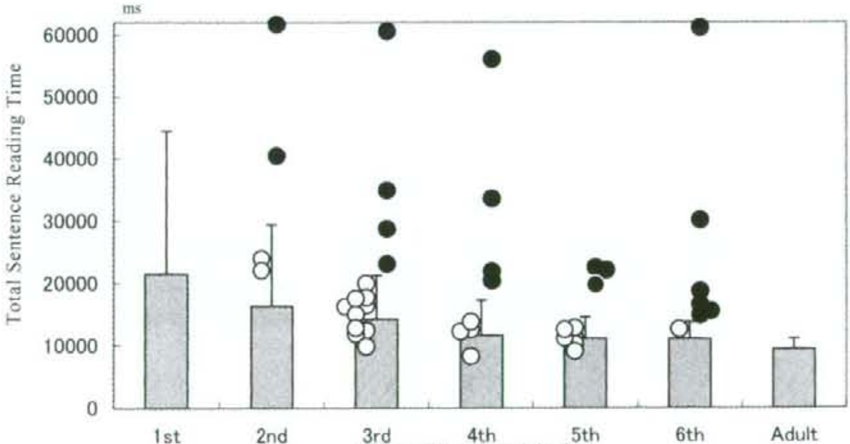

FIG. 1 Results of Kana Sentence Reading Task in Children With and Without LD

Notes. Bars indicate the means and lines, 2SD of total reading time in each group without LD. Filled circles indicate total reading time for each child with a specific reading disorders (SRD). Open circles indicate total reading time of each child without a specific reading disorders (NSRD).

Huynh-Feldt ε correction was used to evaluate the F ratios.

ANOVA on the data from reading meaningful words by the normal children without LD indicated that the main effects of grade ($F(5, 157)=9.45$, $p<.01$) and word length ($F(2, 314)=41.21$, $p<.01$) were statistically significant. The grade by word length interaction was also significant ($F(10, 314)=2.02$, $p<.05$, $\varepsilon=.79$).

ANOVA for of the data from reading pseudo words indicated that the main effects of grade ($F(5, 157)=8.27$, $p<.01$) and word length ($F(2, 314)=154.78$, $p<.01$) were significant. The grade by word length interaction was also significant ($F(10, 314)=2.31$, $p<.05$, $\varepsilon=.91$)

In order to evaluate the attainment of development of reading in the children without LD, the sixth graders' results were compared to the adults'. ANOVA indicated that the group by word length interaction for reading pseudo words was significant ($F(2, 52)=3.93$, $p<.05$, $\varepsilon=.74$), but that for reading meaningful words was not ($F(2, 52)=2.32$, *n.s.*).

ANOVA on the data from reading meaningful words by children with LD indicated that the main effects of word length ($F(2, 80)=11.51$, $p<.01$) and type of learning disability ($F(1, 40)=10.66$, $p<.01$) were significant. The word length by type of learning disability interaction was significant ($F(2, 80)=4.01$, $p<.05$, $\varepsilon=.62$). ANOVA on the data from reading pseudo words indicated that the main effects of word length ($F(2, 78)=39.9$, $p<.01$) and type of learning disability ($F(1, 39)=10.74$, $p<.01$) were significant. However, the word length by type of learning disability

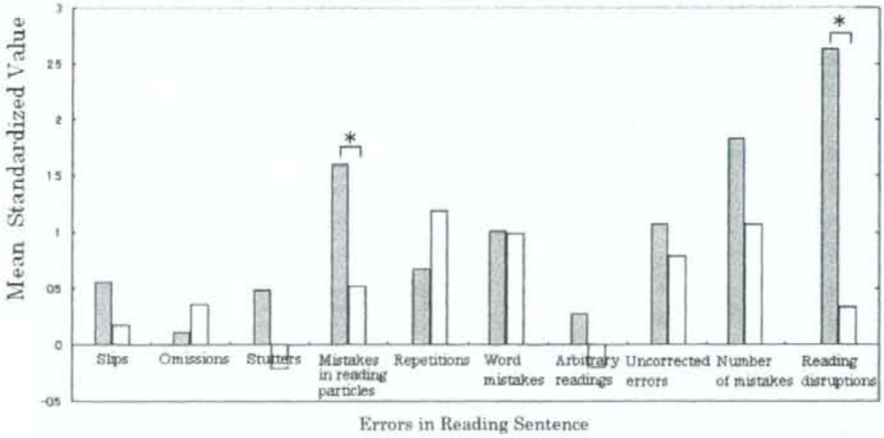

FIG. 2 Mean Standardized Occurrences of Each Type of Error in Children With and Without Specific Reading Disorders

Notes. Shaded bars indicate mean standardized occurrences of error in the children with specific reading disorders; open bars indicate the data for the children without specific reading disorders. Asterisks indicate that the standardized value is of the difference between the two groups of children was statistically significant by the Fisher test ($p<.05$).

interaction was not significant ($F(2, 78)=2.02$, *n.s.*).

The differences in vocal reaction times among words of different length are shown in Fig. 4. The open bars indicate the difference in reaction times between reading one-syllable and two-syllable words. The shaded bars indicate the difference for one-syllable and three-syllable words. The asterisks denote differences that were found to be significant by the Wilcoxon Test, using the Bonferoni inequality method.

Reaction times to meaningful words were differed significantly between one-syllable and two-syllable words in the first, second, and third grade participants. However, these differences were not significant in the fourth graders and above, indicating that the children in the fourth grade and above could read two-syllable words as quickly as one-syllable words.

Reaction times in all grades were significantly different between one-syllable words and three-syllable words. Regarding pseudo words, reaction times in all grades differed considerably between one-syllable words and two- or three-syllable words.

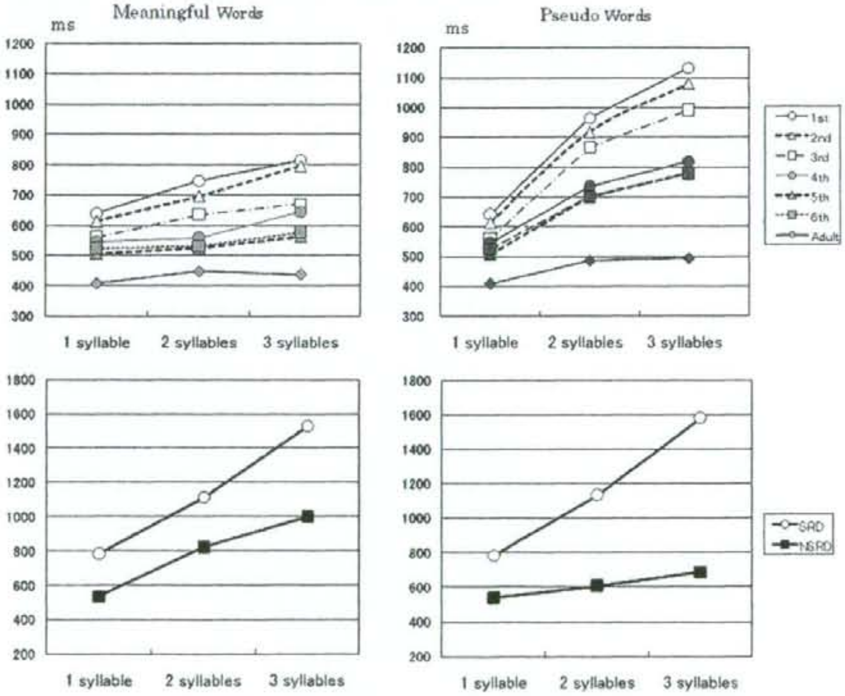

FIG. 3 Mean Vocal Reaction Times When Reading Single Words

Notes. Panels on the left side indicate performance when reading words with meaning. Panels on the right side indicate performance when reading pseudo words. Upper panels indicate the results from the adults and children without LD. Lower panels indicate the results from children with LD.

In order to assess changes in vocal reaction times across conditions in relation to the grade of each child with a learning disability, the differences in reaction times across conditions were compared with the mean $+1$SD of the child's grade. The results of these comparisons for each child are shown in Table 3.

Each line in Table 3 corresponds to one child. The filled circles indicate that the vocal reaction time for one-syllable words was greater than the mean $+1$SD of the child's grade, whereas the open circles indicate that it was less than or equal to that value. The filled squares indicate that the difference in reaction time across conditions was greater than the mean $+1$SD of the registered grade, whereas the open squares indicate that the difference was less than or equal to that value. Asterisks signify that the occurrences of reading errors exceeded those of the mean $+1$SD of the child's grade. Hyphens indicate that all reading trials were incorrect.

Twelve of the children with specific reading disorders showed longer vocal reaction times for one-syllable words and higher frequencies of reading errors compared to the results from the children without LD. Seventeen of the children with specific reading disorders also showed greater differences in reaction times between the one-syllable words and the meaningful words of two or more syllables and higher frequencies of reading errors compared to the children without LD.

The ratios for those children were significantly larger than those for the children without specific reading disorders. For one-syllable words, the Chi-square test was $\chi^2=5.84$, $p<.05$; for meaningful one-syllable vs. two-syllable words, the Fisher test results were significant ($p<.01$), and for one-syllable words vs. three, the Fisher test was also significant ($p<.01$).

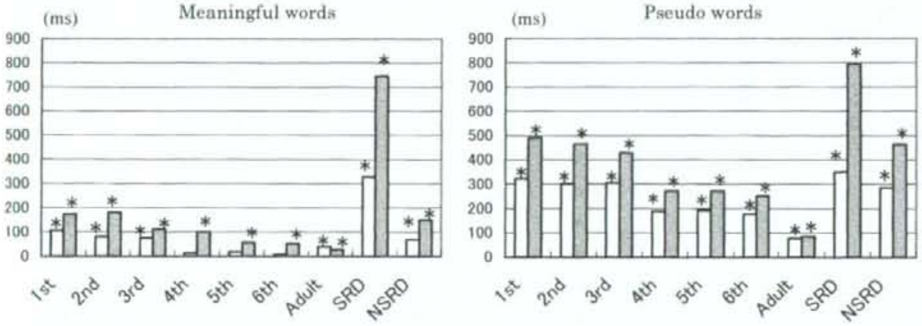

FIG. 4 Differences in Vocal Reaction Time Across Different Word Lengths

Notes. Left graph indicates performance when reading words with meaning. Right graph indicates performance when reading pseudo words. Open bars indicate differences in vocal RT for one- and two-syllable words. Shaded bars indicate differences in vocal RT between one- and three-syllable words. Asterisks indicate that the mean reaction time in each condition is significantly greater than that for one-syllable words.

SRD: LD children with specific reading disorders; NSRD: LD children without specific reading disorders.

TABLE 3 Comparison of Vocal Reaction Time (RT) of Each Child with LD with Usual Development by Using Standardized Values

Participant Number	RT to 1 Syllable	Change in RT Between Words of Different Length			
		Meaningful Words		Pseudo Words	
		1 syllable vs. 2 syllables	1 syllable vs. 3 syllables	1 syllable vs. 2 syllables	1 syllable vs. 3 syllables
SRD 1	●	■	■	■ *	—
2	●	■	■	■	■
3	●	■	■	□	■
4	●	■	■	■	■
5	●	■	■	■	■
6	●	■ *	■ *	■ *	■ *
7	●	■ *	■ *	■ *	■ *
8	● *	■	■	■ *	■ *
9	● *	■	■	□	■ *
10	● *	■	■ *	□	■ *
11	● *	■	■ *	■ *	■ *
12	● *	■ *	■ *	■ *	■ *
13	○	■	■	■	■
14	○	■	■	■	■
15	○	■	■	□	□
16	○	■	□	■	■
17	○	■ *	■ *	■	■
18	○	□	■ *	■	■
19	○	□	□	□	□
NSRD 1	●	■	■	■	■
2	● *	■ *	■	□	■
3	● *	■ *	■	■	■
4	● *	■ *	□	□	■
5	● *	■ *	■ *	■ *	■ *
6	● *	■ *	□	□	■ *
7	○	■	■	■ *	■
8	○	■	■	■	■
9	○	■	■	■	■
10	○	■	■	■	■ *
11	○	■ *	■ *	■ *	■ *
12	○	□	■ *	□	■ *
13	○	□	□	■ *	■ *
14	○	□	□	■	■
15	○	□	□	■	□
16	○	□	□	■ *	□
17	○	□	□	□	■
18	○	□	□	□	□
19	○	□	□	□	■ *

Table 3 (continued)

Participant Number	RT in 1 Syllable	Change in RT Between Words of Different Length			
		Meaningful Words		Pseudo Words	
		1 syllable vs. 2syllables	1 syllable vs. 3syllables	1 syllable vs. 2 syllables	1 syllable vs. 3 syllables
20	○	□	□	□	■ *
21	○	□	□	□	□
22	○	□	□	□	□
23	○	□	□	□	□

Notes. Filled circles indicate that vocal reaction times to one-syllable words were greater than the mean + 1SD of the child's grade. Open circles indicate that the reaction times were less than or equal to the mean + 1SD. Filled squares indicate that the difference in reaction times across conditions was more than the mean + 1SD of the child's grade. Open squares indicate that the difference in reaction times across conditions was less than or equal to the mean + 1SD. Asterisks indicate that the occurrence of reading errors was more than the mean + 1SD of the child's grade. Hyphens indicate that all readings were incorrect. SRD: LD children with specific reading disorders; NSRD: LD children without specific reading disorders.

The majority of the children without specific reading disorders showed greater differences in their reaction times to pseudo words between the one-syllable words and the two- or three-syllable words, or had higher frequencies of reading errors, compared to the children without LD. The ratio of these children did not differ significantly between those LD children with and without specific reading disorders.

Discussion

In terms of typical development in reading meaningful words, children at the fourth grade level or above can read two-syllable words as quickly as one-syllable words. Since, in the lexical process, all graphemes of a word are decoded into phonemes in parallel, based on the Dual Route Cascaded model (Coltheart et al., 2001; Martens et al., 2006), children who are above the fourth grade might be able to read meaningful words of two syllables effectively by the lexical process. Thus, Japanese children show earlier developmental changes in reading via a lexical process, like children in regular orthographic languages such as Italian (Zoccolotti et al., 2006).

The present study demonstrates the greater variability of performance among first, second, and third graders, when reading meaningful words. For effective programs for teaching children with LD in the earlier grades, developmental evaluations of reading one-, two-, and three-syllable words are considered important.

In terms of the typical development of reading pseudo words, the present results demonstrate that vocal reaction times when reading pseudo words decreases after the sixth grade. Considering the need for special educational supports for adolescents with specific reading disorders, typical reading performance in adolescents should be measured.

The majority of the children with specific reading disorders in the present study had longer vocal reaction times or higher frequencies of errors when reading one-syllable words. These results confirm previous evidence indicating longer reaction times when Japanese children with dyslexia read one-syllable words (Wakamiya, Okumura, Mizuta, Kurimoto, Kashiwagi, Tanaka, Suzuki, Satomi, & Tamai, 2006). Wakamiya et al. (2006) indicated that the longer reaction times when reading one-syllable words might be caused by lower efficiency of conversion from grapheme to phoneme. Many of the children with specific reading disorders also showed greater differences in reaction time between one-syllable words and meaningful two-syllable words, compared to the children without LD. These results indicate that a majority of children with specific reading disorders might have difficulty with single grapheme to phoneme conversion and many are not able to read two-syllable words as quickly as one-syllable words. The ratio of such children in the group with specific reading disorders was greater than in the group without specific reading disorders. These results suggest that Japanese children with specific reading disorders might have difficulty in the developmental transition from a non-lexical to a lexical process.

Many of the children both with and without specific reading disorders showed greater differences in reaction time between the one-syllable words and the pseudo words of two or three syllables, compared to the children without LD. Since longer vocal reaction times on pseudo words are considered to reflect an inefficient process of grapheme to phoneme conversion (Matsumoto, 2006), the children without specific reading disorders, as well as those with specific reading disorders, might have had difficulty in efficient conversion of grapheme to phoneme when reading pseudo words of two or three syllables. Because the present study found that the processes of reading go through a developmental change from a non-lexical to lexical process, a developmental study of the longitudinal change in the lexical process of reading in children with specific reading disorders might be effective for elucidating developmentally specific dysfunctions in such children.

In the present study, specific reading disorders were identified on the basis of the developmental standards for reading sentences in the Token Test. Token Test sentences are composed mainly of kana syllables. The way to read words written in kanji is indicated by writing kana syllables next to those words. Since children with specific reading disorders had lower scores on the "reading words" sub-test of the K-ABC, which measures academic attainment in reading kana as well as kanji words, deficits in reading kana sentences might have a causal relationship to difficulties that children with specific reading disorders have in reading kanji words. Further studies are needed on this point.

In the present study, the task of reading the words required the children to maintain attention during reading. Further studies are also warranted on the characteristics of reading words by children who have difficulty in maintaining attention.

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APPENDIX 1 Stimulus Materials

1 syllable	Meaningful Words		Pseudo Words	
	2 syllables	3 syllables	2 syllables	3 syllables
は	ほし	おかね	おは	あきま
か	あお	おんな	すせ	いしく
ほ	いか	くるま	そひ	いとよ
も	かれ	あいす	てゆ	いなき
い	した	あたま	ぬせ	おいこ
き	もち	うしろ	けね	かまち
う	うみ	おかし	ねけ	たなこ
し	おか	おとこ	つあ	ゆさい
の	そら	おはし	のゆ	あおこ
ゆ	のみ	おやつ	へめ	いりこ
お	はと	くもり	ほぬ	いりひ
そ	さけ	さかな	むぬ	えきり
こ	ゆき	おさつ	やゆ	おるか
あ	こい	おなか	めふ	かやけ
さ	きく	おやこ	らへ	かしま

APPENDIX 2 Mean Vocal Reaction Time and SD in Single-Word Reading

Group		1 syllable	Meaningful Words		Pseudo Words	
			2 syllables	3 syllables	2 syllables	3 syllables
Grade 1	*Mean*	641	748	814	964	1132
	(*SD*)	(164)	(236)	(299)	(288)	(420)
Grade 2	*Mean*	614	696	796	926	1080
	(*SD*)	(111)	(165)	(247)	(272)	(384)
Grade 3	*Mean*	560	636	671	865	990
	(*SD*)	(112)	(162)	(200)	(304)	(330)
Grade 4	*Mean*	545	559	645	734	818
	(*SD*)	(93)	(105)	(151)	(179)	(268)
Grade 5	*Mean*	507	525	563	699	778
	(*SD*)	(106)	(96)	(96)	(170)	(195)
Grade 6	*Mean*	524	532	577	701	776
	(*SD*)	(78)	(80)	(98)	(173)	(241)
Adults	*Mean*	408	449	437	485	494
	(*SD*)	(64)	(77)	(69)	(73)	(90)

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Original article

Event-related potentials of self-face recognition in children with pervasive developmental disorders

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Abstract

Patients with pervasive developmental disorders (PDD) often have difficulty reading facial expressions and deciphering their implied meaning. We focused on semantic encoding related to face cognition to investigate event-related potentials (ERPs) to the subject's own face and familiar faces in children with and without PDD. Eight children with PDD (seven boys and one girl; aged 10.8 ± 2.9 years; one left-handed) and nine age-matched typically developing children (four boys and five girls; aged 11.3 ± 2.3 years; one left-handed) participated in this study. The stimuli consisted of three face images (self, familiar, and unfamiliar faces), one scrambled face image, and one object image (e.g., cup) with gray scale. We confirmed three major components: N170 and early posterior negativity (EPN) in the occipito-temporal regions (T5 and T6) and P300 in the parietal region (Pz). An enhanced N170 was observed as a face-specific response in all subjects. However, semantic encoding of each face might be unrelated to N170 because the amplitude and latency were not significantly different among the face conditions. On the other hand, an additional component after N170, EPN which was calculated in each subtracted waveform (self vs. familiar and familiar vs. unfamiliar), indicated self-awareness and familiarity with respect to face cognition in the control adults and children. Furthermore, the P300 amplitude in the control adults was significantly greater in the self-face condition than in the familiar-face condition. However, no significant differences in the EPN and P300 components were observed among the self-, familiar-, and unfamiliar-face conditions in the PDD children. The results suggest a deficit of semantic encoding of faces in children with PDD, which may be implicated in their delay in social communication.

Keywords: PDD, pervasive developmental disorders; AD, autistic disorders; Children; Face; Self-awareness; N170; EPN, early posterior negativity; P300; MNS, mirror neuron system

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1. Introduction

Pervasive developmental disorders (PDD) are characterized by a unique behavior in communication. Persons with PDD often have difficulty reading facial expressions and deciphering their implied meaning. PDD may cause developmental deficits in theory of mind (ToM), mind-reading, and empathy underlying social interaction and communication skills [1–5]. They are probably related to face cognition, because in many cases the face information can help us understand others' feelings and recognize the communication situation.

Recently, noninvasive neuroimaging techniques have found dysfunctions in the brain domain related to perception of the face, eye gaze, and facial expression in persons with PDD [6–10]. Some studies showed that

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face-structural analysis contributed to fusiform gyrus. Other studies showed that eye gaze, emotion, and person identity corresponded to the inferior frontal cortex (IFC), amygdala, limbic system, and superior temporal sulcus (STS) [11,12]. These areas are partly referred as mirror neuron system (MNS), which is associated with execution and observation of actions by oneself and/or others [13,14]. In other words, the MNS affects social cognition significantly [15,16]. Hence, we hypothesized that self-awareness and familiarity of a face also correspond to the MNS because both processes mutually affect social skills and communicative abilities. Indeed, the areas IFC and STS showed strong activity during self-face cognition [7,17–20]. Such a neurophysiological approach would help to define the etiology of autistic disorders (ADs) in PDD and to improve poor social skills; however, such studies are rare.

Many studies have evaluated the developmental stages of cognitive function following visual and auditory perception using event-related potentials (ERPs) [9,21–23]. This technique is advantageous for clinical application, because ERP can be measured noninvasively and repeatedly, even in children. Analysis of the P300 component is especially effective for checking developmental stage and symptom severity because this component influences discrimination ability of stimulus features i.e., frequency, size, shape, and familiarity [21]. In the present study, we measured P300 followed by the face-specific response N170, and compared among the responses to one's own face, a familiar face and an unfamiliar face. This may be the first study based on neurological evidence to explore person identity nodes in face cognition in AD.

2. Methods

2.1. Subjects

The PDD group consisted of eight children (seven boys and one girl) with Asperger's syndrome (AS) or high function autism (HFA) aged 10.8 ± 2.9 years, one of whom was left-handed (FIQ: 97 ± 12; VIQ: 102 ± 15; PIQ: 92 ± 11). The subjects were recruited from National Center Hospital of Neurology and Psychiatry (Kodaira, Japan), and their diagnosis was based on DSM-IV criteria (American Psychiatric Association, 1994) by two pediatric neurology specialists [24]. The subjects' intelligence quotients were evaluated on the basis of the Wechsler Intelligence Scale for Children-Third Edition (WISC-III) (Wechsler, 1991; Japanese translated and adapted version, Azuma et al., 1998) [25,26]. The control groups consisted of healthy adults without AD (Adult group: six men and five women; aged 26.9 ± 5.6 years; two left-handed) and typically developing children (Children group: four boys and five girls; aged 11.3 ± 2.3 years; one left-handed). None of the subjects had a neurological disorder.

Informed consent to participate in the experiment was obtained from the mother of each subject in the PDD group, from each subject in the Adult group, and from both the subject and his or her mother in the Children group. The present study was approved by the Ethics Commission of National Center of Neurology and Psychiatry.

2.2. Tasks

Subjects were instructed to view stimuli, which consisted of monochromatic photographs of three facial images (self, familiar, and unfamiliar faces), one scrambled-face image, and some object images while sitting on a chair. The comparison of each stimulus condition was supposed to reveal self-awareness, familiarity, and face cognition, respectively (Table 1). The facial images and the scrambled-face image were individually created from photographs taken with a digital camera. For the self-face condition (Self), a mirror image of the subject's own face was used. For the familiar-face condition (Fam), an image of the face of each subject's mother was used in the PDD and Children groups. In the Adults group, an image of the face of a gender- and age-matched familiar person, such as a friend in the subject's school or office, was used in the familiar-face condition because the subjects rarely saw their mothers. Three unfamiliar-face (Unfam) images were respectively morphed from facial photographs of seven young women (22–30 years old), four young men (22–24 years old), and 11 middle-aged women (35–46 years old) who were unknown people to the subjects and were gender- and age-matched to the familiar-face condition using Software for Facial Image Processing System for Human-like "Kansei" Agent (Information-technology Promotion Agency, IPA, Japan) and an extension tool (Harashima-Naemura Laboratory, University of Tokyo, Tokyo, Japan). The scrambled-face image (Scram) was created by randomly rearranging the self-face image for each subject. The subjects were instructed to press a key when an object image (Target) was presented. To keep the subjects' attention and the vigilance level

Table 1
Stimuli

Condition	Factor		
	Self-awareness	Familiarity	Face perception
Self-face (Self)	○	○	○
Familiar-face (Fam)	×	○	○
Unfamiliar-face (Unfam)	×	×	○
Scrambled-face (Scram)	×	×	×
Object (Target)	×	×	×

constant, the target image was changed with each session (e.g., cup, cellular phone, flower, and slide). The average luminance of each stimulus was equalized using Adobe Photoshop 5.0.

Each stimulus, 72 mm in width and 88 mm in length (visual angle: 4.1° × 5.3°), was presented in the center of a gray background using the Multi-trigger system (Medical Try System Inc., Japan). The distance between the monitor screen and the subject was 500 mm. The images of three faces, one scrambled-face, and one object were presented for 800 ms in random order at a random interstimulus interval (ISI) between 1100 and 1800 ms; 110 trials were conducted in one session, and four sessions were conducted alternately with a short rest between each session. A total of 84 trials were conducted for each stimulus condition. Before the experiment began, we confirmed that the subjects could name the stimulus images correctly.

2.3. Recordings

A cap with pure tin electrodes (Electro-Cap International Inc.) was mounted on the head of the subject. Electroencephalography (EEG) was digitally recorded from 19 locations (Fp1, Fp2, F7, F3, Fz, F4, F8, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6, O1, and O2) on the scalp, according to the International 10–20 system, against Cz as a common reference (Alliance Works; VIASYS Healthcare Inc.). We also recorded an electrooculogram (EOG) of the left eye with two electrodes placed 2 cm under the inferior orbicular edge and 1 cm outside of the lateral angle of the eye. The impedance between exploring and referential electrodes was less than 10 kΩ. The EEG and EOG data were transferred on-line and stored with a sampling rate of 250 Hz.

2.4. Analysis

As the behavioral index in this experiment, reaction time (RT) and accuracy with respect to the target were analyzed in each subject using the Multi-trigger system (Medical Try System Inc.). RT was compared between subject groups using one-way analysis of variance (ANOVA) followed by post hoc multicomparison using Fisher's protected least-significant difference (PLSD) test.

For the EEG and EOG data, epochs with artifacts of blink and body movement were deleted before analysis, and the data were then selectively averaged for each condition using a band pass filter of 0.15–50 Hz using the common averaged reference. Artifact-free (48 ± 16; mean ± SD) epochs were thus collected in each condition. The epochs were 1200 ms in length, including a 200 ms pre-stimulus baseline.

For each ERP component, the peak amplitude and latency from baseline to peak were measured in each condition. To determine the face-specific response, the peak latency and amplitude of N170 components were respectively compared using a two-way ANOVA of condition and subject group followed by a post hoc multicomparison using Fisher's PLSD. We subtracted the waveforms in the Fam condition from the Self condition (Self–Fam) and the waveforms in the Unfam condition from the Fam conditions (Fam–Unfam). The peak latency and amplitude of early posterior negativity (EPN) were measured in the different waveforms. To compare the amplitude of the difference between the Self–Fam and Fam–Unfam components in each group, we calculated the integral values of the EPN amplitude of a 200 ms time interval, 100 ms before and after for the Self–Fam components using one-way ANOVA. On the other hand, for the target stimulus, the peak latency and amplitude of P300 were compared using one-way ANOVA of subject group (PDD, Children group, and Adult group) followed by a post hoc multicomparison using Fisher's PLSD. For the non-target stimulus, the integral values were calculated using the P300 amplitude of a 200 ms time interval, 100 ms before and after for the peak latency in the self-face condition in each subject and were statistically tested between the Self, Fam, and Unfam conditions using one-way ANOVA followed by a post hoc multicomparison using Fisher's PLSD.

3. Results

We checked that the subjects could correctly discriminate the stimulus images of each condition prior to the recordings. All subjects successfully pressed a key in response to target stimuli, and the accuracy was 96.4% in the PDD group, 98.8% in the Children group, and 99.8% in the Adult group. The RT was longer ($P < 0.05$) in the PDD (508.5 ± 63.8 ms) and Children (483.0 ± 96.4 ms) groups than in the Adult group (409.7 ± 58.9 ms).

For all subjects, the N170 component was observed in the occipito-temporal regions (T5 and T6) in each condition (Fig. 1). We confirmed a main peak and an earlier negative peak (N170a [35]) of N170 in seven typically developed children and four PDD children. The latency and amplitude in the main peak of N170, which were averaged in each condition for each subject group, are shown in Table 2. Face perception (PDD group: 211.9 ± 48.0 ms; Children group: 211.1 ± 30.4 ms; Adult group: 152.4 ± 12.3 ms) reduced the main N170 latency compared with the perception of noise and object images (PDD group: 237.8 ± 48.0 ms; Children group: 231.4 ± 42.7 ms; Adult group: 164.4 ± 18.6 ms) in each subject-group ($P < 0.0001$). However, latency was not significantly different among the Self, Fam, and Unfam conditions. On the other hand, the amplitude was larger with face perception (PDD group:

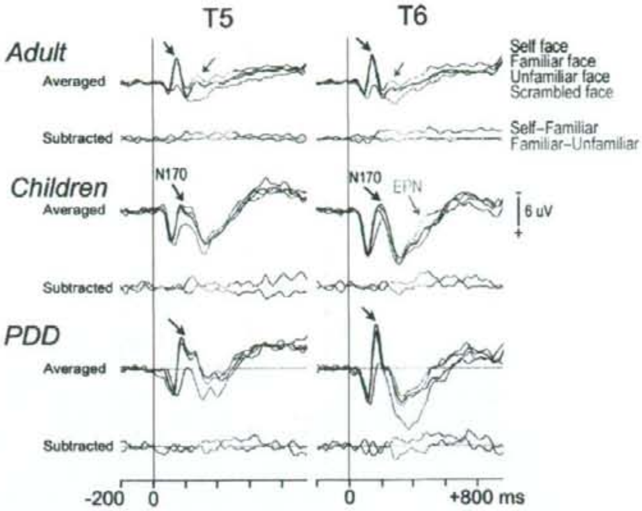

Fig. 1. ERP waveforms in the non-target conditions and the subtracted (Self–Fam and Fam–Unfam) waveforms (grand averaged waveforms). For all subjects, the N170 component was observed in the occipito-temporal regions (left: T5; right: T6) in each condition. To identify self-other discrimination and familiarity, EPN subtraction was calculated in each subtracted waveform (Self–Fam, Fam–Unfam).

Table 2
The latency and amplitude in the main peak of N170

Condition	T5 (left)			T6 (right)		
	Adult	Child	PDD	Adult	Child	PDD
Peak latency						
Face						
Self	151.3 ± 12.8	208.5 ± 36.9	223.0 ± 58.5	152.7 ± 9.8	215.5 ± 28.9	213.0 ± 68.0
Familiar	150.2 ± 10.2	213.5 ± 30.2	222.5 ± 48.4	150.9 ± 10.3	209.5 ± 28.7	202.0 ± 40.4
Unfamiliar	152.0 ± 16.1	211.0 ± 35.2	209.0 ± 42.0	149.5 ± 15.6	208.5 ± 31.5	202.0 ± 34.8
Non-face						
Scrambled	158.5 ± 27.6	236.5 ± 36.8	242.5 ± 57.4	167.3 ± 20.5	225.0 ± 22.6	226.0 ± 53.5
Peak amplitude						
Face						
Self	−5.3 ± 3.8	−1.6 ± 3.4	−6.6 ± 3.6	−5.6 ± 2.3	−1.6 ± 6.0	−5.0 ± 4.1
Familiar	−5.1 ± 3.4	−2.4 ± 1.7	−6.6 ± 3.7	−5.5 ± 2.1	−1.5 ± 4.8	−5.8 ± 4.2
Unfamiliar	−5.4 ± 3.3	−1.1 ± 2.0	−6.5 ± 2.0	−5.3 ± 1.8	−0.5 ± 5.8	−5.9 ± 4.4
Non-face						
Scrambled	−0.5 ± 3.6	0.0 ± 4.3	−2.1 ± 3.5	0.1 ± 3.1	0.4 ± 4.8	0.8 ± 6.5

Face perception reduced the latency and increased the amplitude compared with non-face image perception ($P < 0.0001$). However, semantic encoding of each face might not influence N170 because the latency and amplitude did not show any significant differences among each face condition.

−6.1 ± 4.1 μV, Children group: −1.5 ± 4.1 μV, Adult group: −5.1 ± 2.9 μV) than with non-face perception (PDD group: −0.3 ± 5.5 μV, Children group: 0.5 ± 5.1 μV, Adult group: −1.0 ± 3.3 μV) ($P < 0.0001$), but there were no significant differences among face conditions. The latency and amplitude of N170 showed distinct differences based on the subject group. Latency was shorter in the Adult group than in the PDD and Children groups, and the Children group had the longest latency ($P < 0.0001$). The amplitude was larger in the PDD group than in the Adult and Children groups, and the Children group had the smallest amplitude ($P < 0.0001$). There was no significant difference in hemispheric dominancy in all subjects. In addition, the N170a amplitude was significantly larger in the face perception than the non-face image perception ($P < 0.0001$) but there was no significant difference between the perceptions for the latency (Table 3). The amplitude and

Table 3
The latency and amplitude in the earlier peak of N170 (N170a)

Condition	T5 (left)		T6 (right)	
	Child ($n = 7$)	PDD ($n = 4$)	Child ($n = 6$)	PDD ($n = 4$)
Peak latency				
Face				
Self	166.9 ± 11.0	180.0 ± 24.0	166.4 ± 6.7	168.0 ± 10.6
Familiar	170.3 ± 15.3	177.3 ± 11.5	175.2 ± 12.5	172.0 ± 10.6
Unfamiliar	169.1 ± 13.2	174.7 ± 16.2	175.2 ± 6.6	165.3 ± 11.5
Non-face				
Scrambled	164.0 ± 13.5	166.0 ± 36.8	180.0 ± 16.2	182.0 ± 19.8
Peak amplitude				
Face				
Self	−1.0 ± 4.2	−5.6 ± 3.3	0.6 ± 4.8	−8.8 ± 5.3
Familiar	−2.4 ± 3.2	−9.3 ± 3.1	−0.1 ± 3.2	−9.0 ± 4.0
Unfamiliar	−1.2 ± 2.3	−7.3 ± 3.0	0.7 ± 5.1	−9.7 ± 2.7
Non-face				
Scrambled	4.6 ± 3.8	2.2 ± 2.1	4.0 ± 2.4	−0.1 ± 3.7

There were significant differences for the N170a amplitude between face and non-face image perceptions ($P < 0.0001$) but not for the latency. Semantic encoding of each face might not influence N170a because the latency and amplitude did not show any significant differences among each face condition.

latency were not significantly different among the Self, Fam, and Unfam conditions.

An additional component after N170, EPN, was observed in the Self–Fam (self-face awareness) and Fam–Unfam (familiarity) conditions (Fig. 1). The EPN component peaked at 370 ± 53 ms in the PDD group, was 405 ± 86 ms in the Children group, and was 262 ± 40 ms in the Adult group. The integral value of EPN was larger in the Self–Fam component than in the Fam–Unfam component in both hemispheres in the Adult group ($P < 0.01$) (Fig. 2). In the Children group, the Self–Fam component was enhanced in the right hemisphere ($P = 0.08$), although there were no significant differences between the components in the PDD group.

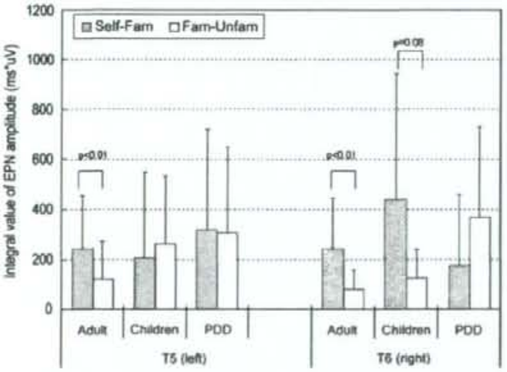

Fig. 2. Integral values for EPN amplitude 200 ms from peak latency in the subtracted waveform. In the Adult group, the EPN amplitude was larger in the Self–Fam waveform than in the Fam–Unfam waveform in both hemispheres ($P < 0.01$). In the typically developing Children group, the enhanced amplitude in the Self–Fam waveform was obtained in the right hemisphere ($P = 0.08$), although there were no significant differences among each component in the PDD children.

Recognition and discrimination elicit a P300 component. In this study, P300 was observed at approximately 350 ms for the target stimulus and even for the non-target stimuli in the parietal region (Fig. 3). For the target stimulus, the latency was longer in the PDD (395.5 ± 82.0 ms) and Children (408.5 ± 92.3 ms) groups than in the Adult group (359.2 ± 27.8 ms) ($P = 0.07$), and the amplitude was larger in the Children group than in the PDD and Adult groups ($P < 0.05$) (Fig. 4). For the non-target stimulus, the integral values of P300 amplitude are shown in Fig. 5. In the Adult group, the P300 amplitude was significantly greater in the Self condition than in the Fam ($P = 0.08$), Unfam ($P < 0.01$), and scrambled ($P < 0.001$) faces conditions, with main effects of condition ($P = 0.0004$) (Fig. 5). In the Children group, amplitude was significantly greater in the Self ($P = 0.08$) and Fam ($P = 0.08$) conditions than in the Unfam condition, but the difference was not significant among conditions in the PDD group.

4. Discussion

Self-awareness is often interpreted by two concepts; one concept is a feedback system to one's own action through somatosensory, visual, and auditory processes. To pinch something, we usually control our fingers through vision and somatosensory information, while motor planning encodes expected sensory traces for actions. We continuously monitor both the efference copy by planned movements and the proprioceptor/

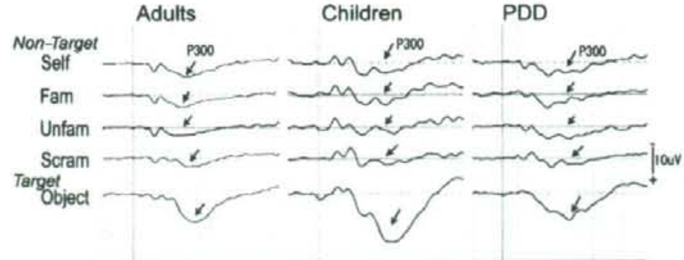

Fig. 3. ERP waveforms for the non-targets in the parietal region (Pz) (grand averaged waveforms). In all subjects, the slow positive potentials (P300) around 350 ms were observed for the target and the non-target stimuli. The P300 amplitude in response to faces was larger than that to the scrambled face ($P = 0.07$).

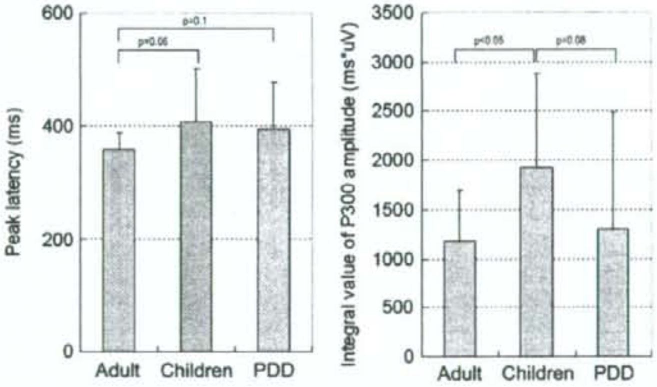

Fig. 4. Peak latency and integral values of the peak amplitude of P300 for the target. Peak latency was shorter in the control Adult group than in the typically developing Children and PDD groups. Peak amplitude was significantly larger in the typically developing Children group than in the Adult and PDD groups.

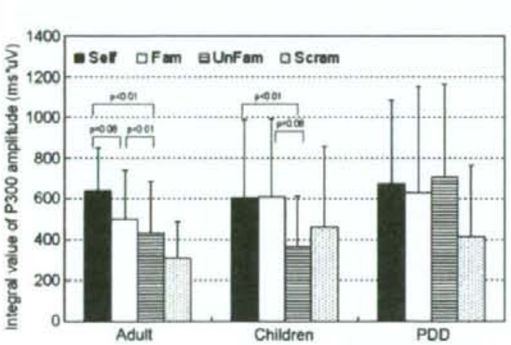

Fig. 5. Integral values of the P300 amplitude for the non-target stimuli. In the Adults group, the P300 amplitude was significantly greater in the self-face condition than in the familiar ($P = 0.08$), unfamiliar, ($P < 0.01$) and scrambled- ($P < 0.01$) face conditions. Amplitude increased more in the Self ($P = 0.08$) and Fam ($P = 0.08$) conditions than in the Unfam condition in the typically developing Children group, but not in the PDD group.

exteroceptor from real movements; thus, the relationship may create self-body image and even self-awareness. The other concept involves finding the subjective self in an object and a phenomenon. It is encountered in various situations, for example, perception of one's favorite things and self-face. Some animal studies reported self-recognition of a mirror image [27,28]; more recently, this approach was also applied in humans [17–20,29–31]. In the present study, we compared ERP in response to the subject's own face, a familiar face, and an unfamiliar face and elucidated the brain domain due to self–other distinction.

Face perception induces the N170 component in the occipito-temporal cortex, mainly in the fusiform gyrus [7,32–42]. In the present study, the N170 amplitude was larger in response to face images than to non-face images, although there was no significant difference among three kinds of faces. Thus, the N170 component might be involved in the structural perception of faces but not person identity [43]. Furthermore, we confirmed the age effect on N170 in control subjects. The present results indicate a longer latency and enhanced amplitude of the N170 component in the typically developing Children group. The earlier negative peak N170a was also seen in some children. This is consistent with a previous finding in which N170 in children consists of two subcomponents in the fusiform gyrus and superior temporal sulcus (STS) [35]. It was concluded from the results that the fusiform gyrus contributed to the both peaks of N170 while STS contributed to the main peak of N170 especially. On the other hand, N170 latency was shorter in the PDD group than in the Children group, although the chronological age of the groups was nearly equal: 10.8 ± 2.9 and 11.3 ± 2.3 years, respectively. The shorter latency may indicate that the development of face cognition was quicker in the PDD group. However, McParland et al. reported that adults with AD (15–42 years old) showed a delay in N170 latency compared with normal adults [34]. Therefore, it is inferred that the unexpected change in N170 latency develops during the transition stage from childhood to adulthood in PDD.

Semantic encoding should be followed by the structural perception of faces. In this study, the negative shift in the parietal areas was probably interpreted as EPN. EPN has been reported to indicate motivated selective attention and processing emotion via the visual cortex [44–47]. The present study showed that the EPN of about 300 ms was remarkable in T5 and T6 for the perception of one's own face. In the Adult group, amplitude was larger in the Self–Fam components than in the Fam–Unfam components in both hemispheres ($P < 0.01$), whereas such self-other distinction was reflected only in the right hemisphere (T6) in the Children group ($P = 0.08$). Schupp et al. (2007) reported that emotional visual processing showed EPN to have right hemispheric dominancy [45]. In addition, many neuroimaging studies have suggested that the recognition of one's own face is predominant over the recognition of others' faces, and was dominant in the right hemisphere [17,19,20,29,48,49]. Thus, in the present study, the differences in EPN were thought to include a specific response to self-awareness compared with familiarity [19,20] and may be supported by the right hemispheric network with developmental changes. In the PDD children, there was no significant difference between Self–Fam and Fam–Unfam EPNs. Some researchers have indicated that EPN is related to emotion in the temporal and lateral-occipital regions, including the amygdala and fusiform gyrus [44,45,50–52]. The areas are also involved in MNS. These findings suggest that the unstable process of person identity was closely connected with unique communication in PDD children, which might be caused by attenuation in MNS [53,54].

An event-related discrimination elicits the late positive potentials (P300) in the parietal area, even to the non-target stimuli. We observed a remarkable effect that depends on the subject group, that is, the P300 amplitude decreased more in the unfamiliar-face condition than in the familiar-face condition in the typically developing children and adults, but not in the PDD group. Furthermore, self-face perception resulted in a greater increase in the P300 amplitude than the familiar-face perception in the Adult group. Because the P300 amplitude was influenced by complexity and attention level [21], we suggest that person identity nodes may have altered the P300 amplitude in the present study [55]. In the Children group, the P300 amplitude in response to the Fam condition was approximately equivalent to the response to the Self condition. This finding might explain that P300 is strongly reflected by affection to mother's face and a mother–child relationship in childhood. In addition, the prolonged latency of EPN may have been responsible for the failure of P300 to increase in response to the Self condition in the Children group, because EPN in the Adult group was proceeding to P300 with the enhancement to the self-face. The variations in P300 may be a criterion for self-awareness and familiarity in the Adult group. However, in the Children group, self-awareness and familiarity should be evaluated on the basis of variations in both P300 and EPN.

On the other hand, no significant differences in P300 amplitude were observed among the Self, Fam, and Unfam conditions in the PDD children. Dawson et al. also reported that perception to mother's face increased the ERP amplitude by 400 ms in typically developing infants but not in infants with autistic disorders [6]. Face cognition may involve interactions between visual structural perception and semantic encoding [47,55]. In the present study, the cognitive system may have influenced the self–other distinction. We usually give precedence to self-awareness and familiarity, even in inattentive conditions, although children with PDD may process such equally. But they can recognize their faces, their mothers' faces, and unfamiliar faces correctly. Thus, in PDD children, we considered that a shortcut route, such as a process without regard to face identification, decreased working efficiency on the face cognition network in an inattentive situation. By advancing this research we hope to better understand communication deficits in children with autistic disorders, which is the key to supporting them.

In conclusion, the enhanced N170 was observed as a face-specific response in all subjects. However, semantic encoding of each face might not influence N170 because the amplitude and latency did not show any significant differences among face conditions. On the other hand, the EPN might have reflected self-awareness and familiarity in the control adults and children. Furthermore, self-face perception increased the P300 amplitude com-