CHUGOKUGAKUEN J. 2014
Vol. 13, pp. 39-45

CHUGOKUGAKUEN Journal
http://www.cjc.ac.jp/

Original Article

Categorical Perception and Reading Skill: A Survey of Japanese Second Graders

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Background: The relationship between reading ability and categorical judgment of speech sounds in children whose native language is Japanese is unclear. The purpose of this study is to elucidate the impact of categorical perception on the development of reading ability in children whose native language is Japanese.
Methods: First, forty second-graders (F18, M22; 7y4m−8y4m) attending a public elementary school were tested for reading time and reading errors using the monomoraic syllable reading test, the word and non-word reading tests, and the single sentence reading test. Reading time scores and reading error scores which lay more than 1.5 times the interquartile range (IQR) higher than the third quartile were considered outliers. Next, 30 out of these 40 children were tested using the categorical perception task. A thirteen-step stimulus continuum from /ka/ to /ga/, made by changing voice onset time, was presented to the subjects with the steps in random order, and the subjects made judgments as to whether each stimulus sounded more like /ka/ or /ga/.
Results: Reading time as assessed through all 4 tasks and reading errors as assessed through the non-word reading test and the single sentence reading test correlated weakly with the Categorical Perception Index (CPI), which indicated the stability of categorical judgment. In addition, the number of scores which were outliers also showed a weak correlation with CPI.
Conclusion: These results suggest that categorical perception ability affects the development of reading ability in children whose native language is Japanese.

Key Words: Categorical Perception, Dyslexia, Japanese Children, Second-Graders, Voice Onset Time

Introduction

Developmental dyslexia is understood to be a longstanding chronic disorder affecting between 5 and 17.5% of children [1]. Various factors such as dysfunctions of the magnocellular pathway

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[2], impairment of cognitive interpretation of rapidly changing sensory stimuli [3], or cerebellar dysfunctions [4] have been purported to contribute to its occurrence. To date, however, no theory has been put forth that by itself completely explains the pathophysiology of dyslexia.

Several disturbances of the neural system in dyslexia have been shown through imaging studies. Converging evidence from fMRI studies has demonstrated reduced activation in the left parietotemporal system and the occipitotemporal system of dyslexic patients during reading or phonological analysis [5]. Recently, disturbed integrity of the left arcuate fasciculus, which connects the parietotemporal region and the inferior frontal gyrus was demonstrated by means of diffusion tensor imaging tractography [6].

There is a broad consensus among researchers in the USA and Europe that phonological awareness is largely missing in dyslexic children and adults [1]. When phonological awareness is impaired, children cannot understand that spoken words are assembled from essential speech components such as syllables and phonemes. Consequently, the development of decoding ability, that is, the development of the ability to transform letters, which are mere visual symbols, into speech sounds, is hampered. In fact, disturbances of phonological processing, including phonological awareness, have been demonstrated in preschool children who have turned out to be dyslexic later in their school life [7, 8]. Although research in this field has been scarce in Japan, some authors have reported that Japanese children with dyslexia exhibit the characteristic disturbances in phonological awareness [9–11]. Some researchers have proposed that the origin of these disturbances in phonological awareness is an impairment of general auditory cognition, such as difficulty in perceiving rapidly changing sounds [12, 13]. Other authors, in contrast, have emphasized the significance of problems in higher-order linguistic abilities rather than impairment of general auditory function [14].

In addition to phonological awareness, problems in the perception of speech sounds have also been investigated among patients with dyslexia in countries where languages using alphabets are predominant. In these investigations, many researchers have evaluated the ability to discriminate phonemes by testing categorical perception [15]. Upon hearing a phonetic continuum of sounds, changing, for example, from /pa/ to /ba/, typically-developing children tend to judge each sound clearly as one sound or the other, that is, as either /pa/ or /ba/. Many dyslexics are unable to make such clear categorical judgments [14, 16–18], however, although the rate of dyslexics who cannot make these categorical judgments is not necessarily high. McBride-Chang [19] has documented that the ability to perceive speech sounds categorically is one of the components that make up phonological awareness.

As far as we know, no previous report has focused on the relation between speech sound perception ability and reading competence among those whose first language is Japanese. To elucidate whether speech perception ability is involved in the development of reading competence among Japanese speaking people, we conducted this study, which examined the categorical perception ability of Japanese second-graders at a public elementary school using a phonetic continuum changing from /ka/ to /ga/.

Subjects and Methods

Subjects

This study consisted of 2 steps: 1) an assessment of competence at reading aloud [20], and 2) an evaluation of categorical perception ability.

A letter explaining the purpose of this study and requesting participation was sent to the parents of each of the 182 second-graders at a public elementary school situated in a local city. Forty children (F 18, M22; age range: 7 years 4 months–8 years 4 months; mean age: 7 years 11 months) responded to the invitation and completed Step 1. Parents responded to a questionnaire before the study began. None of the parents reported that their children had any obvious developmental retardation at the time of the study. No child had any visual or auditory disturbances that interfered with reading, writing, or other daily activities.

Out of these 40 children, 30 also later participated in Step 2 (F14, M16; age range: 7y6m–8y6m, mean: 8y1m; number of right-handed children: 24). Among these 30, 2 children had a history of speech delay during the preschool period, but had caught up and were developing normally by the time of the study. One girl had congenital dilatation of the lateral ventricles, and one boy had been diagnosed with attention-deficit/hyperactivity disorder and with a specific learning disability; further details on these two subjects were not provided.

The Step 1 survey was administered to all subjects in August except for one subject who was examined in October. The tasks that made up Step 2 were administered 0 to 3 months (mean: 1.6 months) after Step 1.

We received written consent from the parents of all participants following a full explanation of the assessments and the publications which we intended to write based on the results. After the tests in each step, we presented small gifts (book tokens) to the subjects.

Methods

Step 1 consisted of four reading tasks, namely, the monomoraic syllable reading test [10], the word and non-word reading tests [21], and the single sentence reading test [22]. In each task, reading time and the number of reading errors were determined. Conforming to Tukey's definition, both reading time scores and reading error scores which lay more than 1.5 times the IQR (interquartile range) higher than the third quartile were considered outliers. The details of Step 1 have been described previously [20].

Step 2 consisted of the categorical perception task (CatPer, described below). Raven's Coloured Progressive Matrices (CPM; Nihon Bunka Kagakusha Co., Ltd., Tokyo) were also administered as an index of non-verbal intelligence on the same day as CatPer.

The stimulus used in CatPer was a phonetic continuum from the voiceless velar plosive mora /ka/ to the voiced velar plosive mora /ga/ in the natural voice of a Japanese adult male (Fig. 1, A and B), which we created using Praat software (http://www. fon. hum. uva. nl/praat/). Generally, plosive stop consonants are classified into "voiced" and "voiceless" categories, which are distinguished based mainly on voice onset time (VOT). VOT refers to the time from the burst of the stop consonant to the onset of laryngeal pulsing [23], VOT is longer for voiceless plosives than for voiced plosives, though specific boundaries vary according to language. In fact, VOT for voiced plosives can sometimes be negative, meaning that the glottal buzz begins before the plosion. In French, for example, the VOT for the voiced bilabial plosive (/p/) has a negative value [24]. The /ka/ stimulus used in this study had a VOT of 30 msec (arrow in Fig. 1 A); by excising various amounts of this VOT, six other stimuli were created whose VOTs were 24 msec, 20 msec, 16 msec, 12 msec, 8 msec, and 4 msec. In addition, by attaching segments of the negative VOT of /ga/ (arrow in Fig. 1B) immediately before the plosion of the stimulus whose VOT was 4 msec, six other stimuli were created whose VOT were −4 msec, −8 msec, −12 msec, −20 msec, and −28 msec. This gave us our 13-step continuum from /ka/ to /ga/.

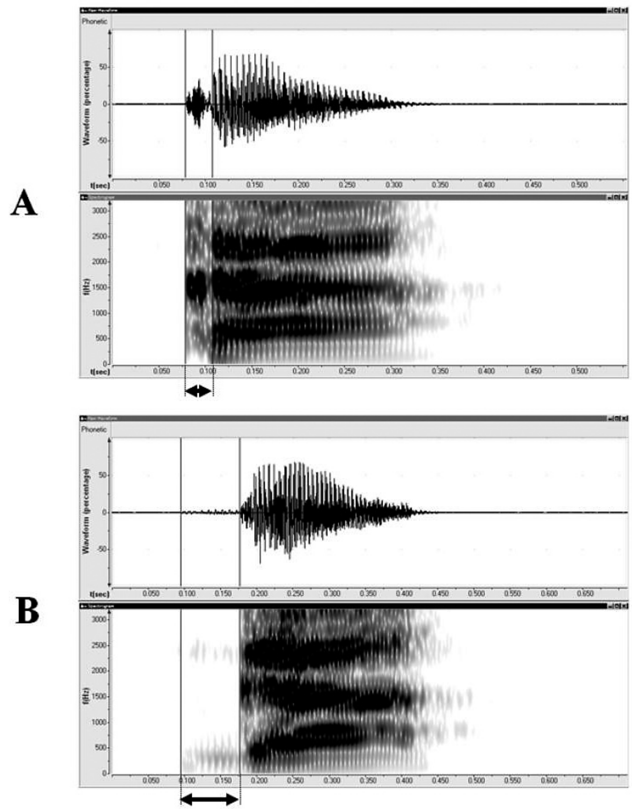

Fig. 1 The spectrogram of a natural voice pronouncing /ka/ (A) and /ga/ (B). In each panel, the VOT is indicated by the double arrow.
(A) The laryngeal pulsing begins 30 msec after the burst (release of airflow); accordingly, VOT is positive.
(B) The laryngeal pulsing begins 51 msec before the burst; accordingly, VOT is negative.

Each stimulus was presented 10 times to each subject in pseudo-random order; in other words, 130 stimuli were presented in total. The software for CatPer was programmed using E-Prime Ver. 2 (Psychology Software Tools, Inc., Pittsburgh, PA, USA), and was implemented on a personal computer. The stimuli were presented via noise cancelling headphones (Sony MDR-NC6) to each subject at a volume which that subject found comfortable. Subjects were instructed that, every time a stimulus was presented, they were to judge whether the stimulus was /ka/ or /ga/, and to press "1" on a numeric keypad for /ka/, and "2" for /ga/. There was no time limit, and subjects were told that there was no need to respond in a hurry. A few practice trials were administered which consisted only of the endpoint stimuli, that is, the stimulus with the 30-msec VOT (/ka/) and the stimulus with the −28-msec VOT (/ga/). After we thus confirmed that each participant understood the instructions, the real task was started.

A Categorical Perception Index (CPI) was calculated using the following formula, with *a* representing the number of responses for /ga/ and *b* the number of responses for /ka/ to *i*_th stimulus.

$$CPI = \sum_{i}^{13} (a_i - b_i)^2$$

A high CPI indicates that the subject's categorical judgment is sharp and clear, while a low CPI indicates that categorical judgment is fuzzy. Prior to this study, 21 healthy adults (F 13, M 8; 20y0m −50y1m, mean: 34y2m) underwent the same categorical perception task, and it was confirmed that the boundary between /ga/ and /ka/ existed between the stimulus with the −4-msec VOT and that with the 20-msec VOT. Fig. 2 shows the categorization curve of one 7-year-old boy who participated in this study.

The Pearson's correlation coefficients of reading times/reading errors on the 4 reading tasks and CPI were calculated. Since all the variables were remarkably skewed, logarithmic transformation was applied to reading times, square root transformation to reading errors, and square transformation to CPI. Additionally, the Spearman's rank correlation coefficients between the number of outlying scores according to Tukey's definition and CPI were examined. SPSS 12.0.2J for Windows (SPSS Japan, Inc., Tokyo) was used for statistical calculations.

This study was approved by the Ethics Committee of Chugokugakuen University.

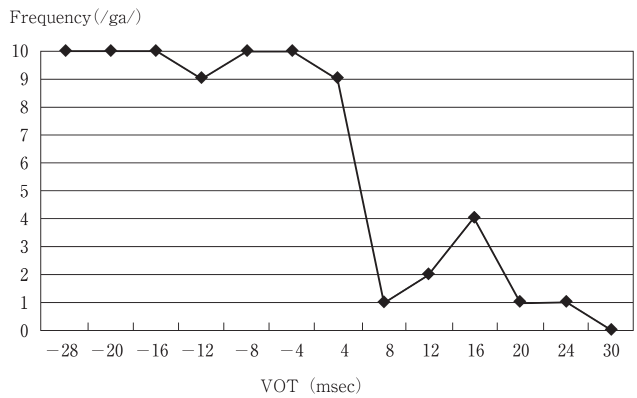

Fig. 2 The /ga/-/ka/ identification function for a boy aged 7 years and 8 months. This subject showed a sharp change from perceiving /ga/ to perceiving /ka/ between 4 and 8 msec of VOT. The CPI of this subject was 24.3, and the number of outlier scores on reading tasks was 1.

Results

The subjects' CPM scores ranged from 21 points to 35 points (mean 28.7 points); this entire range is above the 25th percentile of Raven's norms for children of comparable age [25]. This range also corresponds to a range from −1.5 SD to 1.0 SD (mean −0.1 SD) of the CPM scores of normal Japanese second-graders reported by Uno et al. [26].

Of the 30 subjects who participated in Step 2, 7 subjects (17.5%) obtained outlier scores in at least one of the 8 scores in our 4 tasks (i. e. reading time score and reading error score for each task). Among these 7 subjects, 2 obtained outliers in 1 score, 3 in 2 scores, 1 in 3 scores, and 1 in 5 scores [20].

A summary of the subjects' CPI and raw scores on the reading tasks is shown in Table 1. Table 2 shows the correlation coefficients between the reading times/number of reading errors and CPI. The reading times on all the tasks showed weak negative correlation coefficients (from −0.210 to −0.262) with CPI. Among the 4 tasks, the reading time on the single sentences task showed the strongest correlation with CPI. The number of reading errors on the non-word reading task and on the single sentence reading task showed weak correlation coefficients with CPI: −0.271 and −0.267, respectively.

The number of outlying scores showed a weak

Table 1 Summary of the results

Index		Range	Mean	Median	SD
CPI		7.7–31.2	24.4	26.3	5.5
Reading Times (msec)	Monomoraic Syllables	20.6–161.4	48.5	39.7	31.0
	Words	16.5–107.7	43.2	33.8	22.6
	Non-words	37.4–164.9	68.0	58.0	29.0
	Single-Sentences	7.2–46.8	19.2	14.2	11.1
Reading Errors	Monomoraic Syllables	0–14	4.5	3.5	3.9
	Words	0–7	2.7	2	1.8
	Non-words	3–13	7.1	6	3.3
	Single-Sentences	0–6	1.4	1	1.8

CPI: Categorical Perception Index

Table 2 Correlations between the score on each task and CPI
Correlation coefficients were calculated after the scores were transformed; logarithmic transformation was used for reading times, square root transformation for reading errors, and square transformation for CPI.

Score	Task	Correlation Coefficients (Pearson's r)	p (one-tailed)
Reading Times	Monomoraic Syllables	−0.210	0.133
	Words	−0.229	0.111
	Non-words	−0.238	0.102
	Single-Sentences	−0.262	0.081
Reading Errors	Monomoraic Syllables	−0.039	0.418
	Words	−0.112	0.278
	Non-words	−0.271	0.073
	Single-Sentences	−0.267	0.077

CPII: Categorical Perception Index

Spearman's rank order correlation coefficient (rho=−0.260, p=0.083) with CPI.

Discussion

Various explanations have been proposed concerning the pathogenic mechanism of dyslexia. Among these is the phonological theory, which is supported by a growing body of empirical evidence reported by many investigators [1]. Phonological processing includes several factors such as phonological awareness, phonological recoding in lexical access, and working memory [27]. Each of these factors has been shown to be involved in the manifestation of dyslexia, but phonological awareness may be particularly important, given the large body of evidence showing that it is impaired in dyslexic children [1]. Phonological awareness consists of the processing of the syllables, rhymes, and phonemes which constitute speech sounds.

Research on the correlation between dyslexia and phonological awareness in Japan has been scarce in the past, but several studies on this topic have been published recently. Specifically, scores on the word reversal task [9–11], the mora counting task [9, 11], the syllable deletion task [10], and the rhyming letter task [11] have been reported to be inferior in Japanese children with dyslexia compared to control children. These data indicate that a disturbance of phonological awareness is involved in the mechanism of dyslexia manifestation among native Japanese speakers as among other groups.

The categorical perception task that we adopted in this study evaluates the cognitive processing of speech sounds and discloses the perceptual characteristics with which the subject discriminates among phonemes. Many studies on categorical perception in dyslexic people have been done in Europe and the US, and while many of these authors have reported that the categorical assignments made by people with dyslexia tend to be obscure [13, 14, 16–18], others have reported no clear difference between dyslexic patients and controls [28]. Other researchers have reported that, while category identification tasks like ours do not show a significant difference between dyslexia groups and control groups, two-syllable discrimination tasks do [24, 29]. Several factors, such as the kind of vocal stimuli (ex. natural voice vs. synthetic voice), the variable which determines the characteristics of the stimulus pair (ex. VOT vs. place of articulation), and the method of data analysis, might affect the results.

Our results show a weak negative correlation between CPI, the index of the clarity of categorical decision-making, and reading time in all 4 tasks, as well as a weak negative correlation between CPI and the number of reading errors in 2 of the 4 tasks. Although these correlations were weak, it should be noted that 6 scores out of 8 showed negative correlations with CPI. Moreover, the number of outlying scores also showed a weak correlation with CPI. The correlation between the number of outlying scores and CPI is important because the more kinds of reading task scores are abnormal, the more strongly disturbance of reading skill is suspected.

The correlations mentioned above were not significant given that the p-values ranged from 0.073 to 0.133. In other words, there was a probability equal to each of these p-values that the analysis showed a negative correlation for each pair by chance although there was no such correlation in reality. Yet the probability of the analysis yielding false negative correlations for all 7 pairs by chance is quite low. Given the consistent negative correlations between reading performance and CPI, it is highly likely that the quality of categorical perception somehow affects reading ability in native Japanese speakers.

Although our data show correlations between the clarity of categorical decision-making and reading ability, these correlations are only modest. Considering that the results of past studies on categorical perception in dyslexic people have not been uniform, it seems likely that obscurity of categorical decision-making may only indirectly affect the manifestation of dyslexia, rather than causing dyslexia directly. Phonological awareness is a metalinguistic ability that enables humans to manipulate sub-word phonological elements such as syllables, rhymes, and phonemes [30]. Speech consists of a continuous stream of acoustic energy: from a physical point of view, spectrographs of speech streams do not show the segmentation that we perceive when we hear individual words. The apparent segmentation of speech sounds is a cognitive/perceptual phenomenon [27]. Categorical perception of a series of tokens of phonetic contrast that vary continuously along a single acoustic dimension should be one of the prerequisites for phonological awareness where it is necessary to segment and map the acoustic stream to phonological representations. In fact, it has been shown using structural equation modeling that speech perception ability, including categorical decision-making, can explain a significant portion of the variance in phonological awareness ability [19]. The modest but consistent correlations revealed in the present study might indicate that speech perception ability affects the development of reading ability indirectly through phonological awareness ability. To clarify the relationship between categorical perception ability and reading ability will require a long-term developmental study examining the correlation between the categorical decision-making ability of preschoolers and their subsequent development of reading ability.

Acknowledgements: This work was supported by a Research Grant (19A–8 "Comprehensive study on making practical guidelines for developmental disorders based on neuroscientific findings") for Nervous and Mental Disorders from the Ministry of Health, Labor and Welfare.

References

1. Shaywitz SE and Shaywitz BA: Dyslexia (specific reading disability). Biol Psychiatry (2005) **57**, 1301–1309.
2. Stein J, Talcott J and Walsh V V: Controversy about the visual magnocellular deficit in developmental dyslexics. Trends Cogn Sci (2000) **4**, 209–211.
3. Tallal P: The science of literacy: From the laboratory to the classroom. Proc Natl Acad Sci USA (2000) **97**, 2402–2404.
4. Nicolson RI, Fawcett AJ and Dean P: Developmental dyslexia: The cerebellar deficit hypothesis. Trends Neurosci (2001) **24**, 508–511.
5. Shaywitz SE and Shaywitz BA: Paying attention to reading: The neurobiology of reading and dyslexia. Dev Psychopathol (2008) **20**, 1329–1349.
6. Vandermosten M, Boets B, Poelmans H, Sunaert S, Wouters J and Ghesquière P: A tractography study in dyslexia: Neuroanatomic correlates of orthographic, phonological and speech processing. Brain (2012) **135**, 935–948.
7. Vellutino FR, Scanlon DM, Sipay ER, Small SG, Pratt A, Chen R and Denckla MB: Cognitive profiles of difficult-to-remediate and readily remediated poor readers: Early intervention as a vehicle for distinguishing between cognitive and experiential deficits as basic causes of specific reading disability. J Educ Psychol (1996) **88**, 601–638.
8. Boets B, De Smedt B, Cleuren L, Vandewalle E, Wouters J and Ghesquière P: Towards a further characterization of phonological and literacy problems in Dutch-speaking children with dyslexia. Br J Dev Psychol (2010) **28**, 5–31.
9. Oishi N and Saito S: Phonological Impairment in Developmental Language Disorders: In Cases of Developmental Dyslexics. Jpn J Logop Phoniatr (1999) **40**, 378–387 (in Japanese).
10. Wakamiya E, Okumura T, Mizuta M, Kurimoto N, Kashiwagi M, Tanaka K, Suzuki S, Satomi K and Tamai H: Kana single letter reading ability in Japanese children with reading disability. Psychiat Neurol Paediatr Jpn (2006) **46**, 95–103 (in Japanese).
11. Seki A, Kassai K, Uchiyama H and Koeda T: Reading ability and phonological awareness in Japanese children with dyslexia. Brain Dev (2008) **30**, 179–188.
12. Hurford DP and Sanders RE: Assessment and remediation of a phonemic discrimination deficit in reading disabled second and fourth graders. J Exp Child Psychol (1990) **50**, 396–415.
13. Vandermosten M, Boets B, Luts H, Poelmans H, Golestani N, Wouters J and Ghesquière P: Adults with dyslexia are impaired in categorizing speech and nonspeech sounds on the basis of temporal cues. Proc Natl Acad Sci USA (2010) **107**, 10389–10394.
14. Paul I, Bott C, Heim S, Wienbruch C and Elbert TR: Phonological but not auditory discrimination is impaired in dyslexia. Eur. J. Neurosci. 2006; **24**: 2945–2953.
15. Wolf CG. The perception of stop consonants by children. J Exp Child Psychol (1973) **16**, 318–331.
16. Godfrey JJ, Syrdal-Lasky AK, Millay KK and Knox CM: Performance of dyslexic children on speech perception tests. J Exp Child Psychol (1981) **32**, 401–424.
17. Manis FR, McBride-Chang C, Seidenberg MS, Keating P, Doi LM, Munson B and Petersen A: Are speech perception deficits associated with developmental dyslexia? J Exp Child Psychol (1997) **66**, 211–235.
18. Dufor O, Serniclaes W, Sprenger-Charolles L and Demonet JF: Top-down processes during auditory phoneme categorization in dyslexia: A PET study. Neuroimage (2007) **34**, 1692–1707.
19. McBride-Chang C. What is phonological awareness? J Educ Psychol (1995) **87**, 179–192.
20. Ogino T, Takahashi Y, Hanafusa K, Watanabe K, Morooka T, Takeuchi A, Oka M, Sanada S and Ohtsuka Y: Reading skills of Japanese second-graders. Pediatr Int (2011) **53**, 309–314.
21. Hashimoto R, Kashiwagi M and Suzuki S: Attempt for development of rapid word reading test for children: Evaluation of reliability and validity. No To Hattatsu (2008) **40**, 363–369 (in Japanese).
22. Kasai K, Seki A and Koeda T: Fundamental deficits of reading sentences in Japanese dyslexia. Psychiat Neurol Paediatr Jpn (2008) **46**, 39–44 (in Japanese).
23. Lisker L and Abramson AS: A cross-language study of voicing in initial stops: Acoustical measurements. Word (1964) **20**, 384–422.
24. Bogliotti C, Serniclaes W, Messaoud-Galusi S and Sprenger-Charolles L: Discrimination of speech sounds by children with dyslexia: Comparisons with chronological age and reading level controls. J Exp Child Psychol (2008) **101**, 137–155.
25. Spreen O and Strauss E. A Compendium of Neuropsychological Tests. 2nd Ed. Oxford University Press, New York (1998) pp. 83–90.
26. Uno A, Shinya N, Haruhara N and Kaneko M: Raven's Coloured Progressive Matrices in Japanese Children —As a Screening Intelligence Test for Children with Learning Disorder and Acquired Childhood Aphasia—. Jpn J Logop Phoniatr (2005) **46**, 185–189 (in Japanese).
27. Wagner RK and Torgesen JK: The nature of phonological processing and its causal role in the acquisition of reading skills. Psychol Bull (1987) **101**, 192–212.
28. Veuillet E, Magnan A, Ecalle J, Thai-Van H and Collet L: Auditory processing disorder in children with reading disabilities: Effect of audiovisual training. Brain (2007) **130**, 2915–2928.
29. Brandt J and Rosen JJ: Auditory phonemic perception in dyslexia: Categorical identification and discrimination of stop consonants. Brain Lang (1980) **9**, 324–337.
30. Bentin S: Phonological awareness, reading and reading acquisition: A survey and appraisal of current knowledge. Haskins Laboratories Status Report (1992) SR-111/112, 167–180.

Accepted March 31, 2014.