

Characteristics of Developmental Dyslexia in Japanese Kana: from the Viewpoint of the Japanese Feature

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Abstract

This study identified the individual differences in the effects of Japanese Dyslexia. The participants consisted of 12 Japanese children who had difficulties in reading and writing Japanese and were suspected of having developmental disorders. A test battery was created on the basis of the characteristics of the Japanese language to examine Kana's orthography-to-phonology mapping and target four cognitive skills: analysis of phonological structure, letter-to-sound conversion, visual information processing, and eye-hand coordination. An examination of the individual ability levels for these four elements revealed that reading and writing difficulties are not caused by a single disability, but by a combination of factors. Additionally, the combination of individual elements differed among the participants, which indicates that children with learning disabilities may need different types of support even if they have similar reading and writing difficulties. Furthermore, this study demonstrated that words written in Kana, one of the Japanese syllabic, are easy to segment into phonological units, but difficult to interpret when attempting to link each letter to its corresponding sound. These findings can help change the concept of Japanese dyslexia and have a significant impact on education methods and techniques in Japan.

Keywords: Developmental dyslexia; Japanese; Kana; Individual differences; Test battery

Introduction

Developmental dyslexia is characterized by unexpected difficulties in reading in children and adults who otherwise possess the intelligence and motivation considered necessary for accurate and fluent reading [1]. The definition of dyslexia, adopted by the International Dyslexia Association (IDA) Board of Directors on Nov. 12, 2002 [2], is as follows: Dyslexia is a specific learning disability that is neurological in origin. Dyslexia is characterized by difficulties with accurate and/or fluent word recognition and by poor spelling and decoding abilities. These difficulties typically result from a deficit in the phonological component of language that is often unexpected in relation to other cognitive abilities and the provision of effective classroom instruction. Secondary consequences may include problems in reading comprehension and reduced reading experience that can impede both vocabulary growth and background knowledge. Additionally, people with dyslexia also have problems with writing [3]. Furthermore, dyslexia is often associated with undesirable outcomes, such as lower educational attainment and loss of self-confidence [4,5], because reading is essential for all aspects of learning ranging from using school text books to the latest technology (e.g., ebooks and smart phones). On the basis of these facts, dyslexia should be evaluated at an early stage by an appropriate assessment, and the required learning support should be provided to the dyslexic people before secondary impediments occur [6]. In this regard, remediation, based on explicit, systematic instruction of letter-to-speech integration (decoding strategies), appears to be the most efficient treatment [4,5,7]. However, dyslexia remediation is far from being fully achieved [4] and the cognitive processes underlying the improvement in reading abilities remain unclear [4,8]. Therefore, this study examined the reading and writing difficulties of people with dyslexia to clarify the cognitive functions that cause this disorder and establish an effective support program for these individuals.

According to the IDA, an impaired auditory discrimination of spoken language is widely assumed to characterize dyslexic individuals

in English-speaking countries [1,9,10]. According to this phonological deficit hypothesis, such difficulty results from an impaired ability to segment the speech stream into phonological units and associate each unit with its corresponding letter [1]. According to the double-deficit hypothesis [11-13], the phonological deficits and processes underlying naming-speed deficits represent two separable sources of reading dysfunction. In this hypothesis, they assume two single-deficit subtypes with more limited reading impairments and one double-deficit subtype with more pervasive and severe impairments. In addition, plural activities are included in reading and writing and it is assumed that any impairment can lead to developmental disorders. Numerous studies on developmental dyslexia have addressed various cognitive abilities including: vergence eye movement control [14]; visual perception [15,16]; temporal information processing [15]; orthographic skills for recognizing the visual form of words, which allows one to directly access their meaning [17]; dynamics of spatial visual attention [18]; serial visual search [19,20]; automatization of verbal responses [21]; motor skills [22]; spelling [3]; automatic letter writing, written composition, copying [23]; and dictation with or without visual feedback [23].

As described above, all of the multiple interacting mechanisms that vary among people with developmental dyslexia. Thus, the difficulties of people with developmental dyslexia may reveal various symptoms on the basis of their learning state and life stage. However, we want to focus more on the basic abilities involved in reading and writing; since

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previous studies have suggested that developmental dyslexia could arise from a basic cross-modal association to a word-sound integration deficit [8,24-26], the present study focused on orthography-to-phonology mapping and the cognitive abilities related to this function.

There are different manifestations of developmental dyslexia in various languages [27]. Dyslexia is not a general deficit that will apply to any orthography, but it is an interaction between a cognitive deficit and the specific demands of the orthography to be learned [28]. One of the points of attention is orthographic consistency [28-32]. If the orthography is inconsistent, then the mapping of letters to word sounds will become complicated. Another point of attention is psycholinguistic grain size [28,32,33]. If psycholinguistic grain size is small, then the mapping of letters to word sounds will also become complicated.

In alphabetic languages, where finer “grain” processing of orthography-to-phonology mapping is required, developmental dyslexia occurs in a large group [34]. Compared with alphabetic languages, Japanese is exceptionally peculiar in that it includes many characters with several types of scripts. In fact, the modern Japanese writing system uses three main scripts: Kana (Hiragana, Katakana), Kanji, and Romaji (Romanized Japanese) (Appendix 1). Kana is a pair of syllables consisting of Hiragana (used along with Kanji for native or naturalized Japanese words and for grammatical elements) and Katakana (mainly used for foreign words and names, loanwords, onomatopoeia, scientific names, and sometimes to replace Kanji or Hiragana for emphasis). Modern written Japanese also uses acronyms from the Latin alphabet (e.g., BC/AD, a.m./p.m., and CD). Several thousand Kanji are in regular use and it consists of adapted Chinese characters, while Kana comprises Hiragana and Katakana, each containing 46 basic characters (71 including diacritics), with each character representing one sound in the Japanese language [35]. Almost all Japanese sentences contain both Kanji and Hiragana, while some also include Katakana. Because of this mixture of scripts and the large inventory of Kanji characters, the Japanese writing system is often considered as one of the most complicated in the world. Japanese children begin learning Hiragana at the age of 6 in the first year of elementary school and then learn Katakana by the second year of elementary school. Since Kanji are in significant numbers, children continue learning it in the following years as well. As mentioned above, Kana is a basic Japanese grapheme in which each Kana’s psycholinguistic grain size is a syllable, which means the granularity of the smallest orthographic unit representing phonology is finer than the entire word, but coarser than the phoneme. Moreover, Kana’s orthography-to-phonology translation relationship is at the syllable level and for this reason, Kana does not produce a high incidence of phonological dyslexia [28].

In Japan, official reports claim that 4.5% of elementary and junior high school students enrolled in normal classes experience learning difficulties [36] and the percentages of children categorized as dyslexic differed according to the script. According to further investigation of this percentage with regards to reading and writing, the findings were: 0.2% and 1.6% for Hiragana, 1.4% and 3.8% for Katakana, and 6.9% and 6.0% for Kanji, respectively [34]. At this point, the following two questions arise: 1) Why is the degree of difficulty different for Hiragana and Katakana despite the fact that they include the same features? And 2) Why do some children have difficulties with Katakana and not with Hiragana? Perhaps the reasons are not only due to Katakana’s relatively low use (compared with Hiragana) but also because of some features of Katakana. To answer these questions, examining the cognitive futures related to Kana acquirement is necessary. However, there is no consensus in the opinion of assessment and guidance for developmental dyslexia in Japan [37].

For considering Kana’s orthography-to-phonology mapping, the cognitive abilities related to this function are the subject of focus. During reading, it is important to recognize letters, convert each letter into corresponding sounds, and pronounce each group of sounds correctly, while during writing, one must analyze sounds that he/she hears, convert each sound into corresponding letters, and use a writing instrument to write the letters. Since many dyslexic people do not have problems in pronunciation itself, this study focused on four cognitive skills: analysis of phonological structure, letter-to-sound conversion, visual information processing, and eye-hand coordination. Although the implications of processing speed for diagnosis and intervention in developmental dyslexia has been pointed out [11-13,21], the present study excluded processing speed since it is not included in the cognitive abilities when initially learning how to read or write.

The main ability for analyzing the phonological structure of sound in Japanese, which is necessary for acquiring Kana, is phonological segmentation and phonological isolation [38]. Phonological segmentation requires breaking down the words to individual sounds. For example, when asked “Tell me how many sounds there are in the word ‘ka-ta-tsu-mu-ri’” (the Japanese word for snail), the answer is “five sounds ‘ka’, ‘ta’, ‘tsu’, ‘mu’, and ‘ri.’” Japanese children acquire this ability when they become four and a half years old [38-40]. Phonological isolation requires recognizing the individual sounds in words. For instance, when asked “Tell me the second sound you hear in the word ‘ka-ta-tsu-mu-ri’”, the answer is “ta.” In general, Japanese children acquire this ability when they reach five-and-half years of age [38-40]. Children with phonological disorders and poor phonological awareness are considered to have a high risk of reading difficulties [41,42]. Furthermore, many children with poor abilities in reading and writing have difficulties in segmenting words that include “sokuon,” the geminate consonant of Japanese in words such as “yotto” (the Japanese word for yacht) [43,44]. To assess letter-to-sound conversion, it is important to focus careful attention on the system of reading. There are two strategies in reading, one is a sublexical processing strategy based on sound-to-letter conversion [1,2,] and the other is a lexical strategy based on whole-word recognition. This means that when determining a person’s ability to perform letter-to-sound conversions during reading, word tests and nonword tests must be administered.

Finally, previous studies have examined visual information processing in Japanese children with developmental dyslexia [34,45-47]. In visual information processing, visual function abnormalities affect visual perception, and as a result, visual recognition and visual memory can affect the symptoms of dyslexia [45]. The Rey-Osterrieth Complex Figure Test is commonly used to assess these abilities in dyslexic people [34,45,46]. However, although these tests are commonly used, since they involve making a copy, it is difficult to distinguish whether there are difficulties in visual perception or writing ability based on eye-hand coordination. To avoid this problem, taking the Japanese version of the Developmental Test of Visual Perception (DTVP) [48] is useful for examining the details of visual information processing. More specifically, the DTVP can individually examine visual perception and writing ability based on eye-hand coordination [49-51]. Furthermore, it is important to realize that reading and writing skills can be improved to some extent through training. Kana is easy to acquire since its orthography-to-phonology translation is at the syllable level and it includes almost a one-to-one relationship [28]. Some children with dyslexia study hard and it is not uncommon for them to master reading and writing through self-motivation and determination. However, during research about dyslexia in Japan, children with possible dyslexia are identified according to their levels of reading and writing [52-55].

Thus, the present study selected participants with learning disorders, who have/had difficulties in reading/writing and were judged suitable for this research by doctors.

The purpose of this study is twofold. First, to create a test battery, according to the characteristics of the Japanese language, in order to examine Kana's orthography-to-phonology mapping and target four cognitive skills: analysis of phonological structure, letter-to-sound conversion, visual information processing, and eye-hand coordination. Second, to illustrate the difficulties related to cognitive futures in acquiring Katakana. The authors of this study made the following two predictions: (1) The dyslexia of Japanese Kana, the simplest character to acquire, is the result of multiple causes; and (2) All of the factors related to reading and writing may affect the difficulties that these children encounter in various ways, according to individual differences

Materials and Methods

Participants

The participants consisted of 12 Japanese children (8 boys, 4 girls), who were patients at the Nagoya City Child Welfare Center and Nagoya Central Care Center for Disabled Children. On the basis of the issues presented by their mothers, the doctor judged that all of them had difficulties in reading and writing, which implied that they may have developmental dyslexia. However, no assessment was used for this judgment since an appropriate assessment battery for Japanese dyslexia had not yet been established. As presented in Table 1, the children's mean age was 9.6 years (SD=0.8 years) in December 2010 and their grade level ranged from the third through the sixth grades. All of them were enrolled in regular elementary school classes. The children's mean attendance for the learning support activities at the Nagoya City Child Welfare Center was 1.7 years (0.4-2.5 years). Every child was either diagnosed as having learning disabilities or suspected of being learning disabled by a doctor on the basis of the Diagnostic and Statistical Manual of Mental Disorders, 4th Edition (DSM-IV). According to the Wechsler Intelligence Scale for Children, Third Edition (WISC-III), the Full Scale IQ scores ranged from 79 to 112 (with a mean IQ score of 97.8 (SD=9.4)), the Verbal IQ scores ranged from 72 to 120 (with a mean IQ score of 100.7 (SD=12.0)), and the Performance IQ scores ranged from 80 to 120 (with a mean IQ score of 95.1 (SD=10.4)). None of the children stuttered and all of them could correctly produce

sounds. For these reasons, this study did not analyze pronunciation capabilities. Furthermore, 5 children exhibited symptoms of pervasive developmental disorder (PDD), 2 had attention deficit hyperactivity disorder (AD/HD), and 2 had both PDD and AD/HD. However, reading disability and AD/HD represent separate disorders that frequently co-occur [56] and although there is no report that reading disability can co-occur with PDD, there is evidence that some children with autism spectrum disorder have specific language impairment [57]. In Japan, some children with PDD have difficulties in reading and writing despite being educated, and they are thought to have such difficulties as a result of a learning disability. Finally, we organized the physical environment, in order to scale back the influence of possible PDD or ADHD factors for the tests, and minimized the visual and auditory stimulation since the concentration of children with PDD and ADHD is sometimes inhibited by the environment.

Stimuli and procedure

The data was collected between May 2010 and December 2010. The participants were individually tested in a quiet room at the Nagoya City Child Welfare Center at least five times for approximately 40 minutes each. The children were told that these were not academic achievement tests and that only the investigators would see their results. We administered the basic reading and writing tests in order to determine the participants' level of acquisition for reading and writing skills. We also administered four tasks to analyze the four cognitive skills (analysis of phonological structure, visual information processing, letter-to-sound conversion, and eye-hand coordination).

Basic reading and writing tasks

Each participant performed five reading tests and five writing tests to determine their reading and writing abilities. In this case, the Screening Test of Reading and Writing for Japanese Primary School Children (STRAW) [58] was used, which includes each of the following: Hiragana character reading, Katakana character reading, Hiragana word reading, Katakana word reading, Kanji word reading, Hiragana character writing, Katakana character writing, Hiragana word writing, Katakana word writing, and Kanji word writing tests. The Kanji test was the test used in Japan for every third-grade student. Each character reading/writing test consisted of 20 characters while each word reading/writing test consisted of 20 known words. In the reading tests, the children were asked to read characters or words printed in the STRAW, whereas in the writing tests, the children were asked to write down the characters or words stated by the operator. In each test, the scores were recorded and each score from 0 to 20 was changed into the minimum 0 and maximum 1.

Analysis of phonological structure task

Since no standardized tests exist for phonological awareness, we created new tasks and administered the tests by referring to the tests performed in some previous studies [38-40,42,43]. Each participant performed two phonological awareness tests: the isolation of resonant sounds test and the segmentation of words, including the sokuon test (the segmentation of sokuon test). Isolating resonant sounds requires the participants to recognize the individual resonant sounds in words, for example, "Tell me the second sound of the word that you hear." The experimental stimuli of the isolation of resonant sounds test included 10 words of 5 characters each such as "ka-ta-tsu-mu-ri" (the Japanese word for snail). The participants were asked to identify the second sound in three words, the third sound in four words, and the fourth sound in three words. The achievement scale was above 8/10. Finally, the segmentation of sokuon test requires participants

Child	Gender	Age (Years; Months)	Grade	Dual diagnosis	
A	m	11; 9	6	PDD	
B	m	11; 0	5		AD/HD
C	m	9; 10	4		AD/HD
D	m	9; 9	4	PDD	
E	m	9; 9	4		
F	m	9; 8	3	PDD	
G	m	9; 4	3		
H	f	9; 3	3	PDD	
I	f	9; 0	3	PDD	
J	m	8; 11	3	PDD	AD/HD
K	f	8; 11	3	PDD	AD/HD
L	f	8; 10	3		

Note. M = Male, F = Female, PDD = Pervasive Developmental Disorder, ADHD = Attention Deficit/Hyperactivity Disorder.

Table 1: Participant profiles.

to recognize the number of sounds in the words, as in, for example, “Tell me how many characters are in the word that you hear.” For this test, the experimental stimuli included 10 words, 6 sokuon words and 4 resonant sound words of which all of them consisted of three to six characters. In each test, the scores were recorded, and again, the achievement scale was above 8/10.

Letter-to-sound conversion task

Each of the participants performed six reading tests and six writing tests to examine their letter-to-sound conversion abilities. The eight tests were subtests of the STRAW [58], which included the same tests as the basic reading and writing task: Hiragana character reading, Katakana character reading, Hiragana word reading, Katakana word reading, Hiragana character writing, Katakana character writing, Hiragana word writing, and Katakana word writing tests. The character reading/writing test consisted of 20 characters while the word reading/writing tests consisted of 20 known words. The other four tests, each consisting of 10 non-words, were the Hiragana non-word reading test, the Katakana non-word reading test, the Hiragana non-word writing test, and the Katakana non-word writing test. In the reading tests, the children were asked to read characters or words printed in the STRAW or on paper. In the writing tests, the children were asked to write down the characters or words stated by the operator. In each test, the scores were recorded. The achievement scale of each test was equal to or greater than 90% and each score from 0 to 20 (or from 0 to 10) was changed into the minimum 0 and maximum 1. For the reading task, if a child's score on all of the reading tests (for each condition of Hiragana or Katakana) was above the achievement scale, then he/she passes the letter-to-sound conversion task. Moreover, if a child's score on the word reading test was above the achievement scale, but the character reading test or the non-word reading test was below the achievement scale, then he/she could use a lexical strategy based on whole word recognition. However, he/she could not use a sub-lexical processing strategy based on a grapheme-to-phoneme conversion. In this case, this child fails the letter-to-sound conversion task. Furthermore, if a child's score on the word reading test was below the achievement scale, then he/she was considered as not having acquired the characters. The same was true for the writing tests.

Visual information processing task

Each participant performed two subtests of the DTVP [48]: figure-ground perception and spatial relations. The two subtests were determined by referring to previous research [49]. On the basis of the guidelines of the DTVP, the participants were asked to draw the outlines of figures with colored pencils, link points in the lines, and so on. Perceptual age and the scaled score (SS) of each test were also determined by the test. In this case, if the SS was eight or less, then perceptual age was judged to be younger than calendar age. Moreover, individual tests are not sufficiently different for measuring separate abilities [59] and all of the tests are thought to be related to visual perception. In this study, the participant only passed the task if his/her score was more than eight on all of the subtests.

Eye-hand coordination task

Each participant performed one subtest of the DTVP [48]: eye-hand motor coordination. The subtest was determined by referring to previous research [49]. The participants were asked to draw lines with pencils according to the guidelines of the DTVP. Perceptual age and the SS of each test were determined by the using the DTVP. In this case, if perceptual age was younger than calendar age, then the SS was equal or less than eight. Again, each participant only passed the task if his/her score on the subtest was more than eight.

Results

Basic reading and writing task

Table 2 presents the results of the basic reading and writing task of each child as well as the average and standard deviation of third-grade children (103 boys and 88 girls) from the STRAW [60]. If a child's score was lower than two standard deviations from the average, then it was deemed clearly abnormal [58]. In the reading test, Child L had difficulty reading Katakana characters, while Child F had difficulty reading both Katakana characters and Katakana words. In the Kanji word reading test, Child H, J, and L had difficulties. In the writing test, except for Child C and L, all of the children had some type of difficulty. However, Child C and L also had low scores when they began their reading and writing lessons (before the beginning of this research).

Child	Reading					Writing				
	Hiragana Character	Hiragana Word	Katakana Character	Katakana Word	Kanji Word	Hiragana Character	Hiragana Word	Katakana Character	Katakana Word	Kanji Word
A	1	1	1	1	0.95	1	1	0.75	0.7	0.75
B	1	1	1	1	1	0.7	0.5	0.65	0.65	0.3
C	1	1	1	1	1	1	0.9	0.75	0.95	0.9
D	1	1	1	0.95	1	0.95	0.85	0.95	0.8	0.9
E	1	1	1	1	1	1	0.9	0.9	0.7	0.55
F	0.95	0.9	0.3	0.2	0.9	0.55	0.25	0.05	0	0.25
G	1	1	0.95	1	1	1	0.9	0.85	0.55	0.65
H	0.95	1	1	0.95	0.85	0.7	0.75	0.85	0.9	0.3
I	1	1	1	1	1	1	0.95	0.9	0.75	0.75
J	0.95	1	0.95	1	0.8	0.9	0.9	0.25	0.45	0.45
K	0.95	1	1	1	0.95	1	0.95	0.9	0.9	0.85
L	0.95	0.95	0.75	0.9	0.6	0.95	0.9	0.15	0.1	0.25
Control -boys (SD)	0.995 (0.02)	1 (0.01)	0.995 (0.02)	0.995 (0.015)	0.955 (0.045)	0.97 (0.045)	0.975 (0.05)	0.855 (0.175)	0.9 (0.18)	0.95 (0.08)
Control -girls (SD)	1 (0.01)	1 (0.01)	0.995 (0.02)	0.995 (0.015)	0.95 (0.045)	0.985 (0.035)	0.985 (0.035)	0.915 (0.135)	0.97 (0.055)	0.985 (0.035)

Note. Each score from 0 to 20 was changed into the minimum 0 and maximum 1. The control scores are the averages of the boys (n = 103) and the girls (n = 88) in the third grade from the Screening Test of Reading and Writing for Japanese Primary School Children (STRAW).

Table 2: Details of the basic reading and writing tasks.

Analysis of phonological structure task

As shown in Table 3, every child passed the isolation of resonant sounds test (Table 3). In the segmentation of sokuon test, only Child F failed. On the basis of this result, Child F is thought to have difficulty segmenting words that include sokuon. In addition, he had difficulty writing down sokuon words correctly since he could not distinguish sokuon words from the non-sokuon words. In this study, only 1 participant had difficulties in phonological awareness and this finding is in agreement with previous research [28]. Since the Japanese language is based on sub-syllabic units or morae [60], it is relatively easy to segment spoken words into phonologic parts.

Letter-to-sound conversion task

Table 4 presents the details of the letter-to-sound conversion task, while Table 5 shows the results of the letter-to-sound conversion task. With regard to reading tests, 4 children (Child A, B, I, and K) passed all of the reading tests, and as a result, they passed the letter-to-sound conversion task. 2 children, Child H and J, had difficulties in letter-to-sound conversion in both the Hiragana and Katakana tasks, while Child F (who did not acquire Katakana) had difficulties in letter-to-sound conversion in Hiragana. 5 children (Child C, D, E, G, and L) passed the task in Hiragana, but failed in Katakana. The children who failed this task in reading seemed to have the ability to read words, but not the ability to use letter-to-sound conversion. Thus, they will have difficulties in reading new words or texts. Concerning writing tests, no child passed all of the writing tests. Four children (Child A, C, I, and L) passed the task in Hiragana, but failed (or were judged to not acquire) the task in Katakana. Meanwhile, some other children failed in both Hiragana and Katakana. The children who failed this task in writing seemed to have the ability to write words, but not the ability to use letter-to-sound conversion. Therefore, they will have difficulties in writing new words or texts with accuracy.

Since the children who failed this task read or wrote letters using the aid of vocabulary, rather than using letter-to-sound conversion, it is extremely important to determine whether they can perform letter-to-sound conversions, which can be tested by adding nonsense word reading and writing tests to the standard reading and writing tests for Japanese children. Additionally, there are important differences between the results of the reading and writing tests. In Japan, children with difficulties in writing are often considered to have difficulties in

reading. However, it is important to evaluate their capabilities through individual assessments rather than making premature assumptions.

Furthermore, there can be significant differences between the results of Hiragana and Katakana capabilities. Although there are some typical children who have difficulties in writing Katakana, almost every child can read Katakana once they pass the third grade [58]. Thus, difficulties of letter-to-sound conversion in Katakana should be especially mentioned. Since none of these participants stuttered and all of them could correctly produce sounds, the reading results of the letter-to-sound conversion task may show the children's true abilities regarding such conversion. Conversely, the writing results of the letter-to-sound conversion task may be somewhat influenced by other abilities and thus, they may not present these true abilities.

Visual information processing task

As presented in Table 3, only 3 out of the 12 children (Child B, F, and L) passed the visual perception task, which means that the other nine children had problems recognizing the characters at some level. This difficulty in visual information processing with developmental dyslexia is in agreement with the findings of previous studies [34,45,46,47]. Children with difficulties in visual information processing may also have difficulties distinguishing similar characters and writing letters correctly. In English-speaking countries, some children have visual confusion with a tendency to transpose letters (e.g., "was" for "saw," "god" for "dog"), reverse letters (e.g., "words" for "worbs"), and they experience distortion, blurring, and superimposition [15]. In Japanese, some characters include the following features: similar forms, as in the case of [a] and [me] in Hiragana; or forms that are almost the same, but differ in direction, as in the case of [shi] and [tsu] in Hiragana (Appendix 2). There are many types of characters in Japanese, such as Hiragana, Katakana, Kanji, and Romaji (Appendix 1), and Kanji, in particular, includes many strokes. Thus, since difficulties in visual perception possibly create problems in acquiring the Japanese written system, future examination regarding this possibility is important.

Eye-hand coordination task

As shown in Table 3, 3 out of the 12 children (Child E, H, and L) passed this task, which means that the other nine children's writing movements may be related to their writing difficulties. Children with difficulties in eye-hand coordination may also have difficulties in

Child	Phonological Structure Task			Visual Information Processing Task			Eye-hand Coordination Task	
	JUDGE	Isolation of Resonant Sounds Test	Segmentation of sokuon Test	JUDGE	Figure Ground	Spatial Relations	JUDGE	Eye-hand Motor Coordination
A	P	10	10	F	10	7	F	5
B	P	10	10	P	10	10	F	5
C	P	9	10	F	7	8	F	6
D	P	10	10	F	6	8	F	8
E	P	10	10	F	10	8	P	10
F	F	10	6	F	5	7	F	6
G	P	10	8	P	10	9	F	7
H	P	10	10	F	8	7	P	10
I	P	10	10	F	8	9	F	7
J	P	10	9	F	8	9	F	9
K	P	10	10	F	7	9	F	5
L	P	10	9	P	9	9	P	10

Note. P = Passed and F = Failed.

In the phonological awareness task, the raw scores from 0 to 10 are shown and the achievement scale is above 8/10. In the visual perception and the writing movement tasks, the scaled scores from 0 to 10 are shown and the achievement scale is above 9/10.

Table 3: Results of the analysis of phonological structure task, the visual information processing task, and the eye-hand coordination task.

Child	Reading						Writing					
	Hiragana Character	Hiragana Word	Hiragana Nonword	Katakana Character	Katakana Word	Katakana Nonword	Hiragana Character	Hiragana Word	Hiragana Nonword	Katakana Character	Katakana Word	Katakana Nonword
A	1	1	0.9	1	1	0.9	1	1	0.9	0.75	0.7	0.9
B	1	1	1	1	1	1	0.7	0.5	0.6	0.65	0.65	0.7
C	1	1	0.9	1	1	0.7	1	0.9	0.9	0.75	0.95	0.7
D	1	1	1	1	0.95	0.7	0.95	0.85	0.9	0.95	0.8	0.8
E	1	1	0.9	1	1	0.7	1	0.9	0.6	0.9	0.7	0.6
F	0.95	0.9	0.6	0.3	0.2	0	0.55	0.25	0.6	0.05	0	0
G	1	1	0.9	0.95	1	0.8	1	0.9	0.6	0.85	0.55	0.7
H	0.95	1	0.7	1	0.95	0.8	0.7	0.75	0.7	0.85	0.9	0
I	1	1	1	1	1	0.9	1	0.95	1	0.9	0.75	0.8
J	0.95	1	0.6	0.95	1	0.8	0.9	0.9	0.9	0.25	0.45	0.2
K	0.95	1	0.9	1	1	0.9	1	0.95	0.8	0.9	0.9	0.9
L	0.95	0.95	0.9	0.75	0.9	0.4	0.95	0.9	0.8	0.15	0.1	0

Note. Each score from 0 to 20 or from 0 to 10 was changed into the minimum 0 and maximum 1.

Table 4: Details of the letter-to-sound conversion task.

Child	Reading		Writing	
	Hiragana	Katakana	Hiragana	Katakana
A	P	P	P	N
B	P	P	N	N
C	P	F	P	F
D	P	F	N	N
E	P	F	F	N
F	F	N	N	N
G	P	F	F	N
H	F	F	N	F
I	P	P	P	N
J	F	F	P	N
K	P	P	N	P
L	P	F	N	N

Note. P = passed, F = failed, and N = not acquired.

Table 5: Results of the letter-to-sound conversion task.

writing, especially writing based on Japanese baselines (Tome, Hane, and Harai). When difficulties in reading and writing were examined in previous studies, “eye–hand coordination” measurement was seldom performed. However, since the children in the present study had difficulties in writing movement, it was important to examine this ability in order to provide suitable support. In the future, analyzing how the difficulties of writing movements contribute to the difficulties of writing similar characters, such as like [a] and [me] in Hiragana, should be the subject of focus (Appendix 2).

Analysis of the results

Table 6 shows a summary of the results for each task. In Table 6, the results of the letter-to-sound conversion task are shown for the reading task. If children failed the task in either Hiragana or Katakana, then they are shown as failed in the table. Since none of the participants stuttered and all of them could correctly produce sounds, the reading results of the letter-to-sound conversion task may truly show the children’s ability to convert letters into sounds. In contrast, the writing results of the letter-to-sound conversion task may be somewhat influenced by other abilities and thus, the results may not correctly show this particular ability.

Out of the 16 possible patterns from the combination of the 4 cognitive abilities, only 7 patterns were actually observed in the present study. First, although Child L failed the letter-to-sound conversion

task, she currently seems to have no difficulties in reading and writing since she has the ability to read and write words. However, since she has difficulty using letter-to-sound conversion as well as reading and writing new words or texts with accuracy, she has the possibility of being judged as idle by those who have no knowledge of dyslexia. Second, although Child B failed the eye–hand coordination task, he showed good performance in reading. However, he failed to acquire writing (Tables 2, 4 and 5) and thus, instruction that addressed eye–hand coordination (e.g., notebooks with large spaces for writing or being told to write in any easy way without adhering to the usual writing order) was necessary. Third, 2 children (Child E and H) failed the visual information processing and the letter-to-sound conversion tasks. In this case, both children received good scores for reading words, but not for reading nonwords (Tables 2, 4 and 5). Regarding their instruction, extra care was necessary such as highlighting the text for them. Moreover, they also had difficulties in writing, and similar to child B, their difficulties were not from eye–hand coordination, but from visual information processing. This means that they require instruction that focuses on visual information processing (e.g., large characters or the components of the character are classified by color). Fourth, Child G failed the letter-to-sound conversion and eye–hand coordination tasks. Fifth, 3 children (Child A, I, and K) failed the visual information processing and eye–hand coordination tasks. Sixth, 3 children (Child C, D, and J) passed only the analysis of phonological structure test. Finally, since Child F failed all of the tests, he requires consideration from all standpoints, especially in regard to phonological awareness [44].

Discussion

The purpose of this study was twofold. (1) To create a test battery according to the characteristics of the Japanese language to examine Kana’s orthography-to-phonology mapping and target four cognitive skills: analysis of phonological structure, letter-to-sound conversion, visual information processing and eye–hand coordination. (2) To illustrate the cognitive futures related to Katakana acquirement difficulties. In this study, we predicted the following: (a) Dyslexia for Japanese Kana, the simplest character to acquire, is a result of multiple causes; and (b) All factors related to reading and writing can affect the difficulties these children encounter in various ways based on the individual differences [61].

On the basis of the results of the basic reading and writing tasks, only a few participants in this study, who were supposed to have

Child	APS	LSC	VIP	EHC
A	P	P	F	F
B	P	P	P	F
C	P	F	F	F
D	P	F	F	F
E	P	F	F	P
F	F	F	F	F
G	P	F	P	F
H	P	F	F	P
I	P	P	F	F
J	P	F	F	F
K	P	P	F	F
L	P	F	P	P

Note. APS = Analysis of phonological structure, LSC = Letter-to-sound conversion, VIP = Visual information processing, EHC = Eye-hand coordination, P = Passed, F = Failed.

Table 6: Summary of the results of each task. If children failed in the letter-to-sound conversion task (either in Hiragana or Katakana), then they are shown as failed in Table 6.

developmental dyslexia, had difficulties in Kana. This means that Japanese dyslexia does not always present any difficulties, at least on the surface, as a result of training. However, some difficulties were apparent in the cognitive abilities of reading and writing. As shown in Table 6, by examining the individual scores for the four elements (analysis of phonological structure, letter-to-sound conversion, visual information processing, and eye-hand coordination), it becomes apparent that reading and writing difficulties are not caused by a single disability but by a combination of factors. Furthermore, the combination of individual elements differs depending on the individual. Confirmation of our hypothesis is supported on the basis of these results. Children with learning disabilities may need separate support for different elements even if they have the same symptoms or reading and writing difficulties [62].

In this study, only child F failed the analysis of phonological structure task. However, some children failed the letter-to-sound conversion task since they failed the Katakana test (see Table 5). In particular, child L passed the other tasks such as the analysis of phonological structure task, the visual information processing task, and the eye-hand coordination task. Thus, the following two questions arise: 1) Why is the degree of difficulty different for Hiragana and Katakana despite the fact that they include the same features? And 2) Why do some children have difficulties with Katakana and not with Hiragana? The possible common reason is not only due to Katakana's relatively low use (compared with Hiragana), but also because of some features of Katakana [34]. However, because Katakana's script changes are almost the same as those in Hiragana [63], there must be the influence of other mechanisms as well. Therefore, we reconsidered the characteristics of Kana, which is said to have a one-to-one orthography-to-phonology translation relationship [28]. However, Kana also includes a one-to-one relationship from the character standpoint (not from a sound standpoint), which is illustrated in Figure 1. Notably, seven children passed the phonological awareness task, but failed the letter-to-sound conversion task (Table 6).

The findings of this study can have a significant impact on education methods and techniques in Japan in two ways. First, it can help change the concept of Japanese dyslexia in the phonological model. According to the phonological model, dyslexic children have certain difficulties in writing and reading because of their impaired ability to segment the speech stream into phonological units and associate each phonologic unit with its corresponding letter [1]. In this regard, Kana includes

the following feature: it is easy to segment into phonological units, but difficult when attempting to link each letter to its corresponding sound. When acquiring Katakana (the second script of Kana), Hiragana (the first script of Kana) may cause difficulties in retaining it, which can explain the confusion of writing in Hiragana and Katakana. As shown in Figure 2, these sentences were written in Hiragana, but the letters with circles were written in Katakana. In addition, the student was learning how to write in Katakana, but the Katakana letters had caused confusion when recalling Hiragana. First language literacy learning strategies can be influenced by the acquisition of second language literacy skills [64], which can be both a good and bad influence. Depending on the individual's cognitive ability, considering the influence of previously acquired letters when learning new letters is necessary.

Second, the results of this study will be useful for examining developmental dyslexia in other languages that include multiple scripts in a single language. For example, the Serbian and Bosnian languages both use Cyrillic and Latin scripts [65], and since they derive from the Greek script [66], the characteristics of their letters are similar to a certain degree. As a result, children learn how to write using both alphabets (i.e., they are essentially "bigraphic") [67]. However, there are some characters that look similar in both systems, but have a different sound (e.g., H, P, C, and B) [67]. This situation is similar to that in Kana. Thus, additional studies of languages with more than two scripts are required.

The modern Japanese writing system uses three main scripts Kana (Hiragana, Katakana), Kanji, and Romaji (Appendix 1), and it includes multiple characters that are similar to one another (Appendix 2). In addition, there are numerous strokes in Japanese Kanji. Even if children have some difficulties in the cognitive abilities of reading and writing, some children can still acquire Kana with some effort so that they are not recognized as having dyslexia. In this study, we created a test battery according to the Japanese language characteristics, and succeeded in examining the features of Japanese dyslexia. This test battery will be useful for screening Japanese dyslexia and providing children with suitable support.

When children have difficulties in analyzing phonological

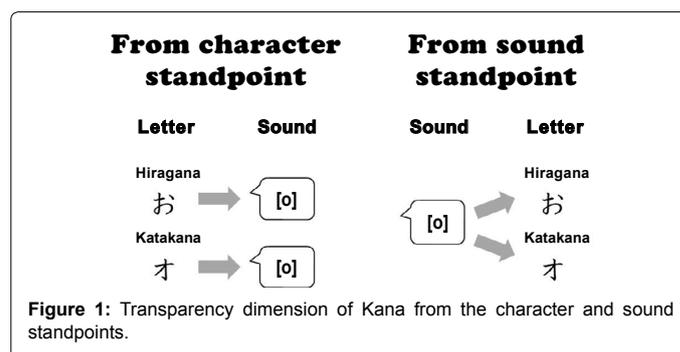


Figure 1: Transparency dimension of Kana from the character and sound standpoints.

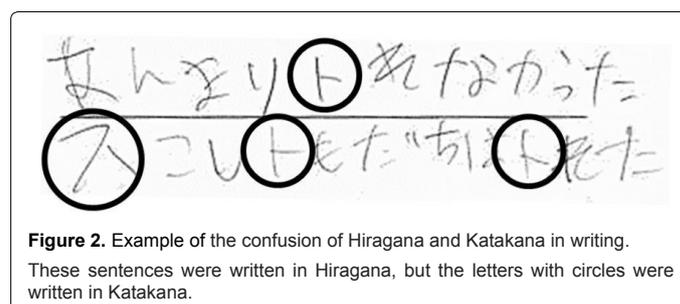


Figure 2. Example of the confusion of Hiragana and Katakana in writing. These sentences were written in Hiragana, but the letters with circles were written in Katakana.

structure, training for phonological awareness can be an effective treatment [42,44] and when children have difficulties in letter-to-sound conversion, e-learning programs can be helpful for acquiring letters [6]. In addition, a Japanese syllabary table may be a suitable education support tool and it may be utilized as a location map of phonemes [62]. If children have already learned Hiragana, then using a Japanese syllabary table of Katakana may help them learn the Katakana characters. When children have difficulties in visual information processing, training in the figure ground perspective and spatial relations will be more effective than repeatedly writing letters. In regard to the four cognitive skills, a higher percentage of children were considered to have problems with visual information processing. Thus, future studies regarding the influence of visual information processing on difficulties in reading and writing Japanese are necessary.

The groundbreaking discovery of the present study was that there were many children who had poor eye-hand coordination abilities. Stroke order is believed to be extremely important in Japanese education [68]. However, if there are difficulties in eye-hand coordination, it may be hard for these children to write using this stroke order. When considering the difficulties of writing in previous studies, eye-hand coordination was not the subject of focus. Thus, from the viewpoint on the quality of life, it is necessary to determine a child's eye-hand coordination through an assessment battery. If a child has poor eye-hand coordination, then he/she should be supported and taught that the stroke order is not necessarily important. In Japan, it is an accepted practice to learn characters from a set of reading and writing lessons. However, this method is ineffective for children who have poor writing abilities (like child B, who only had difficulties in eye-hand coordination) and these children need support in the form of separate reading and writing practice instead. This should be considered in other languages since stroke order is thought to be important for not only Japanese, but also in languages such as simplified Chinese, traditional Chinese [69,70], and Korean [71].

Notably, 3 children (Child A, I, and K) passed the letter-to-sound conversion task even though they failed the visual information processing task. This may be the result of Japanese education methods. The simultaneous oral spelling method is an effective way for dyslexic children to acquire reading and writing skills [61]. This is similar to current multisensory methods, which are visual, auditory, and tactile [72], and it may be appropriate for dyslexic children. Typical Japanese education methods utilize simultaneous oral spelling techniques and these children presumably studied hard and mastered letter-to-sound conversion through this effort.

The results of this study can also have a significant impact on education in Japan. The unique feature of this research is its individual examination of visual information processing and eye-hand coordination for children with Japanese dyslexia. There were some children who had difficulties in both, whereas others had difficulties in only one of these abilities. Thus, grasping such features is indispensable for devising suitable instruction. Hara [40] presented an argument regarding the need to develop a battery of tests for assessing phonological awareness of the Japanese language. There are some children with phonological disorders who have a low level of phonological awareness and who might also have reading difficulties [41]. In the present study, only 1 child had difficulties with phonological awareness, and this is possibly because of the influence of the participants' ages. Especially for the screening of preschool children, phonological awareness is going to be extremely important [40-42]. In addition, Japanese children begin learning English in earnest in junior high school. Evaluation

of phonological awareness at the phoneme level is important when considering the difficulties in acquiring English literacy. In particular, for students who fail to learn English in junior high school, it is hardly ever acknowledged that there may be a cognitive failure in the background. Several batteries of tests for assessing phonological awareness of English have been developed and are widely used. Thus, it is important to develop a battery of tests for assessing phonological awareness in Japanese.

We also noted the need to assess non-word reading since some children obtained good scores in reading words, but not in reading non-words. This distinction is extremely important for evaluating children who seem to be able to read and write. In the future, assessing the basic ability for letter-speech sound correspondences can be interesting. Aravena et al. [69] developed a short training program aimed at acquiring eight basic letter-speech sound correspondences within an artificial orthography. In addition, they examined whether a letter-speech sound binding deficit was behaviorally detectable within the initial steps of learning a novel script. Dyslexics were outperformed by the controls in a time-pressured binding task and a word reading task within the artificial orthography, thus providing empirical support for the viewpoint that a letter-speech sound binding deficit is a key factor in dyslexia.

Although there were limited participants in this study, it succeeded in showing that individual differences influence the nature of dyslexia with Japanese Kana. In the future, we aim to continue this work with a larger number of participants. Koyama et al. [73] investigated the cortical signatures of developmental dyslexia, particularly from the perspective of behavioral remediation, and found that behavioral remediation may be associated with compensatory changes anchored in the left fusiform gyrus. These findings were bolstered by the significant relations between the strength of the identified functional connections and literacy scores. Thus, it will also be necessary to examine the cognitive changes that accompany behavioral remediation in the future. Due to the Japanese language's unique writing system, which consists of phonograms and ideograms, reading impairments of Japanese brain-damaged patients have attracted the interest of numerous researchers [74,75]. However, many of these studies targeted Kanji as ideograms and Hiragana as phonograms, and they did not target Katakana [74]. Since the present study showed that Katakana must be included when considering the features of Kana, we hope that research including Katakana will be performed in the future. The same can also be said for cognitive experiments. Koyama et al. [75] found that Hiragana literacy performance was significantly predicted by low-level sensory processing (both auditory frequency modulation sensitivity and visual motion sensitivity) as well as by phonological awareness, but not by visual memory. In contrast, Kanji literacy performance was strongly predicted by visual memory (particularly visual long-term memory), but not by either low-level sensory processing or phonological awareness. Their results show differences in the skills that predict literacy performance in phonographic Hiragana and logographic Kanji in addition to providing experimental evidence that visual memory is important when learning Kanji. Although these were important findings, including Katakana will also be necessary in any future investigations to solve the literacy problems of Japanese children.

Finally, in this study, we created a test battery according to the characteristics of the Japanese language to examine Kana's orthography-to-phonology mapping and target four cognitive skills: analysis of phonological structure, letter-to-sound conversion, visual information processing, and eye-hand coordination. We demonstrated that reading

and writing difficulties in the Japanese language attributed to learning disabilities are caused by a various factors and that individual differences influence the presented difficulties. Furthermore, we demonstrated that Kana is not one-to-one transparent from a sound standpoint. However, we can conclude that Kana is easy to segment into phonological units, but difficult when attempting to link each letter to its corresponding sound. These findings will have a considerable impact on education methods and techniques in Japan.

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Kana		Kanji	Romaji
Hiragana	Katakana		
あめ	アメ	雨	ame

Appendix 1: The Japanese writing system uses three main scripts: "ame" (the Japanese word for rain) is written in Kana (Hiragana, Katakana), Kanji, and Romaji (Romanized Japanese).

[a]	[me]	[shi]	[tsu]
あ	め	し	つ

Appendix 2: Example of Japanese characters [a], [me], [shi], and [tsu] in Hiragana.