*Original Article***Working Memory in Junior High School Students
With Reading Difficulties: Results From an
N-Back Task**

Tomonori YANAI and Hisao MAEKAWA

Working memory characteristics of students with reading difficulties were investigated using 4 types of n -back tasks with different stimuli. The participants, 14 ninth-grade students with reading difficulties and pervasive developmental disorders and 40 students with typical development, were required to judge whether a stimulus was identical to the one that had been shown n before. The results indicated that the students with reading difficulties did not have difficulty at $n=0$. However, they had difficulty at $n=1$, if both of the stimuli were numbers or hiragana and kanji characters that required linguistic processing, and with random figures that did not need linguistic processing. The present results suggest that students with reading difficulties may have problems with memory representations that are operated internally. Moreover, it is possible that these students have more fundamental problems, such as attention deficits, which may influence multiple modalities.

Key Words: n -back task, reading difficulty, attention, junior high school students with reading difficulties and pervasive developmental disorders

Introduction

Developmental difficulty in reading is considered to be a learning disability, and often becomes an issue in education. Studies of dyslexia in countries where the language uses the alphabet suggest that reading difficulty is related to disorders in the processing of phonological information (Faust & Sharfstein-Friedman, 2003; Stanovich, 1986; Wolf, Bowers, & Biddle, 2000) and in the processing of visual information (Skottun & Parke, 1999; Solan, 1999; Stein, 2001; Stein & Walsh, 1997). Studies on reading difficulty in Japan, which uses a syllabic language written in kanji, hiragana, and katakana characters, have also suggested involvement of a phonological information processing disorder (Hosokawa, Muroya, Futakami, & Maekawa, 2004; Oishi & Saito, 1999) and visual

Graduate School of Comprehensive Human Sciences, University of Tsukuba

problems (Uno, Kaneko, Haruhara, Matsuda, Kato, & Kasahara, 2002). The relationship of processing in multiple perceptual domains to reading difficulty suggests that causes of reading difficulty relate not only to problems limited to a specific perceptual domain but also to problems that extend across multiple domains.

In order to understand factors limited to a specific perceptual domain as well as factors in non-perceptual domains, it is important to understand aspects of information processing such as working memory. Working memory has a role in systematizing, maintaining, and searching for information already learned in the performance of complex tasks, and at the same time, in storing, interpreting, and remembering complex information such as language, visual stimuli, and special factors relating to a task at that time (Baddeley, 1996, 2003). In countries where the language uses the alphabet, it has been reported that results on working memory tasks, such as the Reading Span Test and the Listening Span Test, relate to reading ability (Dixon, LeFevre, & Twilley, 1988; Friedman & Miyake, 2004; Waters & Caplan, 1996), and that working memory capacity is limited in children and adults with reading difficulties (Chiappe, Hasher, & Siegel, 2000; de Jong, 1998; Siegel & Ryan, 1989).

Furthermore, when causes of limitations in the working memory capacity of children and adults with reading difficulties were reviewed, it was found that many had been interpreted as a deficiency in phonological processing (Shankweiler, Crain, Katz, Fowler, Liberman, Brady, Thornton, Lundquist, Dreyer, Fletcher, Stuebing, Shaywitz, & Shaywitz, 1995). On the other hand, however, there have also been reports suggesting that children and adults with reading difficulties have difficulty performing tasks not only in the Reading Span Test but also working memory tasks that require visual and spatial processing (Swanson, 2003; Swanson & Ashbaker, 2000; Swanson & Sachse-Lee, 2001). Based on these facts, Swanson (1999) points out that causes of reading difficulty cannot be explained only by a deficiency in phonological processing, but rather that should be explained on the basis of a deficiency in attention and executive functions.

While some reports in Japan have suggested the possibility of a correlation between poor results in performance of the central executive function of working memory and reading difficulty (Kawamura, Nakayama, & Maekawa, 2004), experimental evidence for this relationship has not been obtained. It has been pointed out that not only are problems of processing specific to a perceptual domain such as vocal sound and visuoperception, but also that problems of processing specific to non-perceptual domains, such as attention and executive functions, are related to reading difficulty. In order to clarify these issues, it is important to use working memory tasks involving management of processing in the perceptual domain, such as vocal sounds and visuoperception, as well as processing in non-perceptual domains, such as attention and executive functions.

When stimuli are presented one after another, the task used in the present

Working Memory in Students With Reading Difficulties

study requires the subject to judge whether or not the stimulus being presented is the same as a stimulus seen n items before, i.e., the so-called “ n -back task”. With the n -back task, it is possible to review problems specific to a perceptual domain, such as vocal sound and visuoperception, and at the same time, review problems specific to a non-perceptual domain, such as attention or central executive function, depending on the characteristics of the task. Thus, it is possible to review the level of perception in the processing of phonological information, as well as visual and perceptual information, by presenting verbal and nonverbal stimuli. It is also possible to evaluate higher-level cognitive functions, such as attention and the central executive function, by gradually increasing the n value.

The relation of the n -back task to functions of the frontal lobe, which is believed to be the center for the central executive and attentional functions, has been pointed out (Owen, McMillan, Laird, & Bullmore, 2005). The n -back task is considered to be useful for evaluation of attention and executive functions.

The aim of the present research was to examine the relation between retention of representations in working memory and the manipulative load, to the speed and accuracy of searching, through a comparison of performance on an n -back task of students who have reading difficulties and students with typical development. The research also addressed whether or not the students who have reading difficulties had problems with attention and the executive function.

Method

Participants

The participants in the present study were 54 male right-handed students (14 with reading difficulties and 40 with typical development) in the ninth grade (third year of junior high school) with 1.2 or higher binocular visual acuity including those with corrected visual acuity.

The students with reading difficulties had been diagnosed as having learning disabilities or reading difficulties by either medical or educational professionals; their FIQ scores on the WISC-III were 80 or higher, and their reading age, as obtained from the TK-Style Reading Ability Diagnosis Test (Kitao, 1984), was more than two grades lower than their calendar age (see Table 1).

The students with typical development were attending regular classes. Their gender and calendar age were matched with the students with reading difficulties (average CA: 178 months; range: 176–182 months).

Prior to the start of the experiment, details of the study were explained to the students and their parents, and written consent to participate in the study was obtained.

Materials

The experimental procedures included an n -back task and a simple response task.

TABLE 1 Description of the Participants With Reading Difficulties

Participant	Gender	Chronological age (months)	WISC-III Scores							TK-Style Reading Ability Test	Diagnosis
			VIQ	PIQ	FIQ	VC	PO	FD	PS		
A	Male	178	84	104	92	86	105	79	83	9 ; 10	PDD
B	Male	178	85	113	98	88	115	73	89	10 ; 07	PDD
C	Male	180	91	103	96	94	103	85	94	10 ; 07	AS
D	Male	176	92	101	96	94	105	82	86	10 ; 07	AS, ADHD
E	Male	174	85	101	93	85	103	88	89	< 8 ; 00	PDD
F	Male	176	101	76	88	105	82	85	69	10 ; 07	PDD
G	Male	176	94	90	91	95	93	85	80	10 ; 07	PDD
H	Male	182	97	92	94	102	93	82	83	10 ; 04	PDD
I	Male	178	92	111	101	99	111	82	94	10 ; 04	PDD
J	Male	179	91	103	96	94	110	82	72	9 ; 10	PDD
K	Male	177	104	97	101	108	105	91	75	10 ; 07	PDD
L	Male	176	101	93	97	105	97	91	83	10 ; 07	PDD
M	Male	180	106	96	101	109	97	94	80	11 ; 07	AS
N	Male	178	105	94	100	111	97	88	83	10 ; 04	PDD

Note. All participants were ninth graders (third year of junior high school).

PDD: Pervasive developmental disorder; AS: Asperger's disorder; ADHD: Attention-deficit hyperactivity disorder.

In the n -back task, visual stimuli were presented sequentially on the display, and the participants were asked to judge whether or not the presented stimulus was the same as a stimulus displayed n items before. The values of n used in the present experiment were from zero to three. When n was zero, the participants were asked to memorize a given stimulus prior to the trial, and then judge whether the stimulus presented on the display was the same as the memorized one.

The visual stimuli were presented in black on a white background. The visual angle was adjusted to approximately 2.2×2.2 .

In the present experiment, the n -back task used four kinds of visual stimuli: (a) numbers, (b) hiragana characters, (c) kanji characters, and (d) random figures. The experiment involved a total of 800 trials: four kinds of stimuli $\times$ five tasks (four n back tasks and a simple response task) $\times$ 40 trials (10 practice trials + 30 actual trials).

The random figures selected as stimuli were ones considered be difficult to encode phonologically, in order to enable a comparison with the figures most frequently used as stimuli in previous studies and also so that an evaluation could be made as to whether any characteristic of the stimuli was associated with the participants' results.

The numerical stimuli were the numbers from zero to nine, and the hiragana characters, 10 different hiragana syllables. The 10 kanji characters used

Working Memory in Students With Reading Difficulties

TABLE 2 Description of the Stimuli Used in the *N*-Back Task

Numbers	0	1	2	3	4	5	6	7	8	9
Hiragana characters	あ	き	す	て	の	は	み	ゆ	れ	を
Kanji characters	飲	運	営	解	橋	減	港	辞	植	整
Random figures

as stimuli were typically taught at the same elementary school grade level, and had similar regularity (Kaiho & Nomura, 1983). The 10 random figures were selected on the basis of reports of college students who participated in a preliminary experiment. The stimuli are shown in Table 2.

Measurement of response time and errors, and preparation and control of the stimuli, was done by a computer (Windows XP REAL basic 5.5). A game pad was used as the input device for measuring response time and errors. A 15.4-type color display was used to present the stimuli.

Procedures

Prior to the experiment, a pre-test confirmed that all participants were able to read the numbers and hiragana and kanji characters (either the phonetic reading or the Japanese reading) that were to be used in the *n*-back task. Participants were not informed that the experiment would include 10 stimuli of each type.

In the simple response task, participants were instructed to push button 1 as quickly as possible for all stimuli, regardless of type, once a stimulus had appeared on the display.

Before each *n*-back task, participants were requested to judge among three choices, agree (push button 1), disagree (push button 2), or don't know (do not push any buttons), as to whether the stimulus shown had been presented *n* items before, and were also instructed to push the button as accurately and quickly as possible. After the experimenter had demonstrated three trials and explained about the tasks using the demonstration screen, practice trials were conducted, followed by the actual trials. In the 0-back task, participants were requested to memorize a reference stimulus presented for 20 s immediately preceding the trial and to make their judgments based on it.

Immediately after the beginning of the experiment, a fixation point was displayed in the center of the screen for 2 s, after which a stimulus was displayed for 250 ms. After a 4-s interval, the next stimulus was displayed. The trials were conducted successively. The time from when a stimulus appeared on the display until when the participant pushed a button was the response time for that participant for that stimulus. Tasks were conducted in the order of 0-back, 1-back,

2-back, and 3-back, with pauses. The participants' fatigue was taken into consideration, such that one task was conducted on a different day every other week for four weeks. The order of presentation of the four kinds of tasks was counter-balanced across the participants.

All experiments were conducted after it had been confirmed that the display was approximately 50 cm in front of the participant's eyes. If participants said that they could not finish a task because they were tired, it was explained that they could stop at any time, and then the experiment was continued.

Analysis of the Data

For each n -back task, the average percentage of correct answers, the average response time for correct answers, and the standard deviations of those values were calculated.

When the average response time for correct answers was analyzed, wrong answers were defined as those with missing values; they were excluded from the analysis of the average response time for correct answers. Outliers, defined as responses that deviated ± 3 SD from the mean of the distribution of response times for each participant, were also excluded from the analysis.

In order to compare the students with reading difficulties with those with typical development, a Mann-Whitney U test was calculated on group (students with reading difficulties and students with typical development) as the independent variable, and the arcsine transformation values of the average percentage of correct answers, as well as the logarithmic conversion values of the average response time for correct answers, as the dependent variables, in relation to 16 items: four types of stimuli $\times$ four values of n (0-back, 1-back, 2-back and 3-back).

A Wilcoxon assay was performed to analyze the data on the average percentage of correct answers to the various stimuli and the average response time for correct answers.

Results

The average percentage of correct answers, the average response time for correct answers, and the standard deviations of those values are shown in Table 3, in relation to each n -back task for the students with reading difficulties and those with typical development.

When the Mann-Whitney U test was conducted on the results for average percentage correct, a significant difference was not found in the 0-back task for number stimuli, hiragana characters, kanji characters, or random figures, or for the 1-back task for numbers ($p > .05$). However, a significant difference was found for the following: the 2-back task for numbers ($z = -5.326$, $p < .01$, $r = .73$), the 3-back task for numbers ($z = -5.004$, $p < .01$, $r = .68$), the 1-back task for hiragana characters ($z = -4.313$, $p < .01$, $r = .59$), the 2-back task for hiragana characters ($z = -5.716$, $p < .01$, $r = .78$), the 3-back task for hiragana characters ($z = -5.251$,

Working Memory in Students With Reading Difficulties

TABLE 3 Average Number of Correct Answers, Average Response Time for Correct Answers, and Standard Deviations, for Each *N*-Back Task

	Tasks				
	Simple Response	0-back	1-back	2-back	3-back
Students with reading difficulties					
Average percentage correct (%)					
Numbers	—	99.57 (1.1)	99.14 (1.4)	87.21 (3.7)	74.57 (6.0)
Hiragana characters	—	99.14 (1.4)	90.21 (8.7)	77.57 (8.5)	69.07 (8.0)
Kanji characters	—	99.57 (1.1)	79.79 (5.8)	69.21 (5.8)	65.93 (4.0)
Random figures	—	98.93 (1.5)	80.07 (5.6)	68.79 (6.3)	58.43 (7.6)
Average time for correct responses (ms)					
Numbers	271 (12)	381 (10)	585 (75)	936 (108)	1173 (145)
Hiragana characters	274 (12)	415 (20)	840 (174)	926 (196)	1089 (126)
Kanji characters	270 (11)	475 (34)	1015 (105)	1083 (94)	1182 (130)
Random figures	278 (6)	542 (18)	1006 (124)	1071 (173)	1276 (220)
Students with typical development					
Average percentage correct (%)					
Numbers	—	98.95 (1.4)	98.98 (1.9)	97.13 (3.8)	91.20 (7.6)
Hiragana characters	—	99.03 (1.4)	98.40 (2.3)	98.18 (2.8)	92.95 (7.7)
Kanji characters	—	98.83 (1.9)	97.88 (2.6)	97.50 (2.9)	89.18 (9.1)
Random figures	—	98.23 (2.6)	97.68 (3.1)	83.10 (8.5)	68.30 (14.2)
Average time for correct responses (ms)					
Numbers	274 (11)	390 (33)	592 (99)	704 (129)	931 (227)
Hiragana characters	275 (12)	425 (54)	518 (112)	628 (156)	788 (209)
Kanji characters	274 (12)	466 (81)	535 (128)	646 (161)	849 (200)
Random figures	279 (6)	555 (63)	766 (169)	1096 (263)	1331 (275)

Note. Figures in parentheses are the standard deviations.

$p < .01$, $r = .72$), the 1-back task for kanji characters ($z = -5.738$, $p < .01$, $r = .78$), the 2-back task for kanji characters ($z = -5.699$, $p < .01$, $r = .78$), the 3-back task for kanji characters ($z = -5.186$, $p < .01$, $r = .71$), the 1-back task for random figures ($z = -5.677$, $p < .01$, $r = .77$), the 2-back task for random figures ($z = -4.397$, $p < .01$, $r = .60$) and the 3-back task for random figures ($z = -3.082$, $p < .01$, $r = .42$).

A Wilcoxon assay was used to investigate the average percentage correct for the different stimuli and the average response times for correct answers in each group of students. For the group of students with typical development, although no significant difference was found in the 0-back task ($p > .05$), a significant difference was found for the 1-back task between numbers and kanji characters ($z = -2.508$, $p < .05$, $r = .40$), and numbers and random figures ($z = -2.254$, $p < .05$, $r = .36$): a significant difference was found for the 2-back task between numbers and random figures ($z = -5.487$, $p < .01$, $r = .87$), hiragana characters and random figures ($z = -5.446$, $p < .01$, $r = .86$), and kanji characters and random figures

($z = -5.514$, $p < .01$, $r = .87$): and, in the 3-back task, between numbers and random figures ($z = -5.512$, $p < .01$, $r = .87$), hiragana characters and kanji characters ($z = -3.329$, $p < .01$, $r = .53$), hiragana characters and random figures ($z = -5.512$, $p < .01$, $r = .87$), and kanji characters and random figures ($z = -5.512$, $p < .01$, $r = .87$).

For the group of students with reading difficulties, although no significant difference was found in the 0-back task ($p > .05$), a significant difference was found for the 1-back task between numbers and hiragana characters ($z = -3.076$, $p < .01$, $r = .82$), numbers and kanji characters ($z = -3.299$, $p < .01$, $r = .88$), number and random figures ($z = -3.302$, $p < .01$, $r = .88$), hiragana characters and kanji characters ($z = -2.982$, $p < .01$, $r = .80$), and hiragana characters and random figures ($z = -3.041$, $p < .01$, $r = .81$): a significant difference was found for the 2-back task between numbers and random figures ($z = -2.580$, $p < .05$, $r = .69$), numbers and kanji characters ($z = -3.301$, $p < .01$, $r = .88$), numbers and random figures ($z = -3.300$, $p < .01$, $r = .88$), hiragana characters and kanji characters ($z = -3.181$, $p < .01$, $r = .85$), and hiragana characters and random figures ($z = -2.803$, $p < .01$, $r = .75$); and, in the 3-back task, between numbers and kanji characters ($z = -3.081$, $p < .01$, $r = .82$), numbers and random figures ($z = -3.180$, $p < .01$, $r = .85$), hiragana characters and random figures ($z = -2.982$, $p < .01$, $r = .80$), and kanji characters and random figures ($z = -2.710$, $p < .01$, $r = .73$).

A Mann-Whitney U test conducted comparing the average response times for correct answers revealed no significant difference on the 0-back task for numbers, hiragana characters, kanji characters, or random figures; on the 1-back task for numbers, and on the 2-back and 3-back tasks for random figures ($p > .05$). However, a significant difference was found for the following: the 2-back task for numbers ($z = -4.599$, $p < .01$, $r = .63$), the 3-back task for numbers ($z = -3.711$, $p < .01$, $r = .51$), the 1-back task for hiragana characters ($z = -4.974$, $p < .01$, $r = .68$), the 2-back task for hiragana characters ($z = -4.214$, $p < .01$, $r = .57$), the 3-back task for hiragana characters ($z = -4.639$, $p < .01$, $r = .63$), the 1-back task for kanji characters ($z = -5.507$, $p < .01$, $r = .75$), the 2-back task for kanji characters ($z = -5.143$, $p < .01$, $r = .70$), the 3-back task for kanji characters ($z = -4.619$, $p < .01$, $r = .63$), and the 1-back task for random figures ($z = -3.997$, $p < .01$, $r = .54$).

A Wilcoxon assay was used to investigate the average response time for correct answers to the different stimuli and the average response time for correct answers. For the group of students with typical development, a significant difference was found in the 0-back task between numbers and hiragana characters ($z = -3.600$, $p < .01$, $r = .57$), numbers and kanji characters ($z = -5.040$, $p < .01$, $r = .80$), numbers and random figures ($z = -5.511$, $p < .01$, $r = .87$), hiragana characters and kanji characters ($z = -3.698$, $p < .01$, $r = .59$), hiragana characters and random figures ($z = -5.444$, $p < .01$, $r = .86$), and kanji characters and random figures ($z = -5.000$, $p < .01$, $r = .79$), in the 1-back task between numbers and hiragana characters ($z = -3.858$, $p < .01$, $r = .61$), numbers and kanji characters

Working Memory in Students With Reading Difficulties

($z = -2.903$, $p < .01$, $r = .46$), numbers and random figures ($z = -4.570$, $p < .01$, $r = .72$), hiragana characters and random figures ($z = -5.457$, $p < .01$, $r = .86$), and kanji characters and random figures ($z = -5.323$, $p < .01$, $r = .84$); in the 2-back task for numbers and hiragana characters ($z = -2.850$, $p < .01$, $r = .45$), numbers and random figures ($z = -5.457$, $p < .01$, $r = .86$), hiragana characters and random figures ($z = -5.511$, $p < .01$, $r = .87$), and kanji characters and random figures ($z = -5.511$, $p < .01$, $r = .87$); and in the 3-back task, between numbers and hiragana characters ($z = -2.836$, $p < .01$, $r = .45$), numbers and random figures ($z = -4.946$, $p < .01$, $r = .78$), hiragana characters and kanji characters ($z = -3.154$, $p < .01$, $r = .50$), hiragana characters and random figures ($z = -5.511$, $p < .01$, $r = .87$), and kanji characters and random figures ($z = -5.511$, $p < .01$, $r = .87$).

For the group of students with reading difficulties, a significant difference was found in the 0-back task between numbers and hiragana characters ($z = -3.107$, $p < .01$, $r = .83$), numbers and kanji characters ($z = -3.296$, $p < .01$, $r = .88$), numbers and random figures ($z = -3.296$, $p < .01$, $r = .88$), hiragana characters and kanji characters ($z = -3.296$, $p < .01$, $r = .88$), hiragana characters and random figures ($z = -3.296$, $p < .01$, $r = .88$), and kanji characters and random figures ($z = -3.110$, $p < .01$, $r = .83$), in the 1-back task between numbers and hiragana characters ($z = -3.296$, $p < .01$, $r = .88$), numbers and kanji characters ($z = -3.296$, $p < .01$, $r = .88$), numbers and random figures ($z = -3.296$, $p < .01$, $r = .88$), hiragana characters and kanji characters ($z = -2.605$, $p < .01$, $r = .70$), and hiragana characters and random figures ($z = -2.731$, $p < .01$, $r = .73$); in the 2-back task between numbers and kanji characters ($z = -3.233$, $p < .01$, $r = .87$), numbers and random figures ($z = -3.107$, $p < .01$, $r = .83$), hiragana characters and kanji characters ($z = -3.296$, $p < .01$, $r = .88$), and hiragana characters and random figures ($z = -2.982$, $p < .01$, $r = .80$); and, in the 3-back task, between numbers and hiragana characters ($z = -2.668$, $p < .01$, $r = .71$), hiragana characters and kanji characters ($z = -2.794$, $p < .01$, $r = .75$), and hiragana characters and random figures ($z = -2.291$, $p < .05$, $r = .61$).

Discussion

Working memory characteristics of students with reading difficulties were investigated, using four n -back tasks with different stimuli.

A comparison between the students with reading difficulties and those with typical development revealed no significant difference between the groups in the average percentage of correct answers and the average response time for correct answers on the 0-back task with the four kinds of stimuli. On the other hand, the differences between the groups tended to be significant on the 1-back, 2-back and 3-back tasks. These results indicate that the students with reading difficulties had a tendency to get fewer answers correct (a lower average percentage of correct answers) and a longer average response time for correct answers, than the students with typical development, when manipulating the representation of

numbers, hiragana characters, kanji characters, and random figures.

A significant difference was not found between the students with reading difficulties and those with typical development for average response time for correct answers in the 2-back and 3-back tasks for random figures. This may be because those tasks were difficult for all the participants.

The results described above indicate that the students with reading difficulties who participated in this experiment did not have difficulty in determining simple perceptual information, and suggest that the internal operation of memory representation was difficult for them. Internally operated memory representation imposes a heavier burden on the central executive function, and it is likely that the students with reading difficulties exhibited difficulty on those tasks because of the increased burden on the central executive function of working memory.

Results suggesting that the working memory capacity of children and adults with reading difficulties is limited, or, in other words, that they show difficulty when the central executive function is burdened, have also been obtained in previous studies in countries where the language uses the alphabet (Chiappe et al., 2000; de Jong, 1998; Siegel & Ryan, 1989); the results of the present study support these previous studies.

Hypotheses about the cognitive process causes of reading difficulties mainly involve hypotheses about disorders in processing phonological information (Faust & Sharfstein-Friedman, 2003; Stanovich, 1986; Wolf et al., 2000), disorders in visual information processing (Skottun & Parke, 1999; Solan, 1999; Stein, 2001; Stein & Walsh, 1997; Uno et al., 2002), and disorders in attention and the executive functions (Swanson, 1999).

If the hypothesis of disorders in phonological information processing were correct, a difference would not have been found in the present experiment between the students with reading difficulties and those with typical development on the n -back task using random figures. If the problem results from disorders in visual information processing, a difference between the groups would have been found on all n -back tasks, including the 0-back task. If the hypothesis of disorders in attention and executive functions were correct, then a difference would have been found between the groups for the tasks in which $n \geq 1$, whereas a difference would not have been found between the groups on $n=0$ tasks.

Given the results of the present experiment, it is not possible to explain the cognitive process of reading difficult only with hypotheses based on disorders in phonological information processing or problems in visuoperceptual judgments. Rather, the hypothesis of disorders in attention and executive functions was supported.

In the context of the average percentage of correct answers and the average response time for correct answers in relation to the differences among the stimuli, in the 1-back and 2-back tasks, the average percentage of correct answers and the average response time for correct answers for the students with typical devel-

Working Memory in Students With Reading Difficulties

opment was approximately the same whether numbers, hiragana characters, or kanji characters were the stimuli. The exception was the random figures that were hard to manipulate by phonological representations. On the other hand, the students who had reading difficulties had a lower average percentage of correct answers and a longer average response time for correct answers for the hiragana and kanji characters than for the numbers. These data suggest that the students with typical development manipulated the stimuli by phonological representation, whereas the students had reading difficulties did not do so.

Finally, the present study has some limitations. All the students with reading difficulties who participated in the present experiment had pervasive developmental disorders. It has been pointed out in previous studies that children and adults with pervasive developmental disorders have problems in working memory. Therefore, it is premature to generalize the results of the present study to all students who have reading difficulties. The present study was focused on students with pervasive developmental disorders who have reading difficulties. In the future, further investigation is needed to discover whether students who have reading difficulties but not pervasive developmental disorders have problems with their attention and executive functions.

The results of the present study suggest that cognitive background factors of reading difficulty relate to problems in the attention and executive functions. The present results do not exclude the possibility of phonological recognition or visuoperceptual processing as causes of reading difficulty, but rather suggest the need to consider involvement of phonological recognition and visuoperception problems with reading in relation to factors associated with overall cognitive activities, such as attention and executive functions. It is also necessary to review how the vulnerability of the burden on the attention and central executive functions indicated in the present study relates to learning environmental information. Phased instruction, using small steps that focus not only on the problem of phonological recognition or visuoperception but also on the burden on attention and executive functions that accompanies the operation of memory representation, might help improve the reading of students with reading difficulties.

References

- Baddeley, A. (1996) Short-term memory for word sequences as a function of acoustic, semantic and formal similarity. *Quarterly Journal of Experimental Psychology*, 18, 362–365.
- Baddeley, A. (2003) Working memory: Looking back and looking forward. *Neuroscience*, 4, 829–839.
- Chiappe, P., Hasher, L., & Siegel, L. S. (2000) Working memory, inhibitory control, and reading disability. *Memory & Cognition*, 28, 8–17.
- de Jong, P. F. (1998) Working memory deficits of reading disabled children. *Journal of*

- Experimental Child Psychology*, 70, 75–96.
- Dixon, P., LeFevre, J., & Twilley, L. C. (1988) Word knowledge and working memory as predictors of reading skill. *Journal of Educational Psychology*, 80, 465–472.
- Faust, M. & Sharfstein-Friedman, S. (2003) Naming difficulties in adolescents with dyslexia: Application of the tip-of-the-tongue paradigm. *Brain and Cognition*, 53, 211–217.
- Friedman, N. P. & Miyake, A. (2004) The Reading Span Test and its predictive power for reading comprehension ability. *Journal of Memory and Language*, 51, 136–158.
- Hosokawa, M., Muroya, N., Futakami, S., & Maekawa, H. (2004) Review of phonological processing and audio information processing for students who show difficulty in reading hiragana. *Japanese Journal of Learning Disabilities*, 13, 151–162. (in Japanese)
- Kaiho, H. & Nomura, Y. (1983) *The psychology of kanji information processing*. Kyoiku Shuppan, Tokyo. (in Japanese)
- Kawamura, A., Nakayama, K., & Maekawa, H. (2004) Attempt to measure working memory for LD in childhood. *Japanese Journal of Learning Disabilities*, 13, 79–90. (in Japanese)
- Kitao, N. (1984) *Manual of the TK-style Reading Ability Diagnosis Test*. Taken Publishing, Tokyo. (in Japanese)
- Oishi, K. & Saito, S. (1999) Phonological issue in speech development disorder: Case of dyslexia and dysgraphia. *Japan Journal of Logopedics and Phoniatrics*, 40, 378–387. (in Japanese)
- Owen, A. M., McMillan, K. M., Laird, A. R., & Bullmore, E. (2005) N-back working memory paradigm: A meta-analysis of normative functional neuroimaging studies. *Human Brain Mapping*, 25, 46–59.
- Shankweiler, D., Crain, S., Katz, L., Fowler, A. E., Liberman, A. M., Brady, S. A., Thornton, R., Lundquist, E., Dreyer, L., Fletcher, J. M., Stuebing, K. K., Shaywitz, S. E., & Shaywitz, B. A. (1995) Cognitive profiles of reading-disabled children: Comparison of language skills in phonology, morphology, and syntax. *Psychological Science*, 6, 149–156.
- Siegel, L. S. & Ryan, E. B. (1989) The development of working memory in normally achieving and subtypes of learning disabled children. *Child Development*, 60, 973–980.
- Skottun, B. C. & Parke, L. A. (1999) The possible relationship between visual deficits and dyslexia: Examination of a critical assumption. *Journal of Learning Disabilities*, 32, 2–5.
- Solan, H. A. (1999) Letters: Visual deficits and dyslexia. *Journal of Learning Disabilities*, 32, 282–283.
- Stanovich, K. E. (1986) Matthew effects in reading: Some consequences of individual differences in the acquisition of literacy. *Reading Research Quarterly*, 21, 360–364.
- Stein, J. (2001) The magnocellular theory of developmental dyslexia. *Dyslexia*, 7, 12–36.
- Stein, J. & Walsh, V. (1997) To see but not to read: The magnocellular theory of dyslexia. *Trends in Neurosciences*, 20, 147–152.
- Swanson, H. L. (1999) Reading comprehension and working memory in learning disabled readers: Is the phonological loop more important than the executive

Working Memory in Students With Reading Difficulties

- system? *Journal of Experimental Child Psychology*, 72, 1–31.
- Swanson, H. L. (2003) Age-related differences in learning disabled and skilled readers' working memory. *Journal of Experimental Child Psychology*, 85, 1–31.
- Swanson, H. L. & Ashbaker, M. H. (2000) Working memory, short-term memory, speech rate, word recognition and reading comprehension in learning disabled readers: Does the executive system have a role? *Intelligence*, 28, 1–30.
- Swanson, H. L. & Sachse-Lee, C. (2001) A subgroup analysis of working memory in children with reading disabilities: Domain-general or domain-specific deficiency? *Journal of Learning Disabilities*, 34, 249–263.
- Uno, A., Kaneko, M., Haruhara, N., Matsuda, H., Kato, M., & Kasahara, M. (2002) Developmental dyslexia and dysgraphia: Neuropsychologic and cognitive-neuropsychological analyses. *Higher Brain Function Research*, 22, 130–136. (in Japanese)
- Waters, G. S. & Caplan, D. (1996) The measurement of verbal working memory capacity and its relation to reading comprehension. *Quarterly Journal of Experimental Psychology*, 49A(1), 51–79.
- Wolf, M., Bowers, P. G., & Biddle, K. (2000) Naming-speed processes, timing, and reading: A conceptual review. *Journal of Learning Disabilities*, 33, 387–407.

—Received March 4, 2010, Accepted February 19, 2011—