Inhibition of Automatic Semantic Processing in Children With High-Functioning Pervasive Developmental Disorders Having Reading Difficulty

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Inhibition of automatic semantic processing was examined in children who have high functioning-pervasive developmental disorders (HF-PDD) with or without reading difficulty and in typically developing children. In Experiment 1, lexical decision tasks were conducted under three priming conditions: (1) normal character condition, (2) transposed-letter internal nonwords condition, and (3) transposed-letter external nonwords condition. The results indicated that all participants displayed semantic priming under the normal and transposed-letter internal nonwords condition, whereas semantic priming was not observed under the transposed-letter external nonwords condition. In Experiment 2, speed-reading was conducted under normal, transposed-letter internal nonwords, transposed-letter external nonwords condition, and nonword conditions. The results indicated that HF-PDD students with reading difficulty showed low reading scores under the nonword condition. Moreover, their reading score under the transposed-letter internal nonwords condition declined more than that under the nonword condition. The above results indicate that students with HF-PDD and reading difficulty have problems in conducting bottom-up processing while inhibiting top-down processing, when automatically generated semantic processing interferes with the processing conducted through the phonological route.

Key Words: inhibition of automatic semantic processing, reading difficulty, high-functioning pervasive developmental disorders, priming

It is known that executive function disorders affect reading skills (Swanson, 1999; Swanson & Jerman, 2007). It has been shown that students with high functioning-pervasive developmental disorders (HF-PDD) also have executive function disorders (Happe, Booth, Charlton, & Hughes, 2006; O’Hearn, Asato, Ordaz, & Luna, 2008). These studies do not, however, suggest that disorders in executive functions are always accompanied by reading difficulty and HF-PDD. It is possible that executive functions are just one of the factors that cause reading difficulty and HF-PDD, is an intermediate phenotype. Executive functions are concepts that explain functions of the frontal lobe on the basis of Luria’s observations of patients with brain injuries. These are high-level functions that are necessary for planning and adjusting behaviors to achieve a goal (Ardila, 2008). It has been reported that executive functioning comprises three factors: updating, inhibition, and shifting (Miyake, Friedman, Emerson, Witzki, Howerter, & Wager, 2000).

Yanai and Maekawa (2011) investigated whether updating would affect reading skills. The results indicated that HF-PDD students with reading difficulty have difficulties in performing the N-back task, which requires updating. To date, the relationship between inhibition or shifting and reading difficulty or HF-PDD has not been investigated. The present study examined inhibition of automatic semantic processing in HF-PDD students with reading difficulty. In Experiment 1, character positions of words and semantic priming were investigated. In Experiment 2, on the basis of the results of Experiment 1, inhibition of automatic semantic processing during phonetic reading was investigated. These experiments were based on the hypothesis that executive functional disorders are an intermediate phenotype between reading difficulty and HF-PDD. Participants were classified into
the following two groups: HF-PDD students with and without reading difficulty.

Priming is an effect in which an antecedent stimulus affects the consequent stimulus. When there is a semantic relationship between a prime and a target, it is known as semantic priming. Semantic priming has been explained using the spreading activation model (Collins & Loftus, 1975), which assumes that the concept is united on the basis of semantic correlations and are stored in a semantic network. When a concept is activated, the activation spreads through the network. Semantic priming is explained as the result of spreading activation in the network that has been caused by a prime. This activation can be examined using a lexical decision task in which participants decide whether the target presented after a prime is a real word. The time lag between primes and targets (stimulus onset asynchrony: SOA) can be manipulated in order to distinguish between automatic and inhibitory processing (Neely, 1977).

It is known that the position of letters in a word affects the priming effects. Perey and Lupker (2003) suggested that the exchange of a letter at the center (inside) of a word generates more priming effects than that at the extremes. This result is expected from the neural network model of word reading (Shillcock, Ellison, & Monaghan, 2000), which suggests that automatic semantic processing is conducted when a letter at the center of a word is exchanged. In Experiment 1, the character positions of hiragana words and nonwords and semantic priming were examined using lexical decision tasks.

The model of Coltheart, Curtis, Atkins, and Haller (1993) is a classical model of the process from visual perception to reading aloud. This model explains word perception through the relationship between bottom-up processing (phonological route) and top-down processing (lexical route). In this sense, semantic priming in Experiment 1 is an example of top-down processing, which can be regarded as automatic semantic processing. In Experiment 2, on the basis of the results of Experiment 1, the inhibition of automatic semantic processing was investigated.

**Experiment 1**

**Purpose**

Experiment 1 aimed to examine the character position and semantic priming of hiragana words and nonwords by using lexical decision tasks.

**Participants**

The participants included 61 male right-handed students (14 HF-PDD students with reading difficulty, 7 HF-PDD students without reading difficulty, and 40 typically developing students) in the ninth grade (third year of junior high school) with 1.2 or higher binocular visual acuity, including those with corrected visual acuity.

Students who had a score of over 80 points for FIQ (WISC-III: Wechsler Intelligence Scale for Children third Edition) and were diagnosed as PDD (including Asperger syndrome) at a medical institution were designated as HF-PDD. The students with reading difficulty had been diagnosed as having learning disability by either medical or educational professionals; their reading capacity age, as obtained from the TK-style Reading Ability Diagnosis Test (Kitao, 1984), was more than two grades lower than their calendar age. Furthermore, reading difficulty was confirmed using a reading fluency task (Kumagai, Yanai, & Maekawa, 2010), as shown in Fig. 1. The details of HF-PDD students with and without reading difficulty are shown in Table 1.

The typically developing students were attending regular classes. Their gender and chronological age (CA) were matched with HF-PDD students with and without reading difficulty (average CA: 178 months; range: 176–182 months).

Before conducting the study, an explanation about the content of the research was given to the students and their parents, and the students’ written consent for participation in the experiments was obtained.

**Fig. 1** The Results of a Reading Fluency Task
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Tasks

Lexical decision tasks were conducted using a 2 × 3 factorial design. The first factor was the semantic relationship between primes and targets: related condition, nonrelated condition, and NO condition. The target words in NO conditions were nonwords. The second factor was the character position of primes: normal character condition, transposed-letter internal nonwords condition, and transposed-letter external nonwords condition. Each stimulus was constructed as a character string that consisted of five hiragana characters. The normal character condition included words such as “かぶとむし” (ka bu to mu shi) [beetle]. The transposed-letter internal nonwords condition comprised nonword character strings in which three characters in the center of a word consisting of five characters were randomly exchanged, such as “かぶとむとし” (ka bu to mu to shi). The transposed-letter external nonwords condition comprised nonword character strings in which the first and last characters were exchanged in a word consisting of five characters, such as “しぶとむか” (shi bu to mu ka). A total of 162 sets of stimuli was used in the experiment (nine condition × eighteen sets). The conditions were presented in a random order. Before the experiment, in order to check whether the prime stimulus and target stimulus were related, a questionnaire survey was conducted with junior high school students (N = 30) who did not participate in the experiments, and pairs of words that were easily associated were used as prime-target stimuli in the related condition. Conversely, pairs of words that were not associated were used as prime-target stimuli in the nonrelated condition.

Procedures

The measurement of reaction times and errors, presentation of stimuli, and control of the experiment were conducted using a personal computer (Windows XP, REAL basic 5.5). A gamepad was used as the input device for reaction times and errors. Color display type 15.4 was used to display the stimuli.

On the computer screen, a fixation point was presented for 1500 ms, followed by a blank for 100 ms, a prime for 200 ms, the SOA for 300 ms, and the target, in that order. On the basis of previous studies, the SOA was set at 300 ms, which is considered to be the automatic processing time. Participants were required to read silently the primes and push A (lexical) or B (nonlexical) buttons according to their judgment. The experimental trials started after six practice trials. Reaction times were analyzed for correct responses under the normal character condition, transposed-letter internal nonwords condition, and transposed-letter external nonwords condition, in related and nonrelated conditions. NO conditions were excluded from the analysis. Reaction times for errors were not analyzed.

ANOVA were not conducted because a distribution of reaction time was a positive skew and was not the Gaussian distribution. A Mann–Whitney U test was used to compare between groups for the six variables (related and nonrelated conditions × normal character condition, transposed-letter internal nonwords condition, and transposed-letter external nonwords condition for three groups (HF-PDD students with or without reading difficulty and typically developing students) as independent variables, and the log values of reaction times for correct responses as dependent variables. A Wilcoxon test was also conducted for nine items (three groups: HF-PDD students with or without reading difficulty and typically developing students × normal character condition, transposed-letter internal nonwords condition, and transposed-letter external nonwords condition), with related and nonrelated conditions as independent variables and the log values of reaction times for correct responses as dependent variables.

Results

Reaction times for correct responses to target stimuli in each condition are shown in Fig. 2. The results of the Mann–Whitney U tests indicated that there were no significant differences between any of the groups under the related condition, for the normal character, transposed-letter internal nonwords, or transposed-letter external nonwords conditions (p > .05). On the other hand, in the nonrelated condition, there were significant differences between HF-PDD students with reading difficulty and those without reading difficulty under the transposed-letter internal nonwords condition (z = −2.462, p < .05, r = .54) between HF-PDD students with reading difficulty and typically developing students under the transposed-letter internal nonwords condition (z = −2.507, p < .05, r = .34) and under the transposed-letter external nonwords condition (z = −2.833, p < .01, r = .39). These results indicated that there were no
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significant differences in reaction times between the groups in the related condition. On the other hand, in the nonrelated condition, the reaction times of HF-PDD students with reading difficulty were shorter than those of students in the other two groups under the internal and transposed-letter external nonwords conditions.

The results of the Wilcoxon test indicated that the reaction times for correct responses of the related condition in HF-PDD students with reading difficulty were shorter than that of the nonrelated condition under the normal character condition \((z = -3.296, p < .01, r = .52)\) and the transposed-letter internal nonwords condition \((z = -3.296, p < .01, r = .52)\), whereas there were no significant differences under the transposed-letter external nonwords condition \((p > .05)\). Reaction times for correct responses of the related condition in HF-PDD students without reading difficulty were shorter than that of the nonrelated condition under the normal character condition \((z = -2.366, p < .05, r = .90)\) and transposed-letter internal nonwords condition \((z = -2.366, p < .05, r = .90)\), whereas there were no significant differences under the transposed-letter external nonwords condition \((p > .05)\). The reaction times for correct responses of the related condition in typically developing students were shorter than that of the nonrelated condition under the usual character condition \((z = -5.497, p < .01, r = .87)\), transposed-letter internal nonwords condition \((z = -5.511, p < .01, r = .87)\), and transposed-letter external nonwords condition \((z = -5.175, p < .01, r = .82)\).

Discussion

The results of Experiment 1 showed semantic priming in all HF-PDD students with reading difficulty, HF-PDD students without reading difficulty, and typically developing students under normal character and transposed-letter internal nonwords conditions, but not under the transposed-letter external nonwords condition. This finding is similar to that of studies on the United Kingdom of Great Britain and Northern Ireland (Perea & Lupker, 2003). These results suggest that top-down processing, such as automatic semantic processing, was similarly performed by all groups.

In the nonrelated condition, the reaction times of HF-PDD students with reading difficulty were shorter than those of students in the other two groups under the internal and transposed-letter external nonwords conditions. This finding could be related to the characteristics of perceptual processing in HF-PDD with reading difficulty. Thus, further investigation is needed to clarify this possibility.

Experiment 2

Purpose

The purpose of Experiment 2 was to examine the inhibition of automatic semantic processing on the basis of Experiment 1.
Participants
Participants were same as those in Experiment 1.

Tasks
Participants were asked to read the presented hiragana words or nonwords verbatim, aloud, and as rapidly and accurately as possible, under four conditions: normal, transposed-letter internal nonwords, transposed-letter external nonwords, and nonword. The stimuli were the same words and nonwords that were used as primes in the trials under the normal, internal character-exchange, and transposed-letter external nonwords conditions in Experiment 1.

Procedure
Stimuli were displayed in 32 point, MSP Gothic font as 3 columns×6 rows per page on the screen. Reading speed and the number of errors were measured for each displayed page. Errors were judged on the basis of the passage scores from the Gray Oral Reading Test (4th ed.; Wiederholt & Bryant, 2001). Verbal reactions to the tasks were saved in wave files using audio-recording software to be analyzed by SUGI Speech Analyzer, which is an audio-analysis visualization software, for reading time and the number of errors. Stimuli were created and manipulated by a PC, using PowerPoint 2007 for Windows XP. A 15.4 color display was used for stimuli presentation.

Because reading ability was considered to correlate with reading speed and accuracy, a Mann–Whitney U test was conducted with each group (HF-PDD students with reading difficulty, HF-PDD students without reading difficulty, and typically developing students) as the independent variable and the sum of z scores of reading time and number of errors as the dependent variable. In order to examine the deviation from the mean of reading ability for each participant, z scores were computed: the greater the z score, the lower the reading ability. Furthermore, the z scores of reading time and number of errors were calculated under the four character conditions (normal, nonword, transposed-letter internal nonwords, and transposed-letter external nonwords), as well as their sums, for each group. On the basis of the sums, the levels of deviation from the average reading ability under each condition were also analyzed.

Results
Figure 3 displays the reading times and the number of errors for the rapid reading of hiragana words and nonwords. The Mann–Whitney U test revealed significant differences between HF-PDD students with reading difficulty and HF-PDD students without reading difficulty in the normal character condition (z=−3.545, p<.01, r=.77), transposed-letter internal nonwords condition (z=−3.657, p<.01, r=.80),
transposed-letter external nonwords condition ($z=-3.656$, $p<.01$, $r=.80$), and nonword condition ($z=-3.656$, $p<.01$, $r=.80$). Significant differences between HF-PDD students with reading difficulty and typically developing students were also shown in the normal condition ($z=-4.986$, $p<.01$, $r=.68$), transposed-letter internal nonwords condition ($z=-5.507$, $p<.01$, $r=.75$), transposed-letter external nonwords condition ($z=-5.241$, $p<.01$, $r=.71$), and nonword condition ($z=-5.330$, $p<.01$, $r=.73$). There were no significant differences between HF-PDD students without reading difficulty and typically developing students in the normal character, nonword, transposed-letter internal nonwords, and transposed-letter external nonwords conditions ($p>.05$).

To summarize, students with HF-PDD showing reading difficulty demonstrated lower performance, compared to the other two groups, in all of the normal character, internal character-exchange, external character-exchange, and nonwords conditions. As shown in Fig. 3, the difference in performance is particularly remarkable in the internal character-exchange, external character-exchange, and nonword conditions. Corroborating previous research, HF-PDD students with reading difficulty were shown to have problems in reading nonwords (e.g., Kumagai, Yanai, & Maekawa, 2010). The performance of HF-PDD students without reading difficulty was not significantly different from that of typically developing students in all conditions for other tasks.

Next, deviations from average reading ability computed from speed and accuracy were analyzed. HF-PDD students with reading difficulty performed worse in the transposed-letter internal nonwords condition ($z=3.141$), transposed-letter external nonwords condition ($z=2.843$), and nonword condition ($z=2.837$) than in the normal character condition ($z=1.968$). Moreover, HF-PDD students with reading difficulty performed worse in the transposed-letter internal nonwords condition than in the nonword condition, while showing similar high levels of reading performance in the transposed-letter external nonwords and nonword conditions. On the other hand, HF-PDD students without reading difficulty performed equally well in the normal character condition ($z=-0.531$), transposed-letter internal nonwords condition ($z=-0.857$), transposed-letter external nonwords condition ($z=-0.731$), and nonword condition ($z=-0.720$). Only HF-PDD students with reading difficulty showed lower reading performance in the transposed-letter internal nonwords condition than that in the nonword condition. Under the nonword condition, processing was conducted through the phonological route.

**Discussion**

In the transposed-letter internal nonwords condition, processing is required through the phonological route, but there could be interference from the automatic semantic processing (lexical) route. It is possible that the HF-PDD with reading difficulty group had difficulty in reading aloud while inhibiting automatic semantic processing.

Experiment 2 analyzed top-down and bottom-up processing using rapid reading tasks under normal character, transposed-letter internal nonwords, transposed-letter external nonwords, and nonword conditions. The results demonstrated that HF-PDD students with reading difficulty performed worse when reading under the nonword condition, confirming the problem in phonetic awareness that has been demonstrated in research on reading difficulty. Moreover, their reading performance in the transposed-letter internal nonwords condition was lower than that in the nonword condition. These results indicate that HF-PDD students with reading difficulty have problems in bottom-up processing because of difficulties in inhibiting and controlling top-down processing when automatic semantic processing interferes with processing through the phonetic route. For example, even if HF-PDD students with reading difficulty look at “かむぶとし” (ka mu bu to shi) [beetle], which is visually a nonword, because “かぶとむし” (ka bu to mu shi) [beetle] is read by automatic semantic processing, it becomes difficult for them to literally read “かむぶとし” (ka mu bu to shi). HF-PDD students with reading difficulty may occasionally make a mistake by reading “かぶとむし” (ka bu to mu shi) [beetle].

If HF-PDD students with reading difficulty had problems in inhibition and control, the character information that is visually inputted while reading aloud would be automatically processed semantically.
Previous research (e.g., Ben-Av, Sagi, & Braun, 1992) has demonstrated that processing which does not require attention is conducted in peripheral vision. If automatic semantic processing is conducted not only in central vision but also in peripheral vision, a large amount of semantic information would be inputted and would interfere with processing through the phonetic route. In this case, because semantic processing of many words included in a field of view is automatically performed, such text may serve as a stimulus that interferes with a word or a character that should be read. Incidentally, an inability to utilize bottom-up processing while depending on top-down processing may be indicative of processing that depends on spreading activation of the network which explains priming. Semantic and phonetic paralexia in students with HF-PDD with reading difficulty may be due to such spreading activation in the network.

**Conclusion**

In the present study, Experiment 1 examined character positions and semantic priming, and Experiment 2 examined the problem of inhibition and control of automatic semantic processing when reading aloud, using the same stimuli that were used in Experiment 1.

The results of Experiment 1 showed semantic priming in all HF-PDD students with reading difficulty, HF-PDD students without reading difficulty, and typically developing students under normal character and transposed-letter internal nonwords conditions, but not under the transposed-letter external nonwords condition.

The results of Experiment 2 demonstrated that HF-PDD students with reading difficulty performed worse in reading under the nonword condition, thereby confirming the problem of phonetic awareness, which has been demonstrated in reading difficulty studies. Moreover, their reading performance in the transposed-letter internal nonwords condition was worse than that in the nonword condition.

While the present study examined students with HF-PDD, future research is needed to investigate whether similar results would be obtained from students with reading difficulty but without HF-PDD. In addition, research in top-down processing should address not only semantic priming but also phonetic priming. Last, it is suggested that top-down processing should be analyzed in central and peripheral visions.

**References**


