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論　文　内　容　の　要　約

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【要約】（文章の順番を守り、論理立てて記載してください）

## Introduction

According to diagnostic criteria of DSM-5, specific learning disabilities are significantly lower regarding academic skills in comparison with skills expected for actual age, including disorders of reading-related dyslexia, writing-related dysgraphia or math-related dyscalculia and excluding intellectual, visual, hearing impairments and disabilities caused by educational environmental factors.

It is considered that causal elements or factors for reading and writing disorders are related to some kind of disorder in the central nervous system and the specific aspects part of impairment have not been identified.

In the English-speaking countries, there are three major theories of developmental dyslexia: (i) the phonological theory, (ii) the magnocellular (auditory and visual) theory and (iii) the automaticity/cerebellar theory. In recent Japanese-speaking countries, Uno et al. surveyed 84 children and students with developmental dyslexia regarding phonological skills, visual cognitive skills, and automatization skills. As a result, 15.5% of the students had only phonological problems, but about 77% of all students had phonological problems. In addition, 8.3% of the students had only automatization problems, 10.7% had only visual cognitive problems, and about 57% of all students had visual cognitive problems. This also pointed out the importance of automatization skills and visual cognitive skills as well as phonological skills.

Children with dysgraphia complain about difficulties in copying from a board and textbooks during class. It is natural that typographical errors or prolonged time are observed for copying tasks. Diverse support systems are provided for students with difficulties as reasonable accommodation in school. Typoscopes have been widely used for students with impaired vision. Typoscopes have been introduced with the name “reading slit” as a support tool reading device. Typoscopes are not only equipped in libraries of special support education schools, but also other libraries as a universal design tool. Furthermore, typoscopes are used for students in schools who tend to have a problem to skip words or lines.

Several studies regarding the highlight function of digital text, which was inspired by typoscope usage, clarified effects for students with dyslexia. The effects of this support method were similar to the effects on paper text of typoscopes. Kanamori et al. verified effects of the highlight function with eye tracker experiments. A tendency was suggested that when reading a digital learning material, the usage of the highlight function enabled children with reading difficulties to start reading more quickly from the presentation of the task and to read the text along with sentence flow with less sporadic eye movements.

Copying sentences from a board or a textbook to a notebook requires more load than reading sentences. Children need to alternately look at the target for copying and the notebook for writing and tend to lose their orientation in comparison with a single task of reading. From this viewpoint, functions of highlighting and typoscopes are considered to reduce working load for this complex task, shortening the time and improving accuracy in copying. However, there are a sparse number of academic reports to examine whether the usage of highlighting or typoscopes would reduce difficulties in copying tasks.

Therefore, the purpose of this study was to clarify characteristics of cognitive impairment structures regarding children with writing difficulties and to examine effects of typoscopes to improve difficulties in copying.

## Method

### ***Participants***

Research participants of this study were six schoolchildren in the fourth, fifth and sixth grades of an elementary school, three were boys with learning disability (LD) and three were boys with typical development (TD). The three schoolchildren with LD had writing difficulties, receiving special support from the elementary school as well as day service after school and support from experts of a university. Among the three children, one child had been diagnosed as LD by a pediatrician before participation in this research. All three children with LD showed academic scores less than the mean minus 1.5 standard deviation (SD) in comparison with the mean values of students in their grades in the item of *kanji* writing. It was based on the Standardized Test for Assessing the Reading and Writing (Spelling) Attainment of Japanese Children and Adolescents: Accuracy and Fluency (STRAW-R). Furthermore, examinations for IQ were performed, employing two tests: Wechsler Intelligence Scale for Children-IV or III (WISC-IV or WISC-III), and Raven's Colored Progressive Matrices (RCPM), which was reported to have correlation with WISC-III. Results of the IQ tests confirmed that two students with LD had scores of 85 or higher regarding FSIQ, VCI, PRI, WMI and PSI (FIQ, VIQ and PIQ) in WISC-IV (or WISC-III), and IQ scores in RCPM were more than -1 SD in comparison with other students in their grades. Contrarily, one student with LD had IQ score of less than -1.5 SD for his grade, PSI score of 78 in WISC-IV, which represented the boundary zone, and other scores of 85 or higher. Judging from these data results as well as their learning support conditions, the two students (A and B), who had not been diagnosed as LD, were categorized into LD with writing disabilities based on DSM-5 criteria. Examinations of STRAW-R writing and RCPM, which were performed for children with TD, confirmed that there was no developmental delay regarding writing disabilities of corresponding grade students. Furthermore, it was confirmed that there was no delay of IQ score of less than -1.5 SD. There were no problems of eyesight (or corrected eyesight). This research was conducted with written consents and signatures under the guaranteed right of refusal, after research participants and their parents or other guardians had been fully informed of this research in writing. Furthermore, this research was conducted under approval of the Research Ethics Committee of the university which the author belongs to.

### *Procedure*

#### *Standardized Tests*

The following test was performed for all research participants to assess factors which were reported to relate to writing skills: visual functions, visual-motor integration, visual cognitive function, phonological skills and automatization skills.

Visual acuity with both eyes was measured using a new standard near vision chart. Eye movement was assessed using a development eye movement test (DEM) which using in previous study. Referring to a previous study of Sambai et al. and Inomata et al., which employed a test of visual perceptual skills with a task of copying geometric shapes, this study employed the Beery-Buktenica Developmental Test of Visual-Motor Integration (VMI) as a shape-copying task. Both visual-motor integration and visual perception skills were examined. In previous studies, the original words repetition task and non-words reversal task were performed to evaluate phonological skills. In this study, easy literacy check (ELC) which is a screening test for phonological processing skills was performed regarding the reversal and the deletion of words/nonwords, which were subclass items of ELC. Rapid Automated Naming (RAN) of STRAW-R which was used in previous studies was performed to assess automatization skills.

#### *Copying Tasks*

For the measurement of eye movements and sounds, research participants were equipped with SMI™ eye tracking glasses during the practice of a copying task. The task was to copy from a "target" of 22 letters, a part of a *hiragana* character (phonogram) string, which were randomly arranged on a sample sheet, onto a blank 18 mm square grid sheet. In the test setting, a sample sheet was placed on the side of the non-dominant hand and a blank grid sheet was placed on the side of the dominant hand of a participant. Participants used a pencil and were requested to write letters as fast and neat as possible and to rewrite the letter on the next square when miswriting. The font size was 15 point and three types of line spacing, 15, 7.5 and 0 point were used. Six operations were repeated, which completed six conditions: three types of line spacing and two versions, with and without a usage of the typoscope. The used typoscope was made from a colored and semitransparent plastic film and had a slit with the width of one line. Copying tasks started after pointing the position of a target on the sample sheet. In a task with the usage of a typoscope, before the start signal of pointing, the typoscope was placed, where the target string was set within the typoscope slit.

***Data analysis***

Referring to the previous studies of Goto et al. and Sambai et al., examination results exhibited reductions of performance were the mean value +1.5 SD or more in DEM and RAN, and less than the mean value -1.5 SD in VMI. Assessment of phoneme processing in ELC was designed for the lower graders of primary schools (in the second and the third grade) and the standard range was in the range of 1 SD from the mean value of the enrolled grade. Since the children who participated in this study were in grades 4-6, ELC adopted the standard value for grade 3. Therefore, in this study, we determined reductions of perforemance in ELC were the mean value (the third grade) +1 SD or more in required time, and less than the mean value -1 SD in the number of correct answers.

Data recoded by eye-tracking glasses for copying tasks were analyzed with a sampling frequency of 30 Hz. It was defined that a fixation occurs when the gaze is held on an object or location within 3° of visual angle for 100 ms or longer. Eye mark data, which showed positions seen by research participants, were collected from starting to write the first letter of the target to finishing the last letter of the target. Results of analysis provided the total time of tasks. Eye movements of a participant indicated mainly reciprocation between a sample sheet and a grid sheet as “the participants looked at it, and then remember the target on the sample sheet and next wrote it on the sheet for copying”, which was a copying task. Therefore, the number of times referring to the sample sheet was counted as one time for every movement from visual fixation on the sample sheet to visual fixation on the copy sheet.

The time duration from the first visual fixation to the last visual fixation on the sample was calculated as the text reference times for every time of reference. The duration for reference which was required by a student with LD was irregular. To assess the irregularity, Extremely Long Reference Time (ELRT) , which was an index by the operational definition of this study, was calculated as exceeded time duration. ELRT was the mean value of a text reference time of TD participants +4 SD or longer, where ordinary copying setting was similar to the copying setting of TD participants without using a typoscope. Furthermore, another analysis was performed to obtain standard duration of students without LD at the same age in a natural setting doing copying tasks. Based on text reference time of all TD participants without using a typoscope, Average of Total Text Reference Time+1 SD (ATTRT+1 SD) was calculated in order to estimate standard required time for copying the tasks under a natural circumstance of children without LD at the same age. Sequentially, letters which were written by one text reference were counted. When writing a single letter required multiple references, one letter was divided by the number of references for the one letter. To assess accuracy in copying, the number of errors were subtracted from the number of written letters: errors consisted of four types, mistake, omission, correction and addition.

## Results

### *Standardized Tests*

DEM showed that A and C (participants with LD) had +1.5 SD or more in H/V Ratio, which indicated accuracy of saccadic eye movement, and participants A and B (LD) had +1.5 SD or more in the number of errors. VMI recognized the value of less than -1.5 SD for participants A and C (LD). For ELC, participant A (LD) showed low performances in the item of incorrect answers: low correct answer ratios in both the reversal of words/nonwords, and total required time of less than -1 SD in both the deletion of words/nonwords. Participant C (LD) required long time for the deletion of words. As for RAN, all of three participants with LD indicated values of +1.5 SD or more.

***Copying Tasks***

For all three participants with LD, total times of tasks using typoscopes were shorter than tasks of typoscope non-use. Furthermore, differences between non-use and use were largest specifically in tasks with 0 pt line spacing. The difference of participants A, B, and C (LD) were 149.99, 121.84, and 82.56 seconds, respectively. There were no recognized differences between typoscope non-use and use in the three participants with TD; the largest difference was 23.36 seconds of a task with 7.5 point line spacing in participant E (TD).

The average of total text reference time (ATTRT)+1 SD of all participants with TD, when not using typoscopes, showed 38.56 seconds.

The accumulations of text reference time with 15 point line spacing of participant A (LD) were 31.68 seconds without a typoscope and 29.11 seconds with a typoscope; there was no remarkable difference. Compared tasks between non-use and use of a typoscope, differences regarding 7.5 pt line spacing were 75.97 and 33.46 seconds in non-use and use, respectively. Differences regarding 0 pt line spacing were 175.40 and 28.12 seconds in non-use and use, respectively. The accumulations of text reference time in 7.5 and 0 pt line spacing greatly exceeded ATTRT+1SD in copying tasks without typoscopes, while accumulations of text reference time were shorter with usage of typoscope. The Extremely Long Reference Times (ELRT) were detected multiple times in tasks without typoscopes regarding 7.5 and 0 point line spacing.

Showing results of accumulation of text reference time of participant B (LD), time of the tasks with 15 point line spacing, time was 58.31 and 21.65 seconds without and with a typoscope. Accumulations of time with 7.5 pt line spacing were 51.98 and 28.38 seconds, and time with 0 pt line spacing were 136.06 and 23.79 seconds without and with a typoscope. Accumulations of text reference time without a typoscope were remarkably longer in all three types of line spacing than ATTRT+1 SD and ELRT were detected multiple times. Contrarily, in tasks with a typoscope, accumulation times were within ATTRT+1 SD and no ELRT was detected.

Showing results of accumulation of text reference time of participant C (LD), time of tasks with 15 point line spacing, time was 39.20 and 27.59 seconds without and with a typoscope, where no large difference was recognized. Time with 7.5 pt was 87.02 and 30.10 seconds, and tasks with 0 pt line spacing were 98.21 and 31.25 seconds without and with a typoscope. Accumulations of text reference time without a typoscope were remarkably longer in 7.5 and 0 pt line spacing than ATTRT+1 SD and in tasks with a typoscope, accumulation times were lowered than ATTRT+1 SD. ELRT were detected once in 15 pt and multiple times in 7.5 and 0 pt line spacing in tasks without typoscopes.

From the above results, all children with learning disabilities required more time for referring a sample sheet without a typoscope. Consequently, using a typoscope in a copying task helped them to reduce accumulations of text reference time to less than ATTRT+1 SD.

Participants with TD had no remarkable differences in tasks between typoscope use and non-use regarding accumulation of text reference time: without using a typoscope, participant

E (TD) only showed 47.36 seconds in 0 point line spacing, which exceeded ATTRT+1 SD, and participant D (TD) only showed ELRT once in 0 pt line spacing.

Participants with LD made more errors than participants with TD. There was no remarkable difference in participants regarding conditions of tasks and line spacing.

## Discussion

It has been reported that cognitive factors related to reading and writing difficulties in Japan had a visual perception deficit, phonological deficit, and automaticity deficit. For these disorder structures, some children represent a single structure of phonological deficit or visual perception deficit, dual structure of phonological deficit and visual perception deficit and triple structure of phonological, visual perception, and automaticity deficits.

Observing examination results of the three children with learning disability, participants A and C (LD) indicated performance reductions in DEM, VMI, phonological awareness and RAN. It was suggested that they had triple structure, showing impairments of visual perception, phonological awareness, and automatization as factors of writing difficulties. Participant B (LD) showed performance reductions in DEM and RAN. Therefore, there was a possibility that he had dual structure with visual perception deficit and automatization deficit. From the above findings, the core mechanism for writing difficulties of participants with LD in this study was congruous to the participants with LD on whom the previous studies had reported and it was suggested that the participants with LD of this study showed a structure of complex cognitive impairment.

Children with dysgraphia had diverse problems of writing slowly in copying written letters, writing when hearing spoken words, and writing a composition, as well as rewriting or making errors. They have difficulties in “writing speed” and “writing accuracy”. This study confirmed that in copying tasks with using a typoscope, total time duration and accumulation of text reference time were shortened and no ELRT for text reference was detected in comparison with tasks without a typoscope. Observing eye movement data of ELRT, which were shown in tasks without using a typoscope, when the eye mark moved to the sample sheet from the grid sheet, children with LD lost the target of the text. It was observed that the eye mark was moving on the sample sheet, which required longer time for target search, and their remarks of “I cannot find the target.” were observed. ELRT of text reference time were detected frequently without usage of a typoscope for children with LD, which confirmed that they tended to lose the target and require longer time for the searching of the target in comparison with children with TD. Furthermore, it was suggested that they did not lose the target and needed shorter time for the target search to complete the copying task due to the usage of a typoscope. The accumulation of text reference time of this task was within ATTRT+1 SD. This was in the same level of children with TD without a typoscope, which were supposed to be a setting of general copying environment.

Furthermore, observing that the total of required time and target reference time were shorter with 15 point than with 0 point line spacing for all participants with LD, it was confirmed that even only the adjustment of line spacing could shorten the time for the target search. However, this study did not observe remarkable differences between typoscope use and non-use and among types of line spacing regarding the number of errors such as mistakes and omissions. Kanamori et al. reported that when using highlight function for children with dysgraphia, read latency was shorter but no effects on performance were recognized. Findings of this study, as showed by study of Kanamori et al. on highlight function, showed that the usage of a typoscope shortened the time for searching the target but did not improved accuracy in copying letters. Further examinations are required to develop support systems for children with writing difficulties to improve copying.

## Conclusion

In this study, schoolchildren with LD who had difficulty in writing, showed complexity of cognitive impairment structures, such as visual perception deficits, phonological deficits, and automaticity deficits, indicating difficulties in target search for the task of copying. This research demonstrated that extended time for target search was a factor for children with LD, where they required more time in copying than children with TD and the use of typoscopes was effective in burden reduction of target search and shortening the total time of copying. Furthermore, it was suggested that adjustment of leaving a wide space between lines was effective in shortening total time for copying. So far, there are no studies that have examined copying task in children with writing difficulties using eye tracker. In this study, we were able to propose a measure to reduce the burden on children with writing difficulties in copying by using an eye tracker. It was suggested that the eye tracker is an effective method for verifying the performance of the transcription task in detail. In addition, all children with writing difficulties who participated in this study showed a complex cognitive impairment structure, but it was suggested that there are some differences in cognitive skills that causes writing difficulties among children. Further research is needed to propose more effective support tailored to the cognitive impairment structure of children with writing difficulties.

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