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# EFFECTS OF RST WITH DIFFERENT LINGUISTIC WORKING MEMORY ON CEREBRAL BLOOD FLOW IN FOREHEAD

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Abstract. *The Japanese language has three characters (kanji, hiragana, and katakana) and punctuation marks. We measured the cerebral blood flow during the "Reading Span Test (RST)", a dual-task method, using near-infrared spectroscopy (NIRS) to examine the linguistic working memory for the same sentence with different forms of these characters. The test was conducted using NIRS to measure brain blood flow during the RST, a dual-task method. The text for the reading comprehension test consisted of hiragana, katakana, and three characters including spaces; we experimented with six combinations of the three characters, 1) Kanji-kana mixed with no spaces (Kanji-NS), 2) Kanji-kana mixed with spaces (Kanji-S), 3) hiragana only with no spaces (Hira-NS), 4) hiragana only with spaces (Hira-S), 5) Katakana only with no spaces (Kata-NS), and 6) Katakana only with spaces (Kata-S). The correlation coefficient between cerebral blood flow during task execution and the percentage of correct answers for each form of writing was used to determine the correlation. As a result, we found that "when cerebral blood flow increases in 1) Kanji-NS (right brain), 3) Hira-NS (right brain), 5) Kata-NS (left brain), and 6) Kata-S (left brain), the correct answer rate tends to be higher", but no correlation was found in other conditions.*
**Keywords:** Working memory, RST, NIRS, Cerebral blood flow

1. **Introduction.** The purpose of our study is to look for clues to understanding the disability status of children with reading difficulties through the measurement of cerebral blood flow. Many studies have been conducted on developmental disorders such as learning disabilities, attention deficit hyperactivity disorder (ADHD), and autism. Working memory (WM) has been implicated in these disorders, but there is debate about whether it can be considered of the primary cause of each disorder. However, at least in learning

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disabilities, WM is closely related to the mechanism of the disorder and is said to be an important factor [1].

WM is a memory system that supports higher-order cognitive activities, such as multiple mental tasks, e.g., mental arithmetic and reasoning, in which "task execution" and "information retention" are performed in parallel. The processing involved in reading also involves parallel processing. For example, when we read a sentence, we have to follow the meaning of the words, and at the same time, we have to retain the content of the sentence temporarily. In addition, it is necessary to retrieve relevant information from the reader's long-term memory to help the reader understand the text. Kintsch and van Dijk were the first to introduce the concept of WM into the reading process of such sentences, where they reported the following when reading a sentence, the input information is activated as a semantic network, and new information is added to it to form a new semantic network. In this process, the latest or most central information is selectively retained, and the amount of other information activity decreases, resulting in forgetting. In this case, WM functions as a system that maintains the input information in a constant activity state [2].

In cognitive psychological research, WM has been studied mainly using the dual-task method. While short-term memory tasks measure memory span by memorizing numbers, words, and others, WM tasks measure memory capacity in situations requiring the retention of information and other processing simultaneously. In this study, we used the Reading Span Test (RST), a dual-task method that requires the participants to memorize one underlined keyword in each sentence while reading several short sentences and immediately saying the memorized keyword after reading all the sentences. RST is one of the dual-task methods [3]. Furthermore, the RST is related to text comprehension, as the memory span test, which requires sequential recitation of numbers, letters, words, and some others, does not show any correlation with the reading comprehension test, while a significant correlation was found between the RST and the reading comprehension test [3].

In addition, neurophysiological studies have been conducted to elucidate the brain mechanisms involved in WM, and the dorsolateral prefrontal cortex (DLPFC) is thought to be involved in WM. The DLPFC, superior temporal gyrus, and anterior cingulate gyrus have also been implicated in functional magnetic resonance imaging (fMRI) studies during RST. In particular, the DLPFC is thought to be responsible for the attentional control function for proper information retention [4]. Since the DLPFC can be measured in the near-infrared, in this study, we measured changes in cerebral blood flow during the RST task in real time using near-infrared spectroscopy (NIRS).

In this study, we paid particular attention to the reading activity of sentences. We examined whether there was a correlation between comprehension of sentences and cerebral blood flow by increasing or decreasing cerebral blood flow in the prefrontal cortex during the RST using different notation methods and examining the effects of different notation methods on WM capacity effects of sentence breaks on attention control function. In addition, we conducted experiments to investigate the effects of different writing styles on WM capacity and the effects of sentence breaks on attentional control.

## 2. Methods.

This section will briefly explain RST as an experimental method and HOT-2000 as a measurement device and its measurement function, NIRS.

### 2.1. RST.

Working memory is the function of memory that is temporarily required while performing some cognitive task. Although various models have been proposed, the model with a control system of information retention system (memory retention) and central execution system (cognitive processing) is currently supported by many researchers. When performing cognitive tasks, there is competition for resources between memory retention and cognitive processing. The most common of these tasks is the RST, one of the dual-task methods. Participants are presented with multiple sentences once at a time and asked to memorize the keywords of each sentence while reading them aloud. In the RST, participants are presented with multiple sentences and must memorize the keywords of each sentence while reading it aloud. Individuals' RST scores are calculated from their performance in replaying the memorized words and reflect their working memory capacity. While reading some short sentences, the students must memorize the underlined keywords (only one keyword per sentence) and immediately say the memorized keywords after reading all the sentences.

2.2. **Portable brain activity measurement device.** The HOT-2000 is a two-channel wearable portable brain activity measurement device developed by NeU Corporation. The two channels are assigned to the anterior part of the right and left forehead to measure the relative changes in blood flow in the areas concerned. It uses near-infrared light to monitor changes in blood flow related to brain activity, and Bluetooth communication allows real-time wireless measurement of brain activity indices, heart rate, and 6-axis acceleration using an app on a smartphone or tablet. The HOT-2000 uses a wavelength of light (approximately 800 nm) that is easily absorbed by the hemoglobin in the blood. The detector is located at a distance of about 3 cm from the light irradiation position. When the brain area in the light's path is activated, blood flow increases, light absorption increases, and the amount of light returning to the detector decreases. Brain activation is estimated from the attenuation rate of this detected light intensity. Figure 1 shows an image of the NIRS measurement.

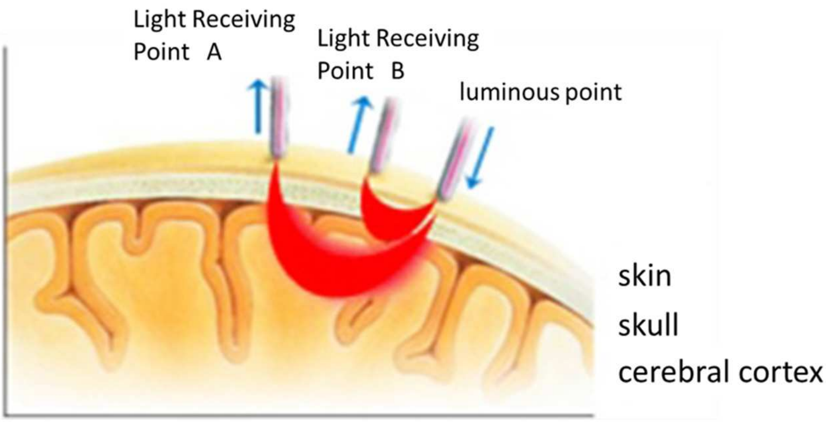


Figure 1. An image of optical measurement of cerebral blood flow changes (https://neu-brains.co.jp/service/equipments/hot-2000/)

3. **Experimental Method.** First of all, we would like to mention that this experiment was conducted with the approval of the Research Ethics Review Committee. Twenty-one college students participated in the experiment. All the participants explained the contents of the experiment in advance, and their signed consent was obtained.

There are three types of writing forms in Japanese: kanji, hiragana, and katakana. This study set up the following six types of writing forms for the RST task: mixed kanji and kana, kana only, and with and without sentence separators (spaces). We created six different presentation sentences for use in RST by combining kanji, hiragana, and katakana characters with and without spaces.

Table 1 shows the six different combinations of three types of characters used in the presentation text used in RST. Here is a supplementary explanation about separating words with spaces. Japanese is written in hiragana, katakana, and kanji, but only in kana when students are not learning kanji. It is challenging to recognize sentence breaks in

TABLE 1. The six different combinations of three types of characters

| No. | Abbreviation | Combination of the letters |
|---|---|---|
| 1) | Kanji-NS | **Kanji**-kana mixed with **N**o **S**paces |
| 2) | Kanji-S | **Kanji**-kana mixed with **S**paces |
| 3) | Hira-NS | **Hira**gana only with **N**o **S**paces |
| 4) | Hira-S | **Hira**gana only with **S**paces |
| 5) | Kata-NS | **Kata**kana only with **N**o **S**paces |
| 6) | Kata-S | **Kata**kana only with **S**paces |

TABLE 2. Six presentation texts for RST

| No. | Mode | Text | Keyword |
|---|---|---|---|
| 1 | Presented text | この物語はどうにも救いようがなく慰めようがない | 救いよう |
| | Everyday expression | (same as above) | |
| | Translation | (*This story is in no way redeemable or comforting.*) | |
| 2 | Presented text | この　絶えざる　不均衡状態に　よって　言葉は　生まれてくる | 絶えざる |
| | Everyday expression | (この絶えざる不均衡状態によって言葉は生まれてくる) | |
| | Translation | (*It is through this constant state of imbalance that words are born.*) | |
| 3 | Presented text | ところがそんななまやさしいことではすまなかった | なまやさしい |
| | Everyday expression | (ところがそんな生易しいことではすまなかった) | |
| | Translation | (*But it was not as simple as that.*) | |
| 4 | Presented text | これは　にんげんの　ぶんかに　ふへんてきな　けいこうで　ある | ふへんてき |
| | Everyday expression | これは人間の文化に普遍的な傾向である | |
| | Translation | (*This is a universal tendency in human culture.*) | |
| 5 | Presented text | シャワーヲアビテテイネイニカラダトカミヲススイダ | アビテ |
| | Everyday expression | シャワーを浴びて丁寧に身体と髪をすすいだ | |
| | Translation | (*I took a shower and carefully rinsed my body and hair.*) | |
| 6 | Presented text | ジブンデハ　コントロール　フカノウナ　ジブンノ　カンジョウ | フカノウ |
| | Everyday expression | 自分ではコントロール不可能な自分の感情 | |
| | Translation | (*My own emotions that I cannot control.*) | |

sentences written only in hiragana, and in textbooks for lower elementary school students, words are often separated by spaces. When spaces do not separate words, reading aloud slows down, and the reader cannot grasp word and clause breaks effectively. In this case, it is believed that even healthy children may stumble in reading, creating a situation similar to that of children with learning disabilities [3].

The four presenting sentences for the RST, created according to the six combinations in Table 1, are shown in Table 2. The first column shows the six patterns, the second column shows the presenting sentences, daily expressions, and English translations, the third column shows the sentences corresponding to the second column, and the fourth column shows the keywords to be answered.

The overall flow of the experiment is shown in Figure 2. The task and rest are repeated using a block design to measure changes in cerebral blood flow. Each RST task presents four sentences (each for 5 seconds) and response for 20 seconds. The rest is 45 seconds of closed-eye rest. A total of six sessions were held in response to the presentation of sentences with six different notation formats.

4. **Results.** The cerebral blood flow of 21 subjects was visualized graphically and assigned to three patterns according to their characteristics, as shown in Table 3 and Figure 3. Figure 3 shows the typical time-series data of the three patterns shown in Table 3. The vertical axis is the relative hemoglobin concentration change measured by the HOT-2000. The solid line represents the measurement results for the left side of the frontal forehead, and the dotted line represents the measurement results for the right side of the frontal forehead.

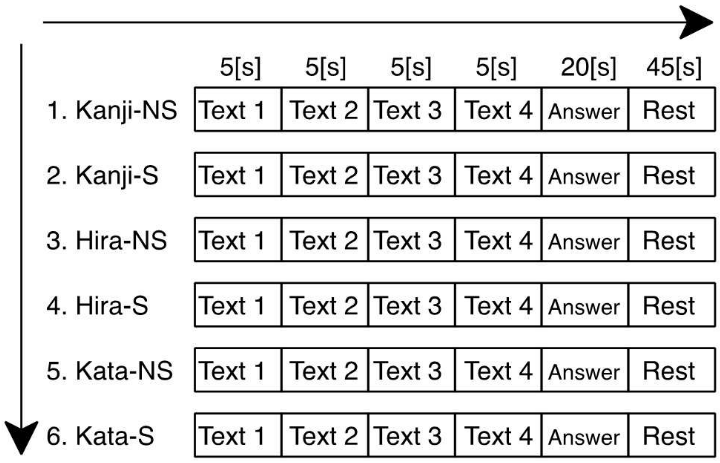


Figure 2. The flow of the experiment with block design

Table 3. Patterns of cerebral blood flow in 21 participants

| Pattern | Number of people | Response |
|---|---|---|
| A | 13 | Cerebral blood flow was activated during task execution. |
| B | 6 | Cerebral blood flow was more active at rest with eyes closed than during the task. |
| C | 2 | There was no change in cerebral blood flow during resting with eyes closed or performing the task. |

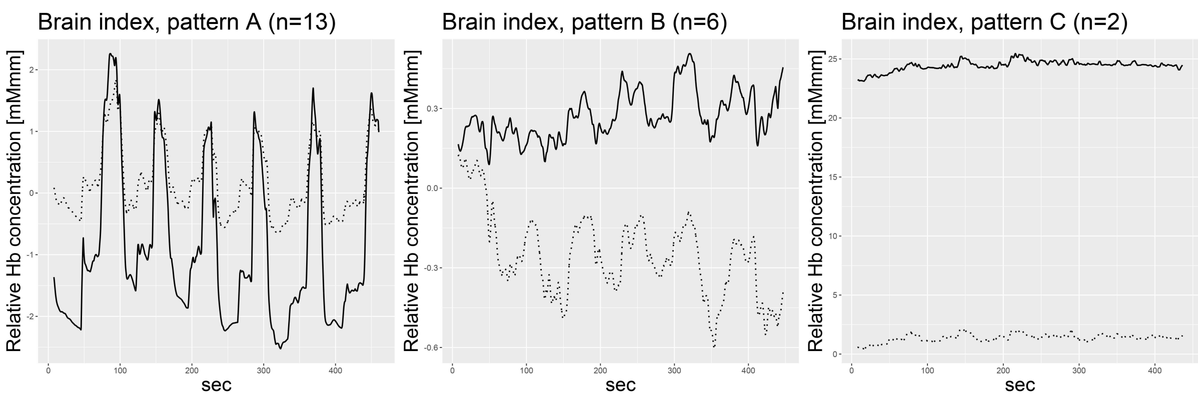


Figure 3. Graph of cerebral blood flow (21 people classified into three patterns)

Some problems probably caused pattern C in the measurement. Pattern B was excluded from our analysis because of the increase in cerebral blood flow during the closed-eye resting state. Therefore, we further analyze pattern A, where cerebral blood flow increased during the task. First, we focused on which activates cerebral blood flow, reading or answering, during task execution, and classified them in Table 4.

Next, we focused on whether the right or left frontal forehead activates cerebral blood flow during task execution and classified them in Table 5. Typical graphs of the patterns classified in Tables 4 and 5 are shown in Figures 4 and 5, respectively.

As further verification, the correlation coefficients between the average percentage of correct answers for each notation format in pattern A (cerebral blood flow is activated during task execution, $n = 13$) and the average relative hemoglobin change of the left and right frontal forehead during task execution are shown in Table 6. The percentages of correct answers were all in the range of 40%-60%, and the correlations tended to be slightly higher at 1) Kanji-NS, right (0.488), 5) Kata-NS, left (0.308), 6) Kata-S, left (0.271), and 3) Hira-NS, right (0.239).

Table 4. Classifying pattern A by focusing on reading and writing

| Pattern | Number of people | Response |
|---|---|---|
| A1-1 | 4 | Cerebral blood flow was more active when reading aloud than when answering. |
| A1-2 | 9 | Cerebral blood flow was more active when answering than when reading aloud. |

Table 5. Classifying pattern A by focusing on the frontal area, right side and left side

| Pattern | Number of people | Response |
|---|---|---|
| A2-1 | 3 | Cerebral blood flow to the left side of the brain was more active than the right side. |
| A2-2 | 4 | Cerebral blood flow to the right side of the brain was more active than on the left side. |
| A2-3 | 6 | Activation of cerebral blood flow in the left and right hemispheres is comparable. |

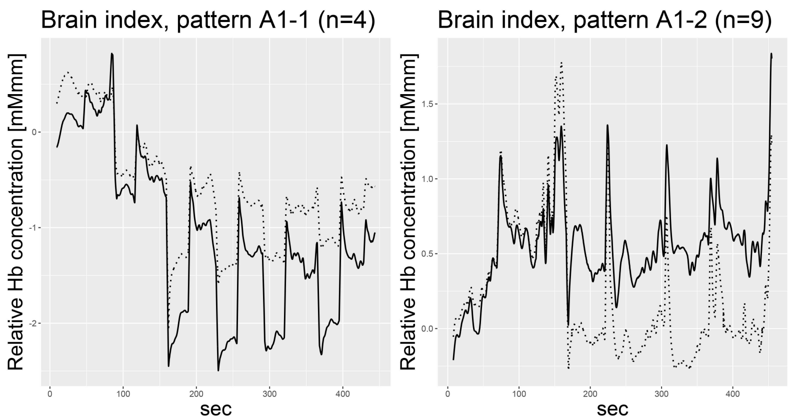


Figure 4. Graph of pattern A classified by reading/answering

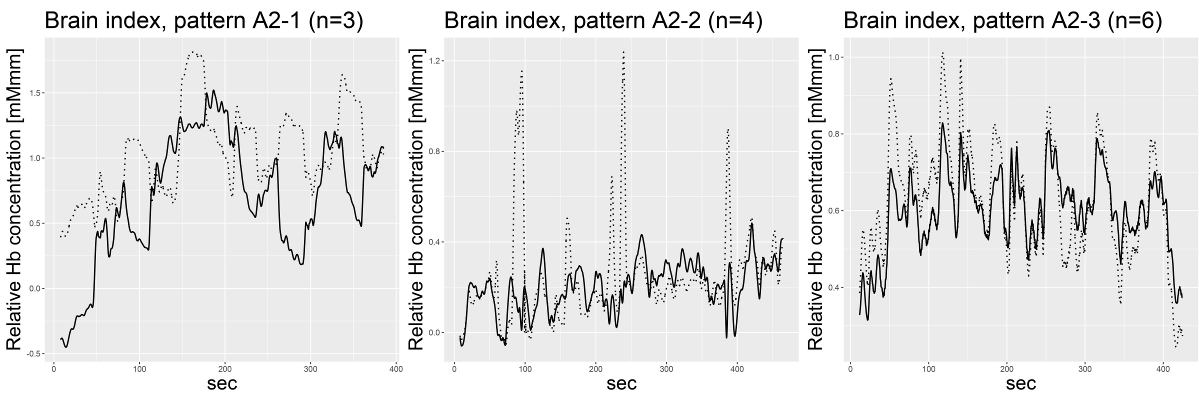


Figure 5. Graph of pattern A classified by left/right

Table 6. Correlation coefficients between the relative hemoglobin change during the task and the percentage of correct answers in each notation format for the 13 participants in pattern A

| **No.** | **Abbreviation** | **Correlation** | | **Mean of correct answers** |
|---|---|---|---|---|
| | | **left** | **right** | |
| 1) | Kanji-NS | 0.174 | 0.488 | 57.69% |
| 2) | Kanji-S | −0.100 | −0.169 | 41.67% |
| 3) | Hira-NS | 0.065 | 0.239 | 54.17% |
| 4) | Hira-S | −0.129 | −0.072 | 56.25% |
| 5) | Kata-NS | 0.308 | 0.152 | 44.23% |
| 6) | Kata-S | 0.271 | 0.146 | 42.31% |

Thus, in this RST task experiment, we did not find any results that would indicate a correlation between response rate and cerebral blood flow.

As for the 6 participants whose cerebral blood flow was more active during resting eye closure than during the execution of the task, research has shown that the brain activity of young people is lowest and that of older people is highest when the background during the execution of the RST task is white [5], and we thought that these 6 participants showed results similar to these results. As we can see from other calculation tasks, cerebral blood flow increased regardless of the percentage of correct answers. The sentences were not long enough, so the results may not have been significantly different. The difference may be due to the shortness of the sentences, which may have required the presentation of several sentences each for the standard and katakana task sentences. Since the tendency for cerebral blood flow to be activated by the execution of the task is 13/21 according to patterns A, B, and C of the experimental results, it would have been better to prepare task sentences in which this ratio is high first and then compare them with task sentences in different writing forms.

5. **Conclusions.** The purpose of this study was to investigate whether there is a correlation between sentence comprehension and cerebral blood flow by increasing or decreasing cerebral blood flow in the prefrontal cortex during RST using different notations. Also, we examined the effects of other notations on WM capacity and the effects of sentence breaks on attentional control functions. These objectives have been achieved. Thirteen of the 21 participants whose cerebral blood flow was activated during the task were analyzed.

As a result, no clear difference was found in the average percentage of correct responses to the RST task in the six conditions with different forms of notation. In the present study, the Kanji-NS condition is a notation form commonly used in daily life, and the Hira-S condition is a notation form commonly used by younger age groups. However, the other four conditions are forms of notation that we do not often see in our experience, and we can infer that they are sentences that contain a sense of discomfort. As a result, Kanji-S, which is supposed to be the least uncomfortable, had the lowest percentage of correct answers to the task. It can be inferred that Hira-NS and Kata-NS, which are entirely unfamiliar to the students, had to be aware of the sentence breaks, while Kata-S had to read the sentences with extra space at the sentence breaks. Therefore, when reading unfamiliar or highly uncomfortable sentences, the experimental collaborators will pay attention to the keywords and the phrases before and after the keywords. WM is activated to suppress information other than the keywords, resulting in a higher correct answer rate. In other words, it can be inferred that the linguistic WM used when reading sentences with unfamiliar notation requires more attentional control functions.

In this study, the correlation was examined using correlation coefficients. However, since correlation coefficients alone are a weak analysis method, it is necessary to use more than one analysis method, such as a t-test to confirm the significant difference between the means of the two groups, or visualization using box-and-whisker diagrams or histograms. In addition, the number of participants in this experiment was not significant, so it is necessary to increase the number of participants.

It is expected that the application of biometric data to education will accelerate in the future. Liao et al. combined brain-wave detection with MOOCs-based teaching to provide participants with the ability to monitor and improve their learning in real time [6]. They also validate the subjective evaluation results of learners by comparing them with brain-wave detection. We would like to consider incorporating the learner's psychological state into the analysis in the future.

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