EVALUATION OF THE EFFECTIVENESS OF READING ALOUD A PROGRAM CODE IN LEARNING PROGRAMMING BASED ON BRAIN-ACTIVITY MEASUREMENTS

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ABSTRACT

We evaluate the effectiveness of reading aloud a program code in learning programming from a neuroscientific perspective by measuring brain activity using a near-infrared spectroscopy device. The results show that when reading aloud and then reading silently, brain activity increases during reading aloud; a similar trend is observed when the reading order is reversed. In addition, written tests, such as C-language fill-in-the-blank questions, result in higher scores when the participants read aloud than when they read silently. Furthermore, no characteristic differences in brain activity were found between students with good programming skills and those without. Significant differences were found for students with average programming skills. In a future study, we will increase the number of participants to verify the above results and clarify the relation between brain activity and the difficulty level of the program code, reading speed, subvocalization during silent reading, and other factors. Our aim is to establish an efficient learning programming method by employing the reading-aloud technique.

KEYWORDS

Brain-Activity, Programming, Learning, Reading Aloud, NIRS

1. INTRODUCTION

Reading aloud can be an effective method for learning programming learning as well as natural language learning [Li J., 2020, Huimin W. et al., 2021]. A reading system for learning C language has been developed by the authors [Ueda M., et al., 2022] and its effectiveness was verified for University students. Additionally, reading aloud was found to be more effective for beginners in programming than silent reading or “shakyo” (sutra copying learning, learning programming by transcribing sample code) [Okamoto M., et al., 2010, Ueda M., et al., 2023]. Experiments involving elementary school students have also shown that reading a program code aloud contributes to improving syntax memorization and code comprehension [Swidan A., et al., 2019].

However, the verification of the effectiveness of the reading-aloud technique in previous studies was based on comparisons of scores obtained from task experiments and subjective evaluations through questionnaires, making it difficult to objectively evaluate the benefits of learning programming. Inspired by the research conducted on the effectiveness of reading aloud in learning natural languages [Takeuchi H., et al., 2021], we evaluate the effectiveness of the reading-aloud technique more objectively than previously evaluated by conducting neuroscientific experiments.

It has already been reported that the reading-aloud technique increases brain activity compared with the reading-silently technique [Kawashima R., et al., 2005, Chiarenza A. G., et al., 2014]. The brain activity during programming has also been reported [Hermans F., 2021]. For example, the use of near-infrared spectroscopy (NIRS) to measure a person’s mental workload during software development has been described in [Nakagawa T., et al., 2014]. The effect of programming with (or without) music on the electromagnetic waves in the brain of software developers has been reported in [Thapaliya A., 2021]. In [Thapaliya A., 2020], it was verified that pair programming leads results to a higher concentration level than solo programming.

However, the effectiveness of the reading-aloud technique in learning programming has not been reported in the literature. In this study, we conduct NIRS experiments to measure the brain activity of persons while they read a program code. The aim is to objectively verify the effectiveness of the reading-aloud technique in learning programming. We also investigate the differences in programming ability and the relation between programming ability and brain activity during reading aloud and reading silently.

In Section II, we explain the NIRS measurement procedure of brain activity. In Section III, we evaluate the effectiveness of the reading-aloud technique in learning programming through a C-language test. In Section IV, we discuss the relation between test scores and brain activity. Section V concludes the paper.

2. MEASUREMENT OF BRAIN ACTIVITY

2.1 Experiment Overview

In this study, we focused on brain (frontal lobe) activity to assess the effectiveness of reading aloud a program code in learning programming. We measured changes in the cerebral blood flow using a 2-channel NIRS device, which is used for measuring work efficiency.

For this purpose, we employed NIRS to measure the brain activity of 19 students of the Faculty of Information Technology, Kanagawa Institute of Technology, when they read a program code aloud and silently. A portable brain-activity measurement device (HOT-2000, NeU, Tokyo, Japan) was used for NIRS measurements. The output values obtained from the HOT-2000 device provide a brain-activity indicator based on changes in the blood flow (hemoglobin concentration) in the frontal lobe of the brain. Since these values are not absolute values, we investigated the changes in brain activity starting from a certain point in time.

After a brief explanation of the measurement procedure, each participant read two program codes aloud and silently while wearing the HOT-2000 device. Table 1. summarizes the measurement procedure. The numbers in parentheses indicate the time in seconds).

Table 1. Measurement procedure

Code1	Rest(10)	Reading Aloud(60)	Rest(25)	Reading Silently(60)	Rest(10)
Code2	Rest(25)	Reading Silently(60)	Rest(25)	Reading Aloud(60)	Rest(10)

2.2 Results and Discussion

HOT-2000 is a 2-channel device featuring two sensors, left and right. Figure 1 shows the measurement results obtained from a participant. The blue and green graphs represent changes in the values obtained from the right and left sensors, respectively. The left sensor values correspond to the brain's left hemisphere, which controls language; therefore, in this measurement, we used the values obtained from the left sensor.

To investigate the overall trend, we divided a 60-s reading into 6 parts and calculated the average value for each 10-s period for each participant. The results are shown in Figure 2. The brain activity indicator values increase during Reading Aloud1 and decrease during Reading Silently1; they remain relatively stable during Reading Silently2 and increase during Reading Aloud2.

To verify this trend, we conducted a paired two-sample t-test to evaluate the amount of change between the start and end of the reading-aloud process and that between the start and end of the silent reading process, as shown in Figure 3.

For Code1, the brain-activity indicator values increase during Reading Aloud1 and decrease during Reading Silently1. These two processes are significantly different ($p = 0.015$). Regarding brain activity from Reading Silently2 to Reading Aloud2 for Code 2, the change in the brain activity indicator values was slightly larger in Reading Aloud 2, but the variance was large and no statistically significant difference was observed.

Figure 1. Example of graphing experimental results

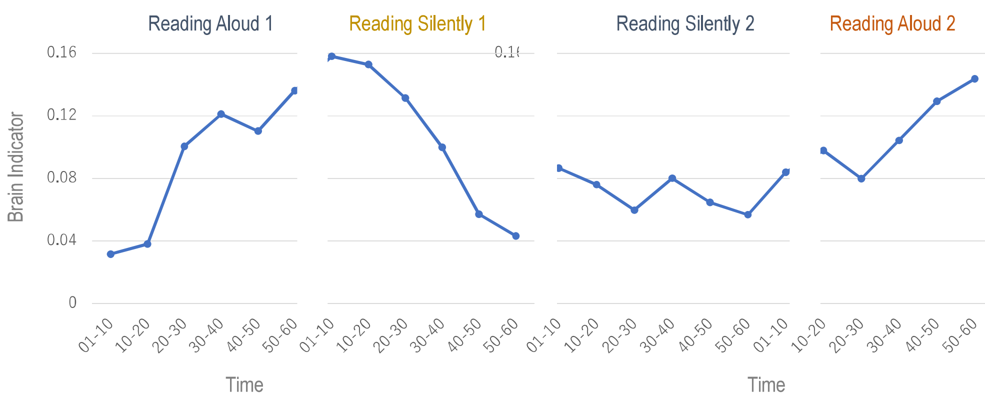
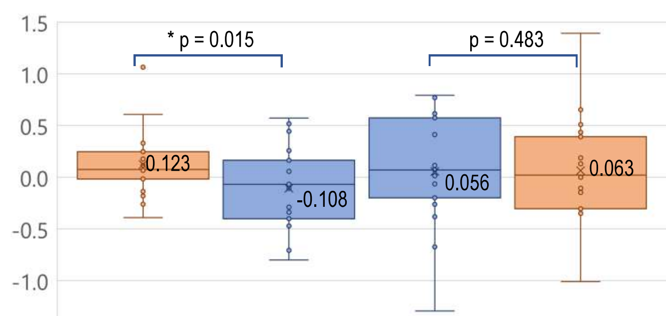


Figure 2. Line graph of 10 s average of left brain indicators



	code1		code2	
	aloud1	silently1	silently2	aloud2
μ	0.123	-0.108	0.056	0.063
σ^2	0.105	0.150	0.268	0.248

Figure 3. Boxplot of changes in left brain indicators (N=19)

Looking at individual data, for some participants, the change in the brain activity indicator values was significantly in the direction opposite to the overall trend. There are various possible reasons for this. Specifically, brain activity increases because the participants have difficulties in understanding the source code, the code is long, the participants perform subvocalization (internal vocalization) when reading silently, and other reasons.

Therefore, to verify the effectiveness of the reading-aloud technique in learning programming, it is necessary to collect and analyze more data and to examine their relation with brain activity indicators. The difficulty and length of the source code used in the measurements, the voice volume when reading aloud, the presence or absence of subvocalization during silent reading, and the participant's programming skills must be considered.

Furthermore, it is possible that the initial Reading Aloud1 process affected brain activity during the subsequent Reading Silently1, Reading Silently2, and Reading Aloud2 processes. The reading speed could also affect brain activity. Therefore, we need to employ measurement procedures that eliminate these problems.

3. INVESTIGATION OF THE EFFECTIVENESS OF THE READING-ALOUD TECHNIQUE ON LEARNING PROGRAMMING USING A WRITTEN TEST

We investigated the differences in programming ability and the relation between programming ability and brain activity when reading aloud and silently.

3.1 Experiment Overview

In this experiment, students participated in two written C-language tests (Test 1 and Test 2) with 10 questions each. The questions included the prediction of the program results and answering the blanks based on the program with blanks and the execution results. Each problem was based on five programs (branches, loops, structures, pointers, functions) of 10–20 lines for beginners in the C language.

The participants were 18 undergraduate and graduate students in their early 20s. Seventeen of them were the same students who participated in the brain activity measurement experiment, and one was a new participant. The 18 participants were divided into two groups of 9 people each: Group 1 and Group 2. Each Group 1 participant answered Test 1 by reading the program code aloud three times and Test 2 by reading the source code silently three times before answering. Conversely, each Group 2 participant, read the program code silently during Test 1 and aloud during Test 2.

3.2 Results and Discussion

Table 2. shows the score results of Tests 1 and 2 for the 18 participants (the maximum score was 10 points), the total scores, and the score difference between Tests 1 and 2. A boxplot of the test scores is shown in Figure 4. (1) is based on data obtained from all participants, (2) is based on data obtained from Group 1, and (3) is based on data obtained from Group 2.

On average, the participants scored 1.2 points higher in test 2 than test 1. As shown in Figure 4. (1), there is a significant difference between them, indicating that Test 2 was easier than Test 1. Furthermore, for both Group 1 participants, who read aloud during Test 1, and Group 2 participants, who read aloud during Test 2, the difference in the mean scores for Tests 1 and 2 was 1.2. Based on the average scores, we cannot say that reading aloud is effective. However, Figure 4. (2) and (3) show no significant difference among Group 1 participants but a significant difference among Group 2 participants. This indicates that in Group 1, the easiness of Test 2 was offset by reading aloud during Test 1. In Group 2, the effect of reading aloud appeared in addition to the easiness of Test 2, indicating the effectiveness of reading aloud.

Table 2. Test score

participants	group	test1	test2	sum	difference
a	1	7	7	14	0
b	1	5	8	13	3
c	1	6	7	13	1
d	1	6	7	13	1
e	1	4	6	10	2
f	1	5	5	10	0
g	1	1	6	7	5
h	1	5	1	6	-4
i	1	1	4	5	3
j	2	8	7	15	-1
k	2	5	7	12	2
l	2	5	6	11	1
m	2	4	7	11	3
n	2	4	4	8	0
o	2	3	5	8	2
p	2	4	4	8	0
q	2	2	6	8	4
r	2	3	3	6	0
average		**4.3**	**5.6**	**9.9**	**1.2**

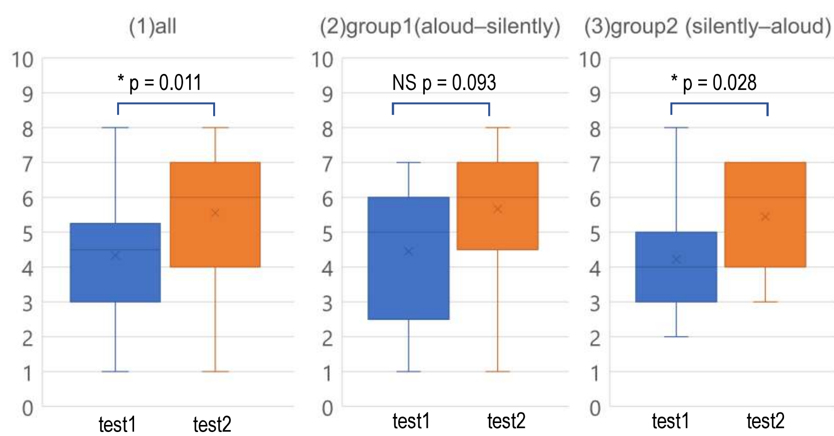


Figure 4. Boxplot of test score (N=18)

4. RELATION BETWEEN TEST SCORES AND BRAIN ACTIVITY

To identify possible differences in brain activity depending on the test performance, in Table 3, we summarize the test scores and brain-activity indicator values of 17 students, who participated in both the brain-activity measurement experiment and the C-language writing test.

We sorted the sums of Tests 1 and 2 in descending order. The following observations can be made:

(1) No significant changes in the amount of brain activity for the two participants with good programming skills (total test scores of 14 points or higher). This can be attributed to the fact that their brain was not overloaded with simple problems.

(2) For the 12 participants with average programming skills (total test scores between 8 and 13 points), their brain activity increased when reading aloud and decreased when reading silently. This confirms the results reported in [Ueda M., et al., 2023] (namely, that reading aloud is effective in learning programming).

ISBN: 978-989-8704-61-0 © 2024

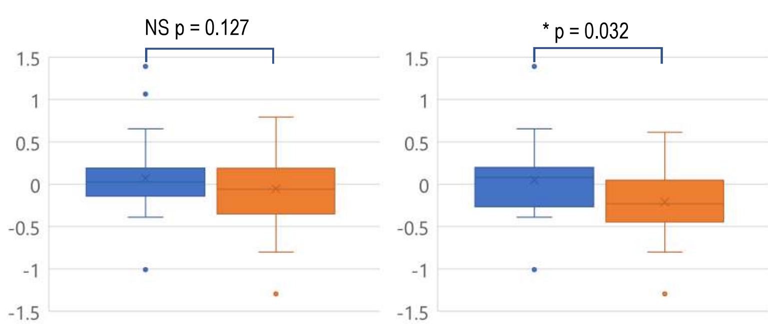
(3) The three participants with poor programming skills (total test scores of 7 points or less) exhibited active brain activity, even when reading silently. This is probably because they were trying to read the code carefully, even when reading silently. This confirms the results reported in [Ueda M., 2023] (i.e., reading aloud is not effective in a programming course that incorporates the reading-aloud technique for students with poor programming skills).

Table 3. Test score and brain activity

subject	test sum	aloud1	silently1	silently2	aloud2
j	15	-0.016	-0.058	-0.189	-0.106
a	14	0.065	0.258	0.074	-0.0004
b	13	0.015	-0.801	-0.674	0.033
c	13	-0.39	0.057	-1.294	0.653
d	13	0.074	-0.472	-0.382	-0.329
k	12	-0.018	-0.29	0.582	-1.009
l	11	0.176	-0.708	0.098	0.187
m	11	0.248	-0.339	-0.262	-0.148
e	10	0.201	0.164	0.113	0.392
f	10	0.35	-0.401	0.016	-0.305
p	8	0.085	-0.058	-0.065	0.134
o	8	0.115	-0.459	-0.199	-0.338
n	8	0.099	-0.266	0.614	1.391
q	8	-0.138	-0.03	0.014	-0.351
g	7	-0.182	0.517	0.769	0.02
h	6	0.009	-0.109	0.792	-0.101
r	6	1.064	0.572	0.574	0.51

We verified observation (2) using the brain-activity data presented in Section 2. Figure 5 shows a boxplot of the amount of brain activity during Aloud1 and Aloud2, Silently 1 and 2, and the results of a paired two-sample t-test. The left side is based on the data obtained from all 17 participants, and the right side is based on the data obtained from the middle 12 participants.

Although no significant difference was observed between reading aloud and reading silently for all participants, a significant difference ($p = 0.032$) was observed in the middle group of 12 participants, confirming that reading the program aloud activated brain activity.



	All aloud (N = 34)	All silently (N = 34)	8-13 aloud (N = 24)	8-13 silently (N = 24)
μ	0.070	-0.054	0.047	-0.210
$σ^2$	0.176	0.222	0.193	0.279

Figure 5. Brain activity during reading aloud and silently
(all participants and participants with test scores of 8 to 13 points)

5. CONCLUSION

We used NIRS to measure the brain activity of participants when they read a source code aloud to investigate the effectiveness of the reading-aloud technique in learning programming from a neuroscientific perspective.

We found that the brain-activity indicator values increase during reading aloud and decrease during reading silently when participants read silently after reading aloud. A similar trend was observed when the reading order was reversed. In addition, a written C-language test conducted when the participants read aloud indicated that reading aloud improved test scores. Furthermore, there was no characteristic difference in brain activity between reading aloud and reading silently between the participants with good programming skills and those with bad programming skills. However, a significant difference was observed for participants with average programming skills.

In the future, we will increase the number of participants to verify the above results. We also analyzed the relation between brain-activity indicator values and the difficulty and length of the source code, reading speed, volume of voice when reading aloud, presence of subvocalization, and programming skills of the participants. Thus, we established an efficient programming learning method employing the reading-aloud technique.

ACKNOWLEDGEMENT

This work was supported by JSPS KAKENHI, Grant Number JP23K02747. We are grateful to Mr. Tomura and Mr. Hasegawa of NeU Co., Ltd., for their help in analyzing the NIRS data.

REFERENCES

Li J. (2020). An Empirical Study on Reading Aloud and Learning English by the Use of the Reading Assistant SRS, *Int. J. Emerg. Technol. Learn. (iJET)*, 15, 103–117

Huimin W. et al. (2021). Application of Reading Aloud in Middle School Oral English Teaching, *Studies in Literature and Language*, 22, June 30

Ueda M., et al. (2022). A Proposal of Programming Learning System with Reading Aloud “ONDOKU”, *IIAI AAI 2022 Proc.*, pp. 260–263

Okamoto M., et al. (2010). Computer Programming Course Materials for Self-Learning Novices, *Proceedings of ED-MEDIA 2010*, 2855–2861

Ueda M., et al. (2023). Basic study on the effectiveness of reading aloud in learning programming languages, *Acoustical Science and Technology*, Vol. 44, No. 1, pp. 33-35

Swidan A., et al. (2019). The Effect of Reading Code Aloud on Comprehension: An Empirical Study with School Students, *Proc. of the ACM Conference on Global Computing Education*, pp. 178–184

Takeuchi H., et al. (2021). Effects of Training of Shadowing and Reading Aloud of Second Language on Working Memory and Neural Systems, *Brain Imaging and Behavior*, Vol. 15, pp. 1253–1269

Kawashima R., et al. (2005). Reading Aloud and Arithmetic Calculation Improve Frontal Function of People with Dementia, *The Journals of Gerontology: Series A*, Vol. 60, No. 3, pp. 380–384

Chiarenza A. G., et al. (2014). The Psychophysiology of Reading, *International Journal of Psychophysiology*, Vol. 94, pp. 111-119

Hermans F. (2021). The Programmer's Brain: What every programmer needs to know about cognition, Manning

Nakagawa T., et al. (2014). Quantifying programmers' mental workload during program comprehension based on cerebral blood flow measurement: a controlled experiment. *In Companion Proceedings of the 36th International Conference on Software Engineering (ICSE Companion 2014)*, pp. 448–451

Thapaliya A. (2021). Effect on brain activity while programming with (without) music, *In Companion Proceedings of the 43th International Conference on Software Engineering (ICSE Companion 2021)*, pp. 93–95

Thapaliya A. (2020). Evaluation of brain activity while Pair Programming, *In Companion Proceedings of the 42th International Conference on Software Engineering (ICSE Companion 2020)*, pp. 104-106

Ueda M. (2023). Trial of programming education for athletic students, *JUCE Educational Innovation Conference*, 2 pages (in Japanese)