Mental Stress Analysis during Visual- and Text-based Language Learning by Measuring Heart Rate Variability

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Abstract. Visual-based programming languages that allow programming by arranging blocks have become popular as an introductory method to learn programming. In contrast, programming experts generally use text-based programming languages such as C and Java. However, a seamless methodology for transitioning from this visual-based language to a text-based language has not yet been established. Thus, this research aims to establish a methodology that facilitates this transition by bridging the gap between the two languages and clarifying the variations in the biometric information of the learners of both languages. In this study, we measured the heart rate variability of the participants and evaluated the variations in mental stress encountered while learning both visual- and text-based languages.The experimental results confirmed that the heart rate variability value decreased (i.e., stress level increased) during visual language learning. As a conclusion of this study, the rationale became clear that the design of an intermediate type language used by students at various levels, should not cause mental stress to students at any level.

Keywords: visual-based language, text-based language, learning analysis, reart rate variability, mental stress

1 Introduction

In recent years, visual programming languages (hereinafter referred to as visual-based languages) have been employed as an introductory method to teach programming to secondary and higher-secondary school students. At universities or college, the students learn text programming languages such as C and Java (hereinafter referred to as text-based languages). A not insignificant percentage of students get frustrated in the early stages of learning a text-based language. However, a seamless transition method from visual-based language to text-based language has not yet been established.

The current research project aims to establish a methodology that facilitates seamless transitioning from a visual-based language to a text-based language. In addition to applying conventional post-learning evaluation methods, we measured the biological information reflecting the state during learning, such as brain waves, gaze, and facial expressions while learning. Subsequently, we analyzed and evaluated whether the intermediate-type learning contents acts as an intermediary between the visual- and text-based languages and contributes to this transition between languages. This research project will enable novice programmers to start learning programming using visual-based languages, and thereafter, seamlessly and voluntarily transition to build expertise through text-based languages.

This study aims to clarify the differences during learning between visual- and text-based languages by analyzing the biological information during learning. Specifically, we focused on heart rate variability (HRV), which is suitable for evaluating mental stress and the variations in stress during visual- and text-based language learning.

2 Previous work

2.1 Comparative study of visual- and text-based language

Several studies have comparatively analyzed visual- and text-based languages. A previous research [1] reported that in case of complex code structure of a program (e.g., a double loop), visual-based language can resolve misunderstandings to a greater extent. Moreover, visual languages are highly advantageous for beginners. Another study [2] stated that Scratch, one of the visual languages, can learn devise logical thinking as it avoids syntax errors, but it cannot learn to generate programs. [3] compared visual- and text-based languages from a psychological perspective, observing that text language programmers first draw mental representations of the control flow, followed by mental representations of the data flow, whereas visual-based language programmers follow the opposite approach. A previous study [4] investigated the effects of visual- and text-based language programming environments on students' learning outcomes. Nonetheless, the authors could not demonstrate the statistical superiority of visual-based languages in terms of utility and efficiency, highlighting the need for further investigation of hybrid languages.

2.2 Hybrid languages

Considerable amount of hybrid research has been conducted. A previous study [5] proposed an environment for using a hybrid language of visual and textual languages. They claimed that the proposed environment is suitable for training beginner-level programmers. Moreover, [6] compared text-based languages, visual-based languages, and hybrid languages, demonstrating that hybrid languages exhibit features of both languages and can outperform visual- and text-based languages in certain domains. Previous research [7] used PencilCode to compare the skill effects of migration using visual, hybrid, and text-based languages. Compared to text-based language learners, visual-based language learners could more readily understand loops and variables. In previous research [8], they created tools such as visual-based display, text-based display, and side-by-side view of both visual and text to evaluate the extent of migration. The results indicated that, compared to transitioning from visual- to text-based, transitioning using hybrid programming improved the students' understanding of programming fundamentals, memorization, and ease of transition by more than 30%.

2.3 Gap between visual- and text-based languages

Numerous studies have been conducted to explore the differences between visual- and text-based languages. Prior research [9] has indicated a gap between visual- and text-based languages. The authors examined the procedure of migrating from a visual-based language (MIT App Inventor 2) to a text-based language (Android Studio) using the Java Bridge Code Generator as a mediator of knowledge transfer. The study claimed that the Java Bridge Code Generator aided in bridging the gap between visual- and text-based languages. Moreover, [10] experimentally evaluated the differences in knowledge transfer after transitioning to a text-based language between learners who started programming using a visual-based language and those who started with a text-based language. As such, no significant differences were observed between the two groups, because the comparative evaluation was performed after the learners acquired the skills of text-based language rather than evaluating their skills during transitioning.

2.4 Our previous research

In our previous studies [11][12], we experimentally confirmed that using intermediate content promotes the comprehension of text-based language, which was proposed to be placed as intermediary module between visual-based language learning and text-based language learning. Through questionnaire, we determined that the proposed intermediate content exhibit features common to visual- and text-based languages [13][14]. More recently, we used electroencephalography (EEG) to monitor the learning progress of learners. We acquired the EEG information from participants engaged in a keyboard typing task, indicating that the value of β/α increases for difficult tasks [15][16]. Upon further analysis of the EEG, a notable difference was observed in the EEG when solving problems in a visual-based programming language (Scratch) and a text-based programming language (C). Specifically, for the visual-based programming language, the value of β/α did not increase with the difficulty of the task, thereby suggesting the existence of various pathways of thinking during the learning process of visual and text-based programming languages [17].

Our previous studies suggested the potential differences in biological responses when learning visual- and text-based languages. Therefore, in this study, we analyzed stress levels by measuring heart rate variability, thereby ascertaining the differences between the two types of language.

3 Experimental method

3.1 Experiment participants

The experiment engaged seven fourth-year students from the Shonan Institute of Technology, Japan, all of whom had studied programming-related courses for several years. Ideally, the participants would in the transition stage from visual- to text-based languages. However, for this experiment, fourth-year university students with experience in text-based languages were included. All participants exhibited similar programming skills.

3.2 Web service used for experiments

Google blockly[18] (Fig. 1) was used for programming in a visual-based language. Although this site allows the user to engage in tasks such as puzzles and mazes, this study targeted music tasks to match the contents with the text-based language. In addition, JSFiddle[19] (Fig.2) was used for programming in a text-based language. This site is an integrated development environment that can execute JavaScript, which is a text-based language. Music can be produced with beep sounds by adding the Beeplay library as a resource setting.

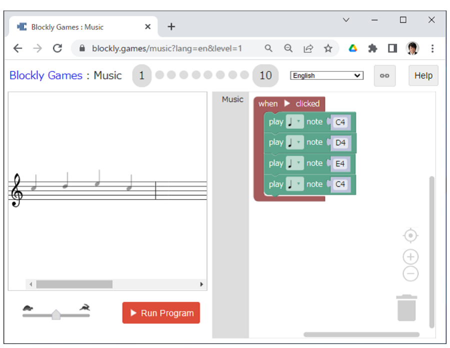

Fig. 1. Screen of Google blockly

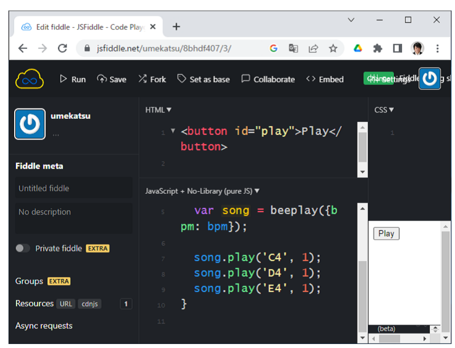

Fig. 2. Screen of JSFiddle

3.3 Tasks used for experiment

The participants were allowed to practice once before performing the actual experiment twice. Specifically, participants were assigned a musical score and instructed to write a program that produces the sounds according to the musical score. The songs targeted in each exercise and experiment are listed in Table 1. These scores were printed out and presented to the participants during the experiment. In particular, the musical notes were represented according to international notation (C3, C4, etc.) below the notes in the music score. Specifically, the participants were asked to create a program that reproduces the music outlined in Table 1, using the provided musical score. If there were utilizing a visual-based language, they were asked to arrange blocks using the mouse and, if they were using a text-based language, they were instructed to enter the code using the keyboard.

Table 1. Experimental song

experiment	song title
practice	Froggy's Song
experiment 1	Mary Had A Little Lamb
experiment 2	Jingle Bells

3.4 Equipment used in experiments

Heart rate variability monitor Generally, the heart rate interval (RR interval) fluctuates and these can be observed even when during resting periods. This periodic variation in the heart rate interval is called "heart rate variability (HRV)." It is generally accepted that when stress levels increase, HRV decreases, while balanced stress levels result in increased HRV.

An Apple "Apple Watch 8" was used to measure HRV. In addition, "HRV analysis/electrocardiogram analyzer" by WMS, Inc. was used as a measurement application. This application can connect with Apple Watch and calculate HRV (root–mean–square of successive differences: rMSSD). When measuring HRV with Apple Watch 8, a finger of the other hand must be placed on the crown part of the watch while wearing it on the wrist for approximately 30 s.

3.5 Experiment flow

The overall flow of the experiment is illustrated in Fig. 3, wherein the participants were randomly segmented into a group that started programming with a text-based language (Group A) and a group that started with a visual-based language (Group B). As discussed in the 3.4 section, HRV cannot be measured during the experiment (during programming) as it requires to touch the crown. Thus, we decided to measure the HRV for 30 s before and after the experiment, as depicted in Fig. 3. In addition, the input information by the key logger was recorded during each experiment.

4 Experimental result

The HRV of Group A (participants A to D) is plotted in Fig. 4, whereas that of Group B (participants E to G) are portrayed in Fig. 5. To address concerns regarding the potential influence of experiment order on changes in HRV, the participants were randomly divided into Group A and Group B for this study,

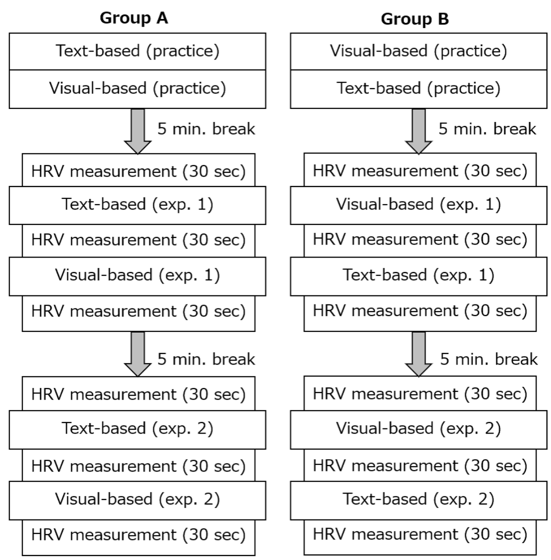

Fig. 3. Experiment flow

with the order of the experiments being switched. The figures reveal that, except for participants C and G, HRV values exhibited an increase before and after the text-based language experiment in both groups. Additionally, for the visual-based language experiment, participants in both groups, except for participant B, experienced a decrease in HRV before and after the experiment. Generally, HRV is known to decrease as stress levels rise, while it increases when stress balance is maintained. Thus, several participants were able to maintain their stress balance with the text-based language, whereas it appears that the visual-based language induced elevated stress levels for most participants. The statistical validity of these findings are investigated in the subsequent sections.

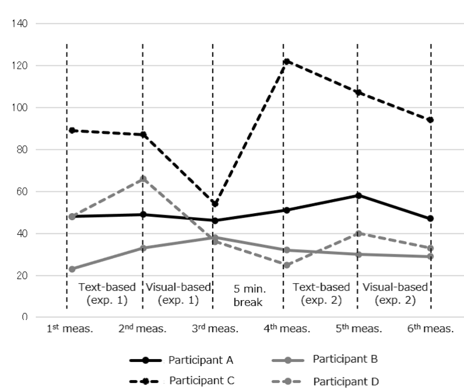

Fig. 4. HRV in Group A

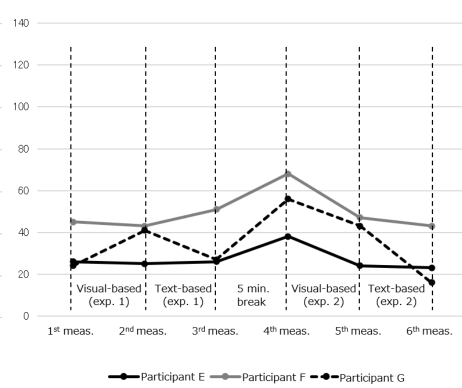

Fig. 5. HRV in Group B

5 Analysis

As depicted in Figs. 4 and 5 from the previous section, the trend of changes in HRV before and after the visual-based language and text-based language experiments appears to be consistent regardless of the experiment order. Consequently, in the subsequent analysis within this section, the measurements before and after the text-based language (exp.1) experiment for Group A (i.e., the first and second measurements) and the measurements before and after the text-based language (exp.1) experiment for Group B (i.e., the second and third measurements) are treated as identical. Similarly, measurements before and after the same type of experiments in both Group A and Group B are considered to be equivalent. The rationale behind this data handling approach is elaborated in Section 5.1.

Furthermore, according to the findings reported in [20], the distribution of rMSSD does not follow a normal distribution. However, the rMSSD values conformed to a normal distribution through natural logarithmic transformation. Moreover, previous research [21] states that parametric tests, such as the t-test, can be employed irrespective of the sample size (where $n \geq 2$), assuming the independence of observations and the normality and homoscedasticity of the population distribution. Additionally, the paired t-test does not necessitate the assumption of homoscedasticity. Therefore, in the forthcoming analysis, a paired t-test will be conducted using the rMSSD data transformed by natural logarithm.

In the measurement of HRV indices, such as rMSSD, using ultrashort time measurements of 30 s as employed in this experiment, a comparison of results across experiments with varying measurement times within the same group should precede the statistical testing between groups, as highlighted in a previous study [20]. However, owing to the limited measurement period of only 30 s, tests within the same group were omitted in this analysis.

5.1 Test of difference between group A and group B

To ascertain whether there is a difference in the measurement results before and after the same type of experiment for Groups A and B, we perform a Mann-Whitney U-test, one of the nonparametric tests of difference between two groups with no correspondence. We will compare the difference before and after the text type of group A (exp.1 and exp.2) (8 data in total) and the difference before and after the text type of group B (exp.1 and exp.2) (6 data in total). The same test is performed for the visual-based language. The results are shown in Table 2. From the Mann-Whitney test table, the significance level is $\alpha = 0.05$, and from the two-sided 5% test table, the limit value is 8.

Table 2. Mann-Whitney U-test result

experiment	test statistic	limit value
text-based	13.5	8
visual-based	21	8

As observed in Table 2, both the text-based and visual-based language experiments yielded a "test statistic $\geq$ limit value" outcome, indicating that no significant difference can be inferred between the data of the two groups. Consequently, the measurements before and after the same type of experiment in both Groups A and B were treated as equivalent.

5.2 Test for population mean difference

Furthermore, we conducted paired t-tests to assess whether there is a difference in the mean values of the natural logarithm-transformed HRV (rMSSD) before and after each text-based (exp.1), visual-based (exp.1), text-based (exp.2), and visual-based (exp.2) experiment, considering all participants. The test results are presented in Table 3 and depicted in Fig. 6.

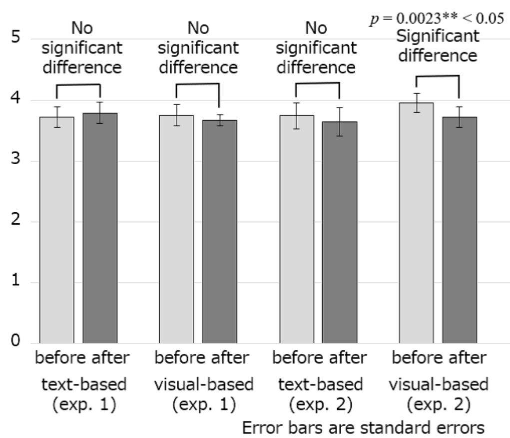

Fig. 6. HRV mean test

Table 3. HRV mean test

exp.	b/a	mean	p-value
text (exp.1)	before	3.7229	0.2604
	after	3.7899	
visual (exp.1)	before	3.7552	0.3005
	after	3.6761	
text (exp.2)	before	3.7443	0.2811
	after	3.6418	
visual (exp.2)	before	3.9580	0.0023**
	after	3.7209	

As listed in Table 3 and Fig. 6, a significant decrease in HRV values was observed before and after the visual-based language experiment (exp.2). However, no statistically significant differences were observed in the remaining experiments. These findings suggest that text-based language learning did not have an impact on stress balance, while visual-based language learning resulted in an increase in stress levels.

In addition to the above analysis, we also attempted verification employing Wilcoxon signed-rank sum test, which is a type of nonparametric test. The conclusion was exactly the same as the above t-test.

6 Conclusion and future work

In our study, we measured the HRV of learners to investigate potential differences in mental stress during the learning of visual- and text-based languages. Our findings revealed a decrease in HRV (rMSSD) during visual language learning, suggesting that stress levels are higher when learning a visual-based language compared to a text-based one. This result is likely reflective of the fact that the participants were students not transitioning from visual- to text-based languages, but were fourth-year university students with a reasonable understanding of text-based language.

In future, we plan to develop an intermediate language that bridges the gap between visual- and text-based languages. Based on the conclusions of this research, an intermediate language should be developed such that it does not impose stress on students with various levels of understanding and proficiency.

Research ethics

All experiments were approved by the Research Ethics Committee of Shonan Institute of Technology . We received written informed consent from the participants and their parents or guardians.

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References

1. Monika Mladenović, Ivica Boljat, and Žana Žanko. Comparing loops misconceptions in block-based and text-based programming languages at the k-12 level. *Education and Information Technologies 23(4)*, pp. 1483–1500, 2018.
2. William Robinson. From scratch to patch: Easing the blockstext transition. *In Proceedings of the 11th Workshop in Primary and Secondary Computing Education (ACM)*, pp. 96–99, 2016.
3. Raquel Navarro-Prieto and Jose J. Ca nas. Are visual programming languages better? the role of imagery in program comprehension. *International Journal of Human-Computer Studies*, pp. 799–829, 2001.
4. Zhen Xu, Albert D. Ritzhaupt, Fengchun Tian, and Karthikeyan Umapathy. Block-based versus text-based programming environments on novice student learning outcomes: A meta-analysis study. *Computer Science Education*, Vol. 29, pp. 177–204, 2001.
5. Rumen Daskalov, George Pashev, and Silvia Gaftandzhieva. Hybrid visual programming language environment for programming training. *TEM Journal*, Vol. 10, pp. 981–986, 2021.
6. David Weintrop and Uri Wilensky. Between a block and a typeface: Designing and evaluating hybrid programming environments. *IDC '17: Proceedings of the 2017 Conference on Interaction Design and Children*, pp. 183–192, 2017.

7. David Weintrop. Blocks, text, and the space between: The role of representations in novice programming environments. *In 2015 IEEE Symposium on Visual Languages and Human-Centric Computing (VL/HCC)*, pp. 301–302, 2015.
8. Hussein Alrubaye, Stephanie Ludi, and Mohamed Wiem Mkaouer. Comparison of block-based and hybrid-based environments in transferring programming skills to text-based environments. *Proceedings of the 29th Annual International Conference on Computer Science and Software Engineering*, pp. 100–109, 2019.
9. Tomáš Tóth and Gabriela Lovászová. Mediation of knowledge transfer in the transition from visual to textual programming. *Informatics in Education*, Vol. 20, pp. 489–511, 2021.
10. David Weintrop and UriWilensky. Transitioning from introductory block-based and text-based environments to professional programming languages in high school computer science classrooms. *Computers & Education*, Vol. 142, , 2019.
11. Katsuyuki Umezawa, Kouta Ishida, Makoto Nakazawa, and Shigeichi Hirasawa. A proposal and evaluation of intermediate content for transition from visual to text-based languagesg. *The Institute of Electronics, Information and Communication Engineers (IEICE) Technical report*, pp. 1–7, 2022.
12. Katsuyuki Umezawa, Kouta Ishida, Makoto Nakazawa, and Shigeichi Hirasawa. Proposal and evaluation of intermediate content for the transition from visual to text-based programming languages. *Proceedings of the 56th Hawaii International Conference on System Sciences (HICSS 2023)*, pp. 83–92, 2023.
13. Katsuyuki Umezawa, Makoto Nakazawa, and Shigeichi Hirasawa. Seamless transition from visual-type to text-type languages. *Proceedings of the 84th National Convention of IPSJ*, Vol. 4, pp. 519–520, 2022.
14. Katsuyuki Umezawa, Makoto Nakazawa, and Shigeichi Hirasawa. A proposal for intermediate content: Transition from visual to text-based languages. *Proceeding of the World Conference on Computers in Education (WCCE2022)*, p. 1, 2022.
15. Katsuyuki Umezawa, Tomohiko Saito, Takashi Ishida, Makoto Nakazawa, and Shigeichi Hirasawa. Learning state estimation method by browsing history and brain waves during programming language learning. *Trends and Advances in Information Systems and Technologies. WorldCIST'18 2018. Advances in Intelligent Systems and Computing, Springer, Cham.*, Vol. 746, , 2018.
16. Katsuyuki Umezawa, Tomohiko Saito, Takashi Ishida, Makoto Nakazawa, and Shigeichi Hirasawa. Learning-state-estimation method using browsing history and electroencephalogram in e-learning of programming language and its evaluation. *Proceeding of the International Workshop on Higher Education Learning Methodologies and Technologies Online (HELMeTO 2020)*, pp. 22–25, 2020.
17. Katsuyuki Umezawa, Yutaka Ishii, Makoto Nakazawa, Michiko Nakano, Manabu Kobayashi, and Shigeichi Hirasawa. Comparison experiment of learning state between visual programming language and text programming language. *2021 IEEE International Conference on Engineering, Technology & Education (TALE)*, pp. 01–05, 2021.
18. Blockly games. https://blockly.games/. Accessed: 17 January 2023.
19. Jsfiddle. https://jsfiddle.net/. Accessed: 17 January 2023.
20. Leandro Pecchia, Rossana Castaldo, Luis Montesinos, and Paolo Melillo. Are ultra-short heart rate variability features good surrogates of short-term ones? state-of-the-art review and recommendations. *Healthcare Technology Letters*, Vol. 5, pp. 94–100, 2018.
21. Atsushi Mizumoto. A comparison of statistical tests for a small sample size: Application to corpus linguistics and foreign language education and research. *The Institute of Statistical Mathematics cooperative research report 238*, pp. 1–14, 2010.