Evaluation of Difficulty during Visual Programming Learning using a Simple Electroencephalograph and Minecraft Educational Edition

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Abstract. There are various difficulties encountered by learners during learning such as good or bad learning content, the difficulty level of the learning content, and the degree of learning proficiency. It is possible to detect these difficulties by measuring the browsing history, editing history, and biological information such as brain waves or eye-tracking information. In this paper, we aim to detect the learning state of each learner by measuring brain wave information during learning of visual programming using the Minecraft educational edition. Furthermore, the detected learning status is statistically correlated using the results of a questionnaire conducted after the experiment. The results show that the assessment of task difficulty by learners is more significantly affected by the experience with Minecraft than by the experience with programming.

1 Introduction

This research aims to develop a self-study system equipped with an artificial teacher who gives advice to students by detecting the learners and to evaluate language learning in a unified framework. "Detecting the learners" means that the system understands the learners' learning conditions, such as the learner's degree of understanding, the difference in the learner's thinking process, the degree of concentration or boredom during learning, and the problem-solving skill of each learner, which can be interpreted from the learning behavior.

Several studies have used Electroencephalograph (EEG) information as a way to understand the learners' learning conditions [1]. It has been found that measuring the ratio of the α wave and β wave is effective for observing human thinking state [2] [3]. Moreover, β/α increases when working on difficult tasks [4].

In this paper, we try to detect the learning state of each learner by measuring the brain wave information during learning of visual programming without

grammatical errors. Specifically, we measure the brain wave information when the learner is learning programming using the Minecraft educational edition. In addition, a questionnaire is conducted after the experiment to statistically analyze the measured learning state.

The rest of the paper is organized as follows. In Section 2, we describe previous works related to this study. In Section 3, we explain the specifics of the experiment. In Section 4, we show the experimental results. In Section 5, we evaluate the experimental results using the questionnaire. Finally, in Section 6, we summarize our study and discuss future work.

2 Previous works

The relationship between intellectual work and brain waves has been studied under the assumption that the β wave is strongly related to a person's mental state. Giannitrapani, for example, investigated the relationship between intellectual work and brain waves by measuring the brain waves of a person taking an intelligence test [1]. The low-frequency component of the β wave was found to be dominant during the reading and comprehension test, mathematics test, and diagram test. Other researchers have found that the power spectra of the α and β waves, the ratio of the α and β waves in relation to all brain waves, and the simple ratio of the α and β waves are effective for estimating a person's state of mind [2]. It was also shown that the activity of a person's brain can be estimated by measuring the α and β waves and estimating β/α [3].

In addition, many studies have been conducted to analyze the effects of visual programming using Minecraft. Zorn et al. [5] proposed a new visual programming tool for Minecraft that could be used as a plug-in, and statistically showed that this tool gave participants a positive perception. Sun et al. [6] also showed that Minecraft improved students' creativity and their feelings of enjoyment, hope, and pride in programming. In addition, Šajben et al. [7] showed that Minecraft can help improve skills such as problem solving, critical thinking, and communication. However, these studies are based on questionnaires of experimental participants [5] [6] and interviews with teachers and lecturers [7].

3 Details of the experiment

We performed experiments using the Minecraft educational edition provided by Microsoft Corporation. We also used reference [8] as a textbook for the experiment.

3.1 Minecraft educational edition

The Minecraft educational edition works in conjunction with visual programming called MakeCode. We can perform various actions (such as stacking blocks) by moving agents (robots) programmatically in the world of Minecraft.

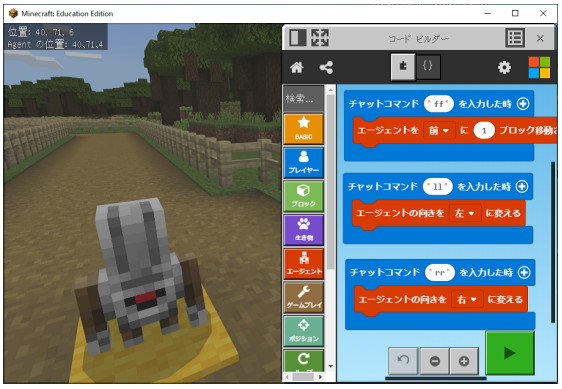

Fig. 1. Mincraft educational edition.

3.2 Textbook used in the experiment

The textbook used in the experiment [8] is a story about the search for a flower called Jade Orchid by manipulating an agent through programming in the world of Eduland. It comprises 5 chapters. Each chapter consists of a manga explaining the story, the main story with a sample of programming, and additional questions for those who finished the main story. In this experiment, we measured the following three types of brain waves.

(a) Brain waves while reading the manga in chapter 3 (we call it Manga).
(b) Brain waves during programming to make a bridge by looking at chapter 3 (we call it Bridge).
(c) Brain waves during programming to make a different kind of bridge while thinking on their own about additional problems (we call it Extra).

3.3 Participants

The experiment was conducted with a total of 30 students comprising of a fourth-year student from the Umezawa lab at Shonan Institute of Technology, a third-year student from the Shonan Institute of Technology High School, and first- to third-year students from Waseda University Honjo Senior High School.

3.4 Method of measuring brain waves

The EEG used for measuring the brain waves was a MindWave Mobile headset (NeuroSky, Inc.).

As shown in Fig. 2, the headset was connected to a ThinkGear Connector by Bluetooth, and the ThinkGear Connector communicated with a log-collection

application by TCP/IP. The ThinkGear Connector is a driver provided by NeuroSky Inc., which transfers brain wave data converted in the headset into the log collection application.

Eight types of brain waves were acquired based on Ref. [9]: these are shown in Table 1.

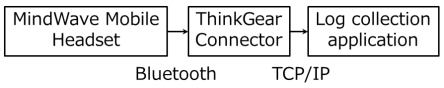

Fig. 2. Outline of the method for measuring brain waves.

Table 1. Acquired brain waves [9].

Type	Frequency (Hz)
δ wave	0.5–2.75
θ wave	3.5–6.75
low α (α_l) wave	7.5–9.25
high α (α_h) wave	10–11.75
low β (β_l) wave	13–16.75
high β (β_h) wave	18–29.75
low γ wave	31–39.75
mid γ wave	41–49.75

4 Experimental result

Figure 3 shows the EEG measurements of participant 27, as an example. Note that the raw data were too large to show in the graph; therefore, Fig. 3 only shows measurements averaged every 60 seconds.

The vertical axis shows the value of β/α. Note, however, that we can also measure high α wave (α_h), low α wave (α_l), high β wave (β_h), and low β wave (β_l). Hence, when considering β/α, which is the ratio between the α wave and β wave, there are four combinations of β_l/α_l, β_h/α_h, β_l/α_h, and β_h/α_l that can be considered. Furthermore, the ratio of the averages of low and high frequencies $(\beta_l + \beta_h)/(\alpha_l + \alpha_h)$ was also considered (hereinafter referred to as β_{l+h}/α_{l+h}).

4.1 Results

Just by looking at Fig. 3, we cannot discern the type of brain wave that increases or decreases. Hence, we first compare Manga and Bridge for each participant, followed by Bridge and Extra.

We first performed an F-test to check if we could assume equal variance, and then performed a t-test for the difference in means. We show the results (p-value) of the t-test of Manga and Bridge in Table 2. The bold cells correspond to values smaller than 0.05, indicating that the average value is significantly different. In addition, the "+" sign on the right shoulder of each number indicates that the average value of Brigde is significantly higher than that of Manga, and the "−" sign indicates that the average value of Brigde is significantly lower than that of Manga.

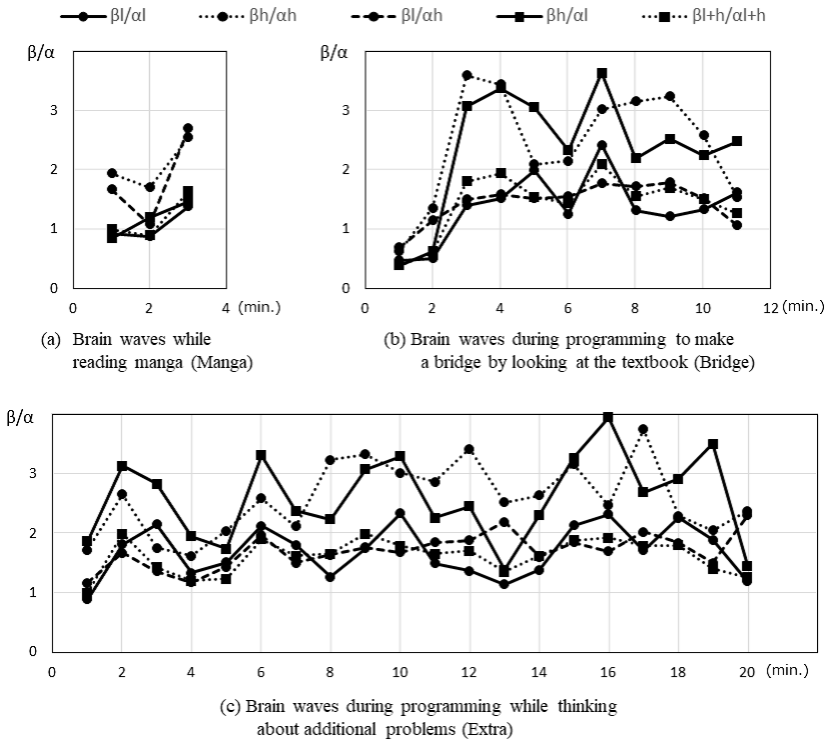

Fig. 3. Value of β/α of experiment participant 27.

In addition, we show the results (p-value) of the t-test of Bridge and Extra in Table 3. The meaning of the bold cell is the same as Table 2. The "+" sign on the right shoulder of each number indicates that the average value of Extra is significantly higher than that of Bridge, and the "−" sign indicates that the average value of Extra is significantly lower than that of Bridge.

4.2 Consideration

We first look at Table 2 and 3. For participant 13 in Table 2 and participant 17 in Table 3, the results showing significant increases in mean value and significant decreases in mean value were mixed, which was not the case for the other participants. This signifies that the choice of the type of EEG brain wave to look into is not important, instead, it is important to use a combination of all types of brain waves.

In addition, looking at Table 2, the average value of β/α for many participants became higher in Bridge than that in Manga. This result is consistent with previous studies showing that the value of β/α increases when solving difficult problems.

Table 2. Comparison between Manga and Bridge.

Participants	β_l/α_l	β_h/α_h	β_l/α_h	β_h/α_l	β_{l+h}/α_{l+h}
01	0.5626	$\mathbf{0.0000}^{+}$	0.6419	0.9329	$\mathbf{0.0049}^{+}$
02	0.1004	0.3886	0.3144	$\mathbf{0.0028}^{+}$	0.1118
03	0.5150	0.4894	0.7718	0.9912	0.7937
04	0.1617	$\mathbf{0.0065}^{+}$	0.2113	0.1978	0.5875
05	0.1842	0.7861	0.8375	0.1805	0.2945
06	0.3709	0.6185	0.1840	0.6578	0.6169
07	0.2375	0.8462	0.3192	0.1194	0.6586
08	0.3076	0.6196	0.4439	0.1229	0.3695
09	0.2780	0.8531	0.2907	0.1940	0.4955
10	0.9274	0.7058	0.9666	0.9567	0.5342
11	0.1077	$\mathbf{0.0000}^{+}$	$\mathbf{0.0000}^{+}$	$\mathbf{0.0000}^{+}$	$\mathbf{0.0000}^{+}$
12	$\mathbf{0.0000}^{+}$	0.0579	$\mathbf{0.0115}^{+}$	0.1248	0.1880
13	$\mathbf{0.0002}^{+}$	$\mathbf{0.0002}^{-}$	$\mathbf{0.0000}^{+}$	0.5109	0.9090
14	0.3137	$\mathbf{0.0000}^{+}$	0.1501	0.4415	$\mathbf{0.0039}^{+}$
15	$\mathbf{0.0036}^{+}$	$\mathbf{0.0412}^{+}$	0.0706	$\mathbf{0.0033}^{+}$	$\mathbf{0.0002}^{+}$
16	$\mathbf{0.0000}^{+}$	$\mathbf{0.0000}^{+}$	$\mathbf{0.0016}^{+}$	$\mathbf{0.0000}^{+}$	$\mathbf{0.0000}^{+}$
17	0.4149	$\mathbf{0.0000}^{+}$	0.2088	0.0795	$\mathbf{0.0008}^{+}$
18	0.3227	$\mathbf{0.0002}^{+}$	0.5957	0.2939	0.3651
19	0.5193	$\mathbf{0.0011}^{+}$	0.2183	$\mathbf{0.0018}^{+}$	$\mathbf{0.0280}^{+}$
20	0.2733	$\mathbf{0.0000}^{+}$	0.4743	$\mathbf{0.0003}^{+}$	$\mathbf{0.0006}^{+}$
21	0.5523	0.6804	0.3221	0.7251	0.6111
22	0.8316	$\mathbf{0.0141}^{+}$	0.2703	0.6676	0.5907
23	0.7221	0.7106	0.6300	0.4343	0.7128
24	0.2561	0.4852	0.4271	0.7199	0.5958
25	0.0511	$\mathbf{0.0066}^{+}$	0.6265	$\mathbf{0.0085}^{+}$	$\mathbf{0.0293}^{+}$
26	0.0520	$\mathbf{0.0001}^{+}$	0.5199	0.3799	0.9471
27	$\mathbf{0.0051}^{+}$	$\mathbf{0.0050}^{+}$	0.4638	$\mathbf{0.0000}^{+}$	$\mathbf{0.0000}^{+}$
28	0.8002	$\mathbf{0.0177}^{-}$	0.2257	0.1982	$\mathbf{0.0081}^{-}$
29	0.1108	0.7917	0.5612	0.2232	0.9590
30	0.4945	0.4080	0.3861	0.5234	0.8058

In Table 3, there are some participants whose average value of β/α was high and some whose value was low. Before the experiment, we thought Extra would be more difficult because the participants have to think on their own. It is thought that the programming method could be understood by performing the programming according to the textbook (Bridge). As a result, it can be considered that there were some participants whose difficulty decreased when they thought and solved additional problems by themselves (Extra).

5 Evaluation by questionnaire

We then performed a cross-analysis using the analysis results above and the results of the questionnaire conducted after the experiment.

Table 3. Comparison between Bridge and Extra.

Participants	β_l/α_l	β_h/α_h	β_l/α_h	β_h/α_l	β_{l+h}/α_{l+h}
01	0.2044	**0.0209**$^-$	0.2068	0.8512	**0.0484**$^-$
02	0.9389	0.5035	0.7836	0.7776	0.7113
03	0.0976	0.0535	0.4809	**0.0496**$^+$	**0.0299**$^+$
04	0.2081	0.3930	**0.0209**$^+$	0.2079	0.2000
05	0.9039	**0.0160**$^+$	0.0539	0.3709	0.2354
06	**0.0188**$^-$	**0.0000**$^-$	0.2140	**0.0000**$^-$	**0.0000**$^-$
07	**0.0041**$^-$	**0.0000**$^-$	0.1452	**0.0000**$^-$	**0.0000**$^-$
08	0.0814	**0.0205**$^+$	0.9662	**0.0001**$^+$	0.7092
09	0.6604	**0.0226**$^-$	0.3045	**0.0411**$^-$	**0.0014**$^-$
10	0.2201	0.1796	0.0887	**0.0490**$^+$	**0.0344**$^+$
11	0.1388	0.7737	0.7192	0.3480	0.9897
12	**0.0002**$^+$	0.4142	**0.0222**$^+$	**0.0357**$^+$	**0.0000**$^+$
13	0.7385	0.9226	0.3749	0.8016	0.9656
14	0.2822	**0.0156**$^+$	0.0629	0.5638	0.0120
15	**0.0049**$^-$	0.7027	0.2765	**0.0391**$^-$	**0.0090**$^-$
16	0.8443	0.2107	0.5516	0.5449	0.3478
17	0.5652	**0.0000**$^-$	**0.0006**$^+$	0.1662	0.7103
18	0.3026	**0.0000**$^+$	0.9481	0.4383	**0.0000**$^+$
19	0.5870	0.4299	0.8853	0.7444	0.2541
20	0.2010	**0.0293**$^-$	0.9732	0.6764	0.5844
21	0.1100	0.4203	0.9605	0.5183	0.8164
22	0.3152	**0.0173**$^-$	**0.0379**$^-$	0.9500	0.1009
23	0.4909	0.2008	0.2880	0.4456	0.3736
24	0.8875	**0.0307**$^-$	0.0903	0.5460	0.0511
25	0.3290	0.6658	0.8995	0.5351	0.5816
26	0.7583	0.1087	0.5516	0.6249	0.3283
27	**0.0106**$^+$	0.7424	**0.0286**$^+$	0.3134	0.0937
28	0.1980	0.6134	0.9928	0.6089	**0.0013**$^+$
29	**0.0247**$^+$	**0.0481**$^+$	0.5068	**0.0020**$^+$	**0.0023**$^+$
30	0.3130	**0.0072**$^+$	0.8393	**0.0498**$^+$	0.6204

5.1 Explanation of questionnaire items

We asked the following four questions (Q1, Q2, Q3, Q4).

Q1 Do you have any programming experience?
- **A1.** Yes
- **A2.** No

Q2 Are you good at programming?
- **A1.** Weak
- **A2.** Weak a little
- **A3.** Normal
- **A4.** Good a little
- **A5.** Good

Q3 Do you have any experience with Minecraft?
- **A1.** Yes

A2. I have experienced Minecraft other than PC
A3. No

Q4 Are you interested in Manga?
A1. Boring
A2. Boring a little
A3. Normal
A4. Interesting a little
A5. Interesting

5.2 Questionnaire evaluation on Manga and Bridge

We analyzed the questionnaire results for Manga and Bridge. We performed a χ^2-test on each cross-tabulated data of Q1 to Q4. Unfortunately, no significant difference could be found from all the questionnaire results.

5.3 Questionnaire evaluation on Bridge and Extra

We next analyzed the questionnaire results for Bridge and Extra. For each questionnaire, we cross-tabulated the results of the questionnaire and changes in β/α values. The results of the cross-tabulation are shown in Tables 4 to 6. The meanings of "Up", "Unchanged (UC)", and "Down" are as follows. For each participant in Table 2, if at least one of the five types of brain waves has "+", the participant interprets that the average value has gone up. The same applies to "down". If "+" and "−" do not exist in all five types of brain waves, or if "+" and "−" are mixed, the participant interprets the average value as "unchanged". The questionnaire Q4 about manga was omitted because it is unrelated to Bridge and Extra.

Table 4. Q1: Do you have any programming experience?

Average	Up	UC	Down	Total
Yes	5	4	2	11
No	7	6	6	19
Total	12	10	8	30

Table 5. Q2: Are you good at programming?

Average	Up	UC	Down	Total
Weak	0	2	2	4
Weak a little	4	2	0	6
Normal	6	4	5	15
Good a little	1	2	1	4
Good	1	0	0	1
Total	12	10	8	30

Table 6. Q3: Do you have any experience with Minecraft?

Average	Up	UC	Down	Total
No	1	0	4	5
Yes (PC version)	7	5	4	16
Yes (Non-PC version)	4	5	0	9
Total	12	10	8	30

Table 7. χ^2-test results of Bridge and Extra.

Questionnaire	p-value	Result
Q1	$0.7240 > 0.05$	No significant difference
Q2	$0.4404 > 0.05$	No significant difference
Q3	$0.0227 < 0.05$	Significant difference

Table 8. Residual analysis results of Minecraft experience.

Average	Up	UC	Down
No	-1.000	-1.732	**2.954****
Yes (PC version)	0.448	-0.259	-0.221
Yes (Non-PC version)	0.325	1.690	**-2.162***

$^{*}: p < 0.05, \quad ^{**}: p < 0.01$

We performed a χ^2-test on each cross-tabulated data from Tables 4 to 6. The resulting p-values are shown in Table 7.

As shown in Table 7, there was a significant difference in "Q3: Minecraft experience". Therefore, we performed residual analysis on "Q3: Minecraft experience", as shown in Table 8. The values shown in bold represent items that have a significant difference (absolute value is 1.96 or more) by residual analysis.

Among the participants who had no experience with Minecraft, the number of participants whose average value of β/α went down (i.e., participants who did not feel that the additional problem was more difficult) increased. Among the participants who had an experience with Minecraft but no experience with the PC version of Minecraft, the number of participants whose average value of β/α went down (i.e., participants who did not feel that the additional problem was more difficult) decreased.

As shown in Table 8, the results were different between the PC version and the Non-PC version. This may be due to game operations rather than Minecraft experience. We would like to conduct a more detailed analysis in future work.

6 Conclusion and future work

In this paper, we detected the learning state of each learner by measuring the brain wave information during learning of visual programming using the Minecraft educational edition. The detected learning status was statistically evaluated using the results of a questionnaire conducted after the experiment. We found that the assessment of task difficulty by learners was more significantly affected by the experience with Minecraft than by the experience with programming. In the future, we plan to conduct a similar experiment using a normal text-based programming language other than a visual programming language to try to detect the learning state by EEG.

Research ethics

The experiments were approved by the Research Ethics Committee of Shonan Institute of Technology. We also received signatures from examinees and parents of the examinees concerning experiment participation.

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