An Electroencephalograph-based Method for Judging the Difficulty of a Task given to a Learner

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Abstract— **Various factors affect learning, such as the quality and difficulty of the learning contents and the learner's proficiency, and it may be possible to detect their effects by using the learner's browsing and edit history as well as biological information such as brain waves and eye movement. We investigated the use of brain waves to estimate the degree of difficulty of a learning task. The first experiment using a simple typing test confirmed a previous finding that the *β*-wave to *α*-wave ratio increases with task difficulty. Furthermore, the low-*β*-wave to low-*α*-wave ratio, where "low" means low frequency, observed under various learning conditions was found to depend on the frequencies of the waves, and the value of the ratio was shown to represent task difficulty. The second experiment in which the change in brain waves was measured using a simple electroencephalograph (EEG) as the examinees became used to the task showed that the values for the examinees who reported that the task was easy fell gradually, supporting our finding that the value of the ratio represents task difficulty. This information could be used to dynamically adjust task difficulty and thereby optimize the learning effect.**

Keywords: learning analytics; simple electroencephalograph; brain wave; e-learning

I. INTRODUCTION

We have investigated the use of brain waves to detect points of failure during learning (particularly during self-study). Such detection would enable the presentation of teaching materials to be automatically adjusted accordingly and the appropriateness of the teaching materials to be evaluated. We conducted two kinds of experiments. One is an experiment using a simple typing test with varying degrees of difficulty, and the other is an experiment of assembling a robot using three-dimensional motion capture.

Both experiments thus demonstrated that the low-β to low-α ratio is a good measure of the degree of task difficulty. This information could be used to dynamically adjust the degree of difficulty of an e-learning task for a particular student. Moreover, learning materials could be adapted to individual students to optimize the learning effect.

II. PREVIOUS WORKS

A. Brain waves

It has been empirically shown by studies in psychology and cerebral science that the corrugation of brain waves can be used as an index of the person's state of mind. In previous studies, the α wave and the β wave (obtained from the result of a discrete Fourier transformation) have been used to determine a person's state of mind.

B. Applicability of brain waves to learning

Giannitrapani investigated the relationship between intellectual work and brain waves by measuring the brain waves of a person taking an intelligence test [1]. In addition, Yoshida et al. showed that the activity of a person's brain can be determined by measuring the α and β waves and estimating the value of β/α [2]. That is, as the processing load increases with task difficulty, so does the value of β/α.

III. EXPERIMENTS

A. First experiment

The first experiment used a typing-practice application with two modes: "basic" and "advanced." In the basic-mode task, the examinee input the indicated Japanese characters one by one. In the advanced-mode task, the examinee input the indicated Japanese sentences, which were quite difficult and required the examinee to first input the text in simple kana characters and then convert it into kanji characters by using the Japanese input system.

B. Second experiment

The second experiment used a LeapMotion™ controller to sense and recognize the examinee's hand gestures in three-dimensional space, which were captured with an infrared camera. This controller recognizes hand movements such as "shaking a hand," "stretching an arm and grasping for something." In this experiment, the examinee was tasked with picking up a square block (the head of a robot) and putting it on the body of a moving robot displayed on a PC. The objective was to assemble four robots. To succeed, the examinee had to become accustomed to the operation of picking up and moving blocks by hand in a virtual three-dimensional space. The process by which the examinee became accustomed to the operation was investigated by measuring the brain waves using a simple electroencephalograph (EEG).

C. Method for measuring brain waves

The EEG used for measuring the brain waves was a MindWave Mobile headset (NeuroSky, Inc.). Eight types of brain waves could be acquired, as shown in Table I. A four-byte (unit-less) floating-point value was acquired for each type.

TABLE I. BRAIN WAVES THAT COULD BE ACQUIRED

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

D. Examinees and experimental methods

In the first experiment (typing), ten of the students participated as examinees. Each examinee performed the typing task in basic mode and advanced mode. In the second experiment (robot assembly), 21 of them participated as examinees. Their brain waves were measured as they made four robots by using the LeapMotion™ controller.

IV. RESULTS AND DISCUSSION – FIRST EXPERIMENT

A. Results

The α_l/β_l for Examinee 2 is shown in Figure 1. The average ratio for the basic-mode task was 0.764 and that for the advanced-mode task was 1.351. Although the figure shows time series data for one examinee, we will calculate the average value of time series data of all examinees. As discussed in the "Previous Work" section, the β-wave to α-wave ratio is an effective index for determining a person's state of mind [1], so we used the value of β/α in this study.

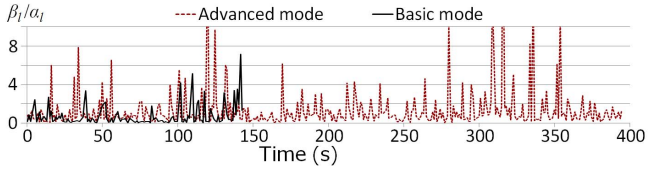

Figure 1. α_l /β_l for Examinee 2 for typing task

As shown in Table I, two kinds of brain waves—one with a high frequency (the α_h wave) and one with a low frequency (the α_l wave)—can be measured with a simple EEG. This means that the β-wave to α-wave ratio (i.e., β/α) has four combinations: β_l/α_l, β_h/α_h, β_l/α_h, and β_h/α_l. Adding the ratio of the average low-frequency wave to the high-frequency wave, $(\beta_l+\beta_h)/(\alpha_l+\alpha_h)$ (hereafter, β_{l+h}/α_{l+h}) gives five combinations of β/α. The ratios of the values of the averages for the basic-mode typing task to the values of advanced-mode task (the "advanced/basic ratios") are listed in Table II. The values above 1.0 (bold face) mean that the ratio for the advanced-mode task was larger than that for the basic-mode task.

TABLE II. ADVANCED/BASIC RATIOS

ID	β_l/α_l	β_h/α_h	β_l/α_h	β_h/α_l	β_{l+h}/α_{l+h}
1	0.933	0.830	0.849	**1.065**	**1.053**
2	**1.768**	**1.566**	**1.579**	**1.986**	**1.771**
3	**1.049**	**1.007**	**1.012**	**1.018**	0.998
4	**1.330**	**1.205**	**1.075**	**1.241**	**1.047**
5	0.724	0.683	0.725	0.562	0.775
6	**1.182**	**1.281**	**1.082**	**1.380**	**1.117**
7	0.903	**1.335**	**1.118**	**1.176**	**1.089**
8	**1.491**	**1.076**	**1.176**	**1.273**	**1.163**
9	**1.108**	**1.063**	0.974	**1.394**	**1.046**
10	**1.087**	**1.480**	**1.201**	**1.436**	**1.242**

B. Discussion

All the β_h/α_l, except that for examinee 5, in Table II were above 1.0. Moreover, many of the other ratios were above 1.0 as well. This indicates that the value of β/α for a difficult task is high, setting aside the difference in effect between a low frequency and a high frequency.

Next is the question of which frequency of α_l, α_h, β_l and β_h wave to use. The times required for the examinees to finish the basic- and advanced-mode tasks and the time differences are listed in Table III. The time required for the advanced-mode task can be considered an index of task difficulty. Alternatively, the difference between the times required for the advanced- and basic-mode tasks can be considered an increment of difficulty.

TABLE III. TIME REQUIRED FOR TYPING TASK

ID	Basic	Advanced	Time difference
1	59.2	154.7	95.5
2	65.8	359.5	93.7
3	59.2	291.1	231.9
4	99.8	403.3	303.5
5	43.8	175.1	131.3
6	126.9	517.9	391.0
7	50.3	262.9	212.6
8	48.7	486.7	438.0
9	46.7	208.0	161.3
10	55.0	154.7	99.7

The calculated coefficients of correlation between the values listed in Tables II and III are listed in Table IV. These results show that β_l/α_l was highly correlated (more than 0.6) with both the time required for the advanced-mode task and the time difference between the basic- and advanced-mode tasks.

TABLE IV. CORRELATION BETWEEN VALUES IN TABLES IV AND V

ID	β_l/α_l	β_h/α_h	β_l/α_h	β_h/α_l	β_{l+h}/α_{l+h}
Basic	0.2589	0.2941	0.1489	0.2466	0.0977
Advanced	**0.6304**	0.3095	0.4201	0.3472	0.2647
Time difference	**0.6556**	0.2843	0.4422	0.3377	0.2777

V. RESULTS AND DISCUSSION – SECOND EXPERIMENT

A. Results

The purpose of the second experiment was to measure the brain waves as the examinee was performing the task and gradually getting used to it. Therefore, the time axis was divided into four equal segments (as shown in Figure 2). This enabled the tendency of the brain waves to change over time to be determined. The value of α_l/β_l for 4 of the 21 examinees are shown in Figure 2. The plotted β/α values are the averages for each quartile.

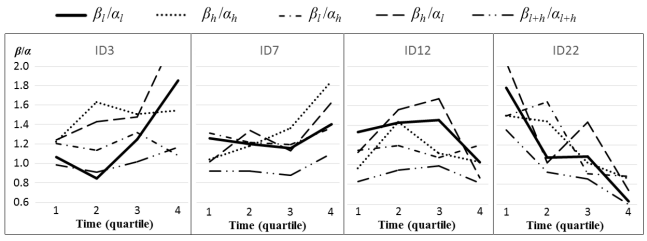

Figure 2. The value of β/α at the time of playing the LeapMotion

B. Discussion

Since the task involved assembling four robots, the time to complete one robot was one quarter of the total time. Looking at the graphs in Figure 2, we determined whether β/α increased (I) or decreased (D) between quartile x and quartile x+1 (x=1, 2, 3). There are $2^3 = 8$ possibilities (from III to DDD) for each graph. Furthermore, a straight line approximating four points can have either positive or negative inclination. The inclination indicates whether β/α increased or decreased overall. There are 16 types of graph in all (I-III to D-DDD). For example, the line for examinee 3 tends to rise overall: β/α decrease from quartile 1 to 2 whereas it increases from quartile 2 to 3 and 3 to 4. Therefore, it is typed as I-DII. Since I-DDD and D-III are impossible combinations, they are excluded.

TABLE V. TRANSITION TYPES AND TASK COMPLETION TIMES

Type	ID	Time (s)	Average Time (s)	Type	ID	Time (s)	Average Time (s)
I-III	-	-		(D-III)	-	-	
I-DII	3	248		D-DII	-	-	
	23	237					
I-IDI	1	144		D-IDI	6	207	
					11	475	
I-DDI	7	460	272.3	D-DDI	4	386	
					21	254	330.5
I-IID	9	612		D-IID	12	297	
	15	287			13	133	
I-DID	16	441		D-DID	8	188	
					22	156	
					25	180	
I-IDD	-	-		D-IDD	5	155	
(I-DDD)	-	-	446.7	D-DDD	24	157	180.9
Average		347.0		Average		235.3	

We classified the transitions of the 18 examinees into 16 types. The types and task completion times, which correspond to task difficulty, are listed in Table V. As shown by the average values at the bottom row of the table, the average completion time was longer for the types in which β_l/α_l increased (left side of table) whereas it was shorter for the types in which it decreased (right side). In particular, the completion time was obviously shorter for the types in which β_l/α_l decreased overall and decreased between the third and last quartile (lower right in table). The examinees with these types of transitions would consider the task to be simple.

The relationship between the slope of the approximate straight line and the average value of β_l/α_l is shown in Figure 3. The gradient increases as going upward; that is, the value of β_l/α_l gradually increases. Conversely, it gradually decreases as going downward. In addition, the value of β_l/α_l as a whole is smaller for transitions on the left side of Table V larger for those on the right side. The diameters of the circles in the figure represent the length of time taken to complete the task, so a larger circle indicates that it took more time to complete the task.

As shown in Figure 3, examinees 22 and 24 had a low average value of β_l/α_l, β_l/α_l which tended to decrease, and they had a shorter completion time. It can thus be said that these examinees found the task to be easy. In the same way, it can be said that examinees 9 and 16 found the task to be difficult. As for examinees 15 and 23, β_l/α_l tended to increase slightly; however, overall, β_l/α_l was low, so they probably found the task to be easy. The transition for examinees 13, 25, and 8 (near the center of the figure) had a downward tendency with a final drop into the last quartile. This means that they found the task to be easy. Finally, the larger circles (for examinees 4, 11, and 21) correspond to the type in which the transition overall drops slightly but increases into the last quartile. It can thus be concluded that the completion time was higher because the examinees felt some difficulty at the end of the task even though they had been getting used to the task.

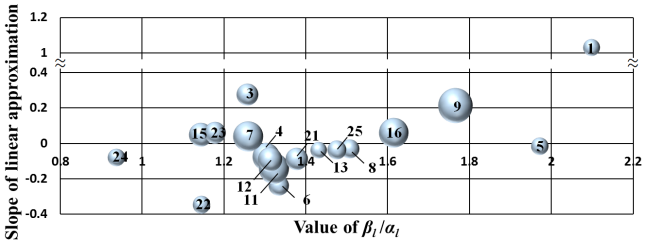

Figure 3. Relationship between slope of approximate line and average value of β_l/α_l

Interpreting the central part Figure 3 in general is difficult. However, the lower side and the left side of the figure tend to have smaller β_l/α_l values, so we can speculate that those examinees found the task to be a simple one to complete. In addition, β_l/α_l tended to be large or large overall on the upper side and the right side, so we can speculate that those examinees found the task to be a difficult one to complete.

VI. CONCLUSION AND FUTURE WORK

To investigate the use of brain waves to estimate the degree of difficulty of a learning task, we performed two experiments. The results of first experiment confirmed the previous finding that the β-wave to α-wave ratio increases with task difficulty. The results of second experiment showed that the values for the examinees who reported that the task was easy fell gradually, supporting our finding that the value of the ratio represents task difficulty.

Future work includes measuring and analyzing the brain waves of students studying mathematics, a foreign language, and programming.

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