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Experimental Verification of the Relationship between Physiological Indexes and the Presence or Absence of an Operation during E-learning

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***Abstract*—**An experiment to verify the relationships between physiological indexes of an e-learner and the presence or absence of an operation during e-learning is described. Electroencephalogram (EEG), hemoencephalography (HEG), skin conductance (SC), and blood volume pulse (BVP) values were measured while participants performed experimental learning tasks. The results show that there are significant differences between the SC values when reading with clicking on learning materials and the SC values when reading without clicking, and between the HEG ratio when reading (with and without clicking) and the HEG ratio when resting for four of five participants. We conclude that the SC signals can be used to estimate whether or not a learner is performing an active task and that the HEG ratios can be used to estimate whether a learner is learning.

***Keywords*—**E-learning, physiological index, physiological signal, state of learning.

I. INTRODUCTION

WE can learn various learning materials anytime and anywhere using a web-based learning system that provides multimedia data, such as text, sounds, images, videos, and quizzes. However, it is difficult for a teacher to use this system to observe the details of a learner's state such as degree of concentration and level of understanding and situation such as learning environment and online interactivity, because the teacher and the learner are located at different sites [1].

Sometimes e-learners answer online quizzes or enter self-reports about their understanding into web forms to convey the extent of their understanding to a teacher. Learners must submit such reports several times when a teacher requests continuous updates on their progress. However, self-reports are subjective assessments and may not reflect the actual degree of understanding. Moreover, it is difficult for a learner to remember the details of their state during learning.

Learner's physiological signals, such as brain waves, blood volume pulse (BVP), and skin conductance (SC), have been studied [1]–[6]. Unlike self-reports, physiological signals are continuous and objective. Some studies investigated methods to estimate emotion, affective components, and intention from physiological signals.

We have verified the possibility of estimating a learner's degree of understanding and the presence or absence of interaction from physiological signals recorded when a learner uses an online learning system. We hypothesized that there were differences among learner states, i.e., not learning, learning not interactively, and learning interactively, because we assumed that physiological signals change relative to the degree of concentration in each state.

This paper describes an experiment to verify relationships between indexes from a learner's physiological signals and the presence or absence of an operation during e-learning, such as clicking a dialog button of a learning material. We set three conditions: "resting" (doing nothing), "clicking" (reading web page content and clicking on part of a page), and "not clicking" (only reading). We measured and recorded electroencephalogram (EEG), hemoencephalography (HEG), SC, and BVP values when a participant performed an experimental task.

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II. RELATED WORK

This section introduces work related to analyses of e-learner's physiological signals.

Nomura et al. measured skin temperature changes and high frequency (HF) electrocardiogram activity of e-learners in interactive and non-interactive conditions [2]. The results showed that skin temperature declined significantly when subjects were engaged with interactive material (IM); however, there was no change when subjects were engaged with non-interactive material (N-IM). It was also found that HF values dropped immediately after the start of both conditions and remained low for the duration of both sessions. Nomura et al. also conducted an experiment on hemodynamic responses of e-learners engaged in IM and N-IM [3]. The results showed that there were remarkable differences between IM and N-IM for cardiac output and stroke volume.

Scotti et al. studied student learning processes during synchronous and asynchronous distance learning. This study focused on student emotions by verifying the relationship between STAI (State Trait Anxiety Inventory) that is a questionnaire according correlation among physio/psyco data and physiological signals, i.e., galvanic skin response (GSR), BVP, electrocardiogram, and EEG values [4]. They found a significant correlation between psychological stress and heart rate/GSR.

Tsianos et al. studied biofeedback in the context of a web-based educational environment focusing on the SC, BVP, and HR [5]. Their goal was to investigate how such physiological measurements are related to traditional measurements, such as questionnaires and self-reports. According to the findings, HR was significantly correlated with individuals' trait anxiety and self-reported anxiety states but not with academic performance in an on-line exam.

Nakamura et al. constructed the self-directed learning system "Ghost-Tutor." Ghost-Tutor can automatically control lecture videos depending on the student's learning pace by detecting eye movement to determine the pace [1]. They confirmed that blinking frequency, gaze period, and gaze direction showed significant differences relative to the learner's degree of concentration.

Shigeta et al. proposed an estimation method for subjective difficulty ("easy" and "difficult") of web-based English listening tests from learners' eye movement characteristics [6]. They showed that the characteristics differed between "easy" and "difficult."

III. Experiment

A. Objective

The objective of the experiment was to investigate the relationship between learners' physiological signals and their states, i.e., learning with an operation, learning without an operation, and doing nothing. We hypothesized that there would be differences among physiological signals between the learning state and the state of doing nothing, and between the state with an operation and the state without an operation. We proposed that the degree of learner concentration in the states results in differences in the values of the physiological signals.

B. Experimental Environment

Fig. 1 illustrates the experimental environment. We used a 19-inch LCD monitor (1280 x 1024 pixels) and a laptop for e-learning. In addition, we used electrodes to measure the EEG and the SC, infrared sensors to measure the HEG and the BVP, and an encoder connected to a laptop for real-time computerized biofeedback and data acquisition.

E-learning content was displayed on the monitor. The learner was able to scroll through pages and click on a part of a page using a mouse.

The encoder (ProComp Infiniti, Thought Technology Ltd.) can sample physiological data at 2048 s/s and 256 s/s via the sensors and electrodes, respectively. The sampled data were recorded on the PC.

Fig. 1 Experimental environment

C. Physiological Signals

Brain waves are weak electrical impulses generated by nerve cell activity in the brain. The waves are classified by frequency: theta (4–8 Hz), alpha1 (8–9 Hz), alpha2 (9–12 Hz), alpha3 (12–14 Hz), and beta (14–26 Hz) waves. The power values of the bands are calculated as physiological indexes. A previous study has shown that mental activity is processed in the frontal lobe [7], [8]; therefore, we attached a sensor electrode (EEG-Z, Thought Technology Ltd.) at the F3 position (Fig. 2 (a)) according to the international 10-20 system of electrode placement.

The HEG ratio is a relative ratio between the amount of oxygenated hemoglobin and the amount of reduced hemoglobin. The *HEG* ratio is calculated as:

$$HEG = \frac{RED}{IR} \times 200 , \quad (1)$$

where *RED* is the absorptive power of oxygenated hemoglobin and reduced hemoglobin during visible red light irradiation, and *IR* is the absorptive power during near-infrared light irradiation. Accepting that mental activity is processed in the frontal lobe [7], [8], we attached an HEG sensor system (MediTech Electronic) at Fp2 (Fig. 2 (b)) as per the international 10-20 system.

The SC value indicates electric conductivity due to emotional sweating from eccrine glands on a participant's hand. We attached two SC-Flex/Pro electrodes (Thought Technology Ltd.) to a participant's left index finger and ring finger (Fig. 2 (c)) to sense electric conductivity between the fingers.

BVPs are changes in vascular volume derived from the cardiac beat. BVP waves are classified by frequency: HF (0.15–0.4 Hz) and low frequency (LF, 0.04–0.15 Hz). The power values of HF and LF and the LF/HF ratio are calculated as physiological indexes. LF/HF indicates the ratio of sympathetic nerve activity to parasympathetic nerve activity. We attached a BVP-Flex/Pro (Thought Technology Ltd.) to the left thumb (Fig. 2 (d)) to measure the BVP.

The values for brain waves, HEG, and SC were normalized with the values of the participants' normal signals as:

$$Z = \frac{X - \mu}{\sigma}, \quad (2)$$

where X is the value from biological signals during the experiment, μ is the average value of the normal signals, and σ is the standard deviation from normal signals.

The indexes for the BVP are normalized as:

$$Z = \frac{X}{Y}, \quad (3)$$

where X is calculated from biological signals obtained during the experiment, and Y is calculated from normal signals.

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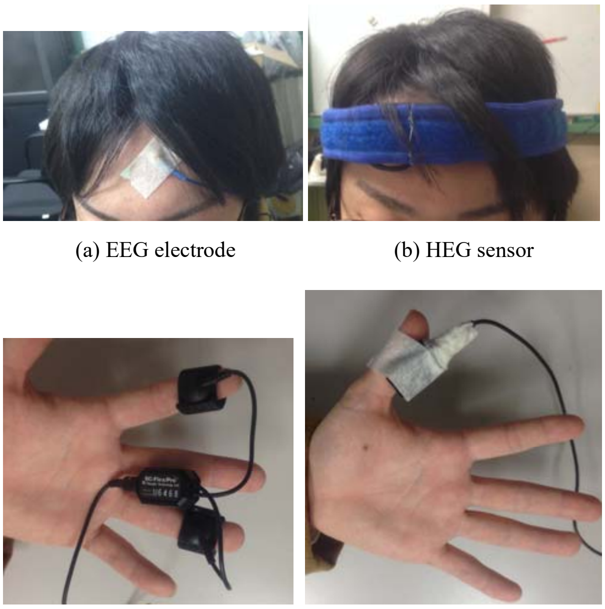

(a) EEG electrode (b) HEG sensor

(c) SC electrode (d) BVP sensor

Fig. 2 Physiological sensors

D. Task

In this experiment, the main task was to read and learn the content of a document on a web page in a learning management system. The document consists of eight slides that include text, figures, and tables.

The sub-task was to mark a part of a page when and where participants thought they understood or did not understand the part during the main task. When a participant believed that they had "understood" or "not understood" a part, they right-clicked on the part. After clicking, a pop-up menu with options "understood" and "not understood" was displayed, and the participant selected the appropriate option. In this task, a part is a technical term, a descriptive text, a figure or a table of the document. Therefore, there may be many parts that a participant clicked par a page and less.

The document that the participants read for the main task consists of slides described about affective interfaces and is material in an interactive systems design course in a master's degree program.

E. Procedure

The experiment was conducted in three phrases, i.e., resting, reading and clicking, and only reading phases.

In the resting phase, after informed consent, physiological signals were measured and recorded for 60 seconds while the participant remained idle and did nothing. The data were used to determine the difference between resting and performing a task.

In the reading and clicking phase, the participants read the entire document and learned the content. There was no time constraint in this phase. Participants marked parts when and where they understood or did not understand the content by clicking on the parts using their right hand. Physiological signals were measured and recorded during the task.

In the reading only phase, the participants read another document entirely. Similar to phase two, there was no time constraint in this phase. Unlike phase two, participants were not required to perform the marking task. The physiological signals were measured and recorded.

F. Participants

The participants were four male and one female computer engineering college students aged 21–23 who had not read the documents prior to the experiment.

G. Data extraction

This section describes the process for extracting data from the recorded signals. Each participant's data in each phase was extracted for 30 intervals in each phase as described previously. The intervals were selected randomly from the physiological signals. However, in clicking phase, the intervals were selected randomly from the signals when clicking events occurred. The length (number of frames) of each interval depended on the type of physiological signal. We referred to previous studies to determine the interval length. The lengths were 0.5 s for EEG data [9], 5 s for HEG data [10], 3 s for SC flow [11], and 4 s for BVP values [12].

Equations (2) and (3) were used to normalize the samples.

IV. Results

A. Relationship between Physiological Indexes and with or without Clicking

Table I shows analysis of variance (ANOVA, $p < 0.05$) results among the three conditions ("resting," "reading and clicking," and "only reading (not clicking)." Here, A through E identify the participants. The rows show ANOVA results for each participant. "All" refers to ANOVA results using all participant data. The "*" denotes significant differences, and the blanks indicate no significant differences. There are no significant differences among the theta, alpha3 and beta waves of EEG which are not showed in Table I.

There are noticeable differences among HF of BVP, HEG, and SC values. Therefore, we performed multiple comparisons of physiological indexes. The results are shown in Tables II-IV. The notations in Tables II-IV indicate degrees of difference ($p < 0.05$): "L," "M" and "S". "L" indicates a large difference between conditions, "S" indicates a small difference, "M" denotes the degree of difference between "L" and "S," and blanks indicate no significant differences.

TABLE I
ANOVA Results for All Experimental Phases

Participants	Alpha1	Alpha2	HEG	SC	HF	LF/HF
A			*	*		*
B			*	*	*	
C	*	*	*	*	*	
D	*	*	*	*	*	*
E			*		*	*
All				*	*	

*p<0.05

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As can be seen, there are significant differences between "clicking" and "not clicking," and between "not clicking" and "resting" in the power value of HF of BVP for three participants. However, there are individual differences in the magnitude of the relationships among the conditions for HF.

There are significant differences between "clicking" and "resting," and between "not clicking" and "resting" in the HEG values for four participants. In particular, the differences between "not clicking" and "resting" are large. There are also significant differences between "clicking" and "not clicking," and between "clicking" and "resting" in the SC values for four participants. There are large differences between "clicking" and "not clicking" for three of those four participants (participant A through participant E and all participants). Fig. 3 shows the results of the SC values for each participant and all participants in each condition. These graphs show that the values for the "clicking" condition are higher than the other conditions.

TABLE II
MULTIPLE COMPARISONS FOR HF OF BVP

Participants	Clicking vs. Not clicking	Clicking vs. Resting	Not clicking vs. Resting
A			
B	S		L
C	L	S	
D	S		L
E		L	S
All		L	S

$p < 0.05$

TABLE III
MULTIPLE COMPARISONS FOR HEG

Participants	Clicking vs. Not clicking	Clicking vs. Resting	Not clicking vs. Resting
A	S		L
B	S	L	
C	M	S	L
D		S	L
E		S	L
All			

$p < 0.05$

TABLE IV
MULTIPLE COMPARISONS FOR SC

Participants	Clicking vs. Not clicking	Clicking vs. Resting	Not clicking vs. Resting
A	L	M	S
B	L	M	S
C	L	S	
D	S	L	M
E			
All	S	L	

$p < 0.05$

There are significant differences among the conditions for the power values of HF and the SC values (ANOVA, $p < 0.05$). In addition, there are significant differences between "clicking" and "resting," and between "not clicking" and "resting" for HF and between "clicking" and "not clicking," and "not clicking" and "resting" for the SC.

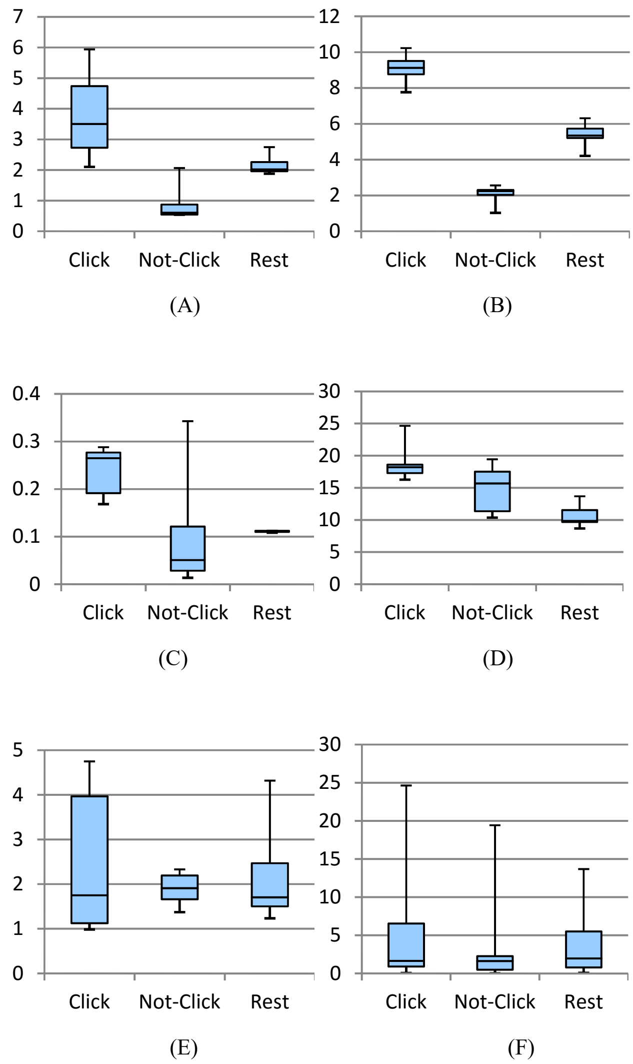

Fig. 3 SC values for each participant (A through E) and (F) all participants

V. DISCUSSION

A. Relationship between Physiological Signals and Active Task

The main difference between the "clicking" and "not clicking" conditions is whether a participant consciously decided to understand a part of the content in both the second and third phase. Thus, "clicking" is an active task and "not clicking (only reading)" is a passive task. We consider that the differences among physiological indexes relative to conditions can be attributed to differences in participants' conscious learning decisions.

We found that the SC signals from a learner's palm can be used to determine whether or not a learner performed an active task during learning because the SC values for "clicking" and "not clicking" differed significantly. In addition, the SC values increase when a person is excited or feels stress [13].

On the other hand, we found that we cannot use the HEG ratio and power value of HF of BVP to determine whether or not a learner performed an active task, because the differences in these values between the conditions were small. Compared to the results of Nomura et al. described in Section Two, a significant difference between active and passive tasks was seen in HF of BVP for three out of the five participants.

B. Relationship between Physiological Signals and Learning

The main difference between "resting" and "learning ("clicking" and "not clicking") is whether the person is learning or not. We found that we could use the HEG signals to determine whether a person is learning from the individual analysis of the participants.

The HEG ratios during learning ("clicking" and "not clicking") for four of the participants were higher than during "resting." For the fifth participant, the ratio during learning was lower than during resting.

We found that the participants could be divided into two groups based on the power values of HF of BVP. In one group, HF of BVP values increased during learning compared to resting. In the second group, HF of BVP values decreased during learning compared to resting. Therefore, we found that it is impossible to determine whether a person is learning or not learning from the BVP signals, because changes in the BVP do not reveal a common tendency between learning and resting.

VI. Conclusion

We have verified significant differences in the EEG, HEG, SC and BVP between reading with an operation, reading without an operation, and resting. The results show that there are significant differences between the SC values when reading with an operation and when reading without an operation. In addition, the results show significant differences between the HEG ratio when reading (with or without an operation) and the HEG ratio when resting. Therefore, we conclude that the SC signals can be used to determine whether a learner is performing interactive learning and that the HEG ratios can be used to determine whether a learner is learning. This conclusion will allow teachers to confirm learner states (learning or not learning, learning interactively or not learning interactively) even though learners are at different sites by measuring learners' SC and HEG continuously. Teachers can determine the details of learner understanding by integrating the estimated states and conventional data, such as quiz results and self-reports. For example, a teacher can determine if an e-learner has not understood the course material from quiz results of the learner and can estimate the reason why the learner has not understood from the indexes by analyzing SC signals during learning. The reason was that the learner simply accessed the material and read it but did not study actively.

In future, we plan to implement our proposed model to estimate whether a learner studied actively or not into an online learning system and evaluate the model. Additionally, we plan to conduct an experiment to verify the relationships between physiological signals and the degree of understanding of an e-learner.

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