Fundamental Studies on Effective e-Learning Using Physiology Indices

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Abstract. In order to apply individual learning methods to an e-learning system, we need some appropriate measures to know the quantitative evaluation for the learning progress of each individual. The ratio of the number of correct answers to the number of questions is a simple measure of the achievement of the learner. However, such a simple measure may not accurately reflect the real progress of the learner. Event Related Potentials (ERPs for short) are measured from electroencephalograms (EEGs for short). We consider that ERPs may contain meaningful information about the level of the learner's achievement. We had experiments measuring ERPs of subjects learning chemical formulae on an e-learning system. We try to characterize the relation among the learner's achievement, hardness of learning, and the waveforms of his ERPs. This kind of characterizations may be useful for evaluating the learner's achievement.

Keywords: EEG, event related potential, achievement, learning, chemical formulae.

1 Introduction

In the modern educational world, various learning systems have been introduced. The effectiveness of these learning systems has been intensively studied. We consider that there might be suitable learning methods for individual cases. In order to apply such individual learning methods, we need some appropriate measures to know the quantitative evaluation for the learning progress of each individual. The ratio of the number of correct answers to the number of questions is a simple measure of the achievement of the learner. However, this simple measure may not accurately reflect the real progress of the learner. In general, we cannot decide by such a simple measure whether the learner chose a correct answer with confidence or without confidence.

ERPs are measured from electroencephalograms (EEGs for short) [2]. We consider that ERPs contain meaningful information about the level of the learner's achievement [1][3][4]. We had experiments of measuring ERPs of some subjects learning chemical formulae on an e-learning system. By analyzing the data of ERPs obtained in the experiments, we discuss some fundamental features that may be useful to find suitable and effective methods for individual learners.

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2 Experiments

2.1 Experimental Methods

The subjects of the experiments learnt the atomic weight of each of commonly known atoms in advance. In each experiment, given chemical formulae in a monitor display, the subjects calculate the molecular weight of each chemical formula. The details of the experiments are as follows:

(1) Subjects: Three adults (male, 20-21 years old) are involved in the experiments. The discussions in this paper are mainly based on the experimental data of *subject a*, one of the three subjects.
(2) Laboratory: We prepared a laboratory shielded from external stimuli so that the subjects could concentrate on the given tasks during the experiments.
(3) A task: Given chemical formulae (Table 1) in the display, the subjects calculate the molecular weight of each chemical formula. For example, C (image 1), O_2 (image 2) and CO_2 (image 3) are displayed sequentially in this order (see Fig. 1 and Table 1). Then the subjects calculate the molecular weight of CO_2 as a sequence of calculation, the molecular weight of C, the molecular weight of O_2, and the molecular weight of CO_2. The last one is calculated by adding the molecular weights of the first two.

C	O_2	CO_2
image 1	image 2	image 3

Fig. 1. Three images of a chemical formula sequentially displayed

Table 1. Chemical formulae used in tasks

No	image1	image 2	image 3
1	C	O_2	CO_2
2	N	H_3	NH_3
3	H_2	S	H_2S
⋮	⋮	⋮	⋮
15	Na	Cl	NaCl

(4) Task display: Around the center of a 19-inch monitor, a set of the images are displayed for one second each at a random interval, ranging from 750-1250 msec. A subject is asked to sit at the position 60-80 cm away from the monitor. The subject is able to see the display without eye movements. He gives each molecular weight using a 10-key pad. The time duration from the start of a task shown in the display to the entry of his answer is recorded. This time duration is called the response time of the subject.
(5) Repetition: In each set of experiments, 15 chemical formulae are displayed in random order. The display of each chemical formula is given in the order of image 1, image 2 and image 3. There is one minute time interval between two consecutive

sets of experiments. During the time interval the subject may take a rest. An experimental set consisting of 15 chemical formulae is carried out 5 times a day.

(6) Experimental duration: The time duration for displaying an image is 3 seconds. Each chemical formula is shown in the display as a sequence of 3 images. A set of experiments includes the task for a subject to calculate the molecular weights of 15 chemical formulae. Therefore, each set of experiments needs approximately 135 seconds.

(7) Electroencephalography: According to the International 10-20 system, A_1 and A_2 are used as reference electrodes. Fp_1, Fp_2, C_3, and C_4 are unipolar leads for EEG measurement. Neurofax EEG8310 (Nihon Kohden) is used to measure EEGs. Its cut-off frequency and time constant are 60 Hz and 0.3 seconds, respectively. The experimental data are processed in real time by a Gateway G7-600 computer annexing an A/D converter board.

(8) A/D converter: The sampling frequency for EEG measurement is 1 kHz. The sampled data is digitalized within a second by the A/D converter. Then the digital data is loaded to the computer.

2.2 Methodology of Data Analysis

Initially, we eliminate high-frequency noise as well as low-frequency noise by an adaptive filter. The cut-off frequency of the adaptive filter changes time to time. Each EEG is normalized. Then we obtain the ERPs of a set of experiments by taking the average of 30 normalized waveforms. Furthermore, we average the normalized ERPs of 10 sets. The value obtained in this way is determined to be the representative ERP for the day of the experiments. For each set of experiments we calculate the ratio of correct answers, and plot it in a graph.

3 Experimental Results

For 4-days experiments of *subject a*, ERPs measured at the stage of image 1 are shown in Fig. 2. The horizontal axis of the graph is the time duration (msec) from the start of the task display, while the vertical axis is the amplitude (μV) of the measured potential. Amplitude plotted vertically direction is the average potential of 30 normalized ERPs. We can observe waveforms with P_{100}, N_{200}, P_{300} and N_{400}, where P_{100} and P_{300} are positive peaks and N_{200} and N_{400} are negative peaks. The time duration from the start of the task to a peak in the waveform is called the latency for the peak. We notice that the latency for P_{100}, N_{200} and P_{300} are shortened by repeating experiments. This means that the results can be improved by repeated learning. The average ERPs for image 1, image 2, and image 3 are shown in Fig 3. In Fig. 3, N_{400} and P_{500} do not appear clearly on the plotted curve for image 1. We judge image 3 to be harder than image 1 and image 2, since it requests more additions than others. From the same reason image 2 is harder than image 1. That is, a sequence of images appears in the display in the order of easy one, harder one and hardest one. In particular, the hardness of image 3 reflects the plotted curve from P_{300} to N_{600}.

The change of the ratio of the number of correct answers to the number of questions is shown in Fig. 4. Each vertical value in Fig. 4 shows the correctness ratio for an experimental set. We can notice the tendency of the improvement of the correctness ratio by repeated learning. The correctness ratio remarkably improves from the 4th day. This improvement is due to the fact that the subject usually notices his calculation errors around the 4th experimental day. The correctness ratio is already about 80% at the initial part of the experiments. This means that the subject has already memorized the molecular weights of some well known chemical formulae.

The response time of the subject also changes by repeated learning. This tendency is shown in Fig. 5. It remarkably improves after the 19th day of the experiments, since the subject finds how to simplify a way of giving his answers to the computer around the 11th day. For lack of concentration of the subjects, the subjects vary in their response time to the tasks. The average of all ERPs is shown in Fig. 6. We can observe the peaks, P_{100}, N_{200}, P_{300}, N_{400}, P_{500} and N_{600}, in the waveforms there.

The average of normalized ERPs for each image during the first 3 days and the last 3 days of the experiments is shown in Fig. 7 and Fig. 8, respectively. Since the subject easily recognizes such a simple chemical formula given at the stage of image 1, the amplitude of P_{100} is larger than other peaks. The waveforms for image 2 and image 3 in Fig. 7 and Fig. 8 resemble each other. Since the calculation for image 2 and image 3 requires some numerical additions, N_{400} and P_{500} appear in the waveforms for these images.

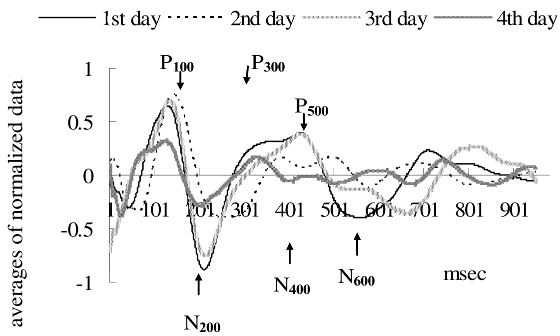

Fig. 2. ERPs of *subject a* measured at C_3

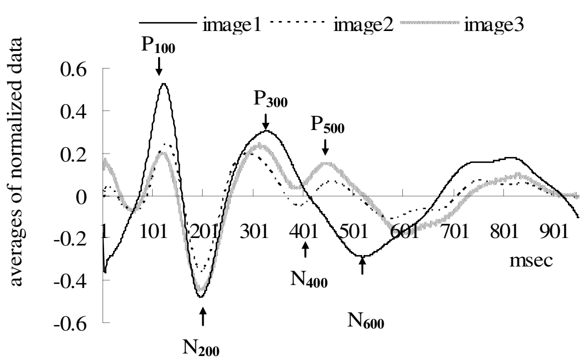

Fig. 3. The average of ERPs of *subject a* for image 1, image 2 and image 3 measured at site C_3

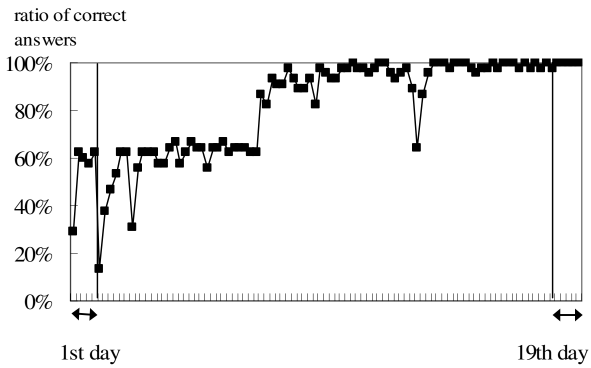

Fig. 4. Correct answer ratio

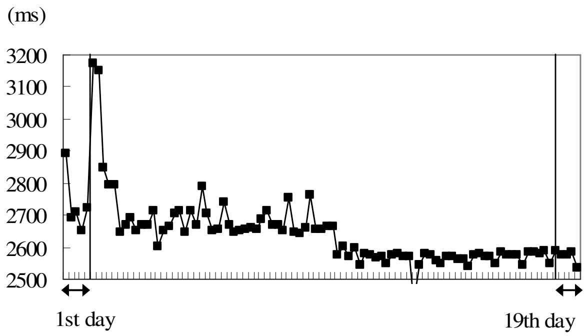

Fig. 5. Answering time

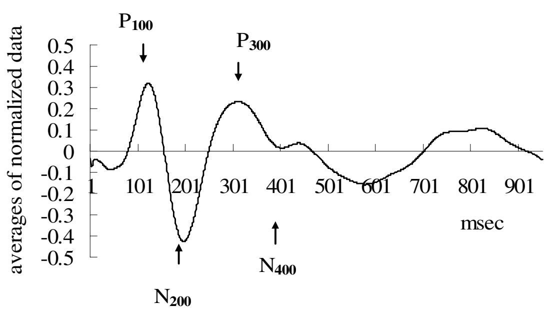

Fig. 6. The average of all ERPs

The averages of normalized ERPs for image 1 during the first 3 days, the intermediate 3 days, and the last 3 days are shown in Fig. 9. The corresponding averaged data for image 2 and image 3 are shown in Fig. 10 and Fig. 11, respectively. For every image, we can notice the tendency that the latency is getting shorter by repeated learning. For image 3, the amplitude of P_{300} is large compared with the amplitude of P_{300} for image 1 or image 2. The change of the latency for N_{400} through all the experimental days is shown in Fig. 12. The latency tends to be shorter by repeated learning. In particular, the improvement of the latency for image 2 and image 3 is notable. Since the calculation for image 3 is harder than other images, the effect of iterative learning is prominent for image 3.

Table 2. The hardness of chemical formulae

images	**Number of additions**	**Average number of digits**
image 1	2	2.1
image 2	7	1.9
image 3	15	2.3

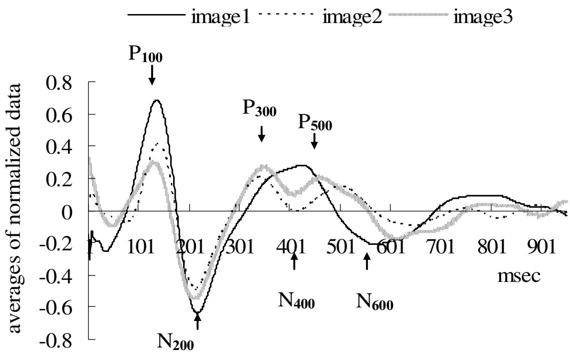

Fig. 7. The average of ERPs for each image during the first 3 days

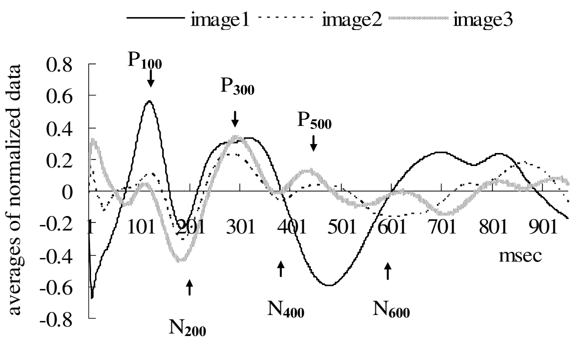

Fig. 8. The average of ERPs for each image during the last 3 days

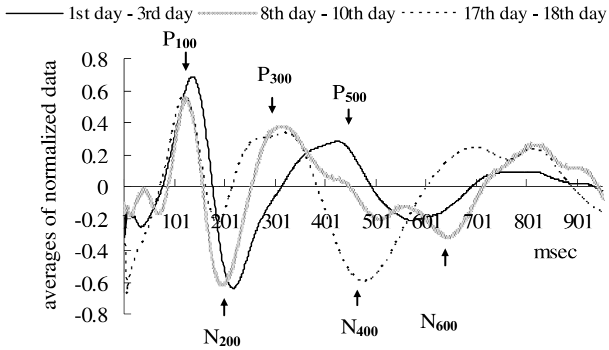

Fig. 9. The average of ERPs for image 1 during each of the first 3 days, the intermediate 3 days, and the last 3 days

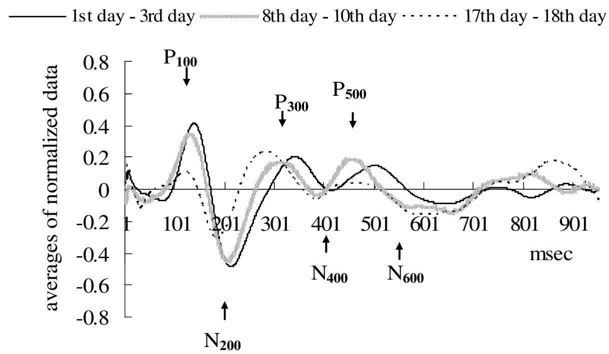

Fig. 10. The average of ERPs for image 2 during each of the first 3, days the intermediate 3 days, and the last 3 days

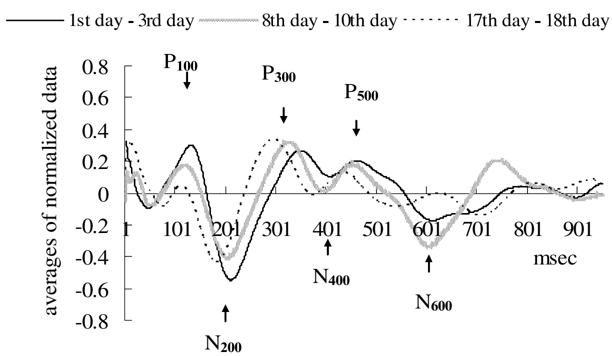

Fig. 11. The average of ERPs for image 3 during each of the first 3 days, the intermediate 3 days, and the last 3 days

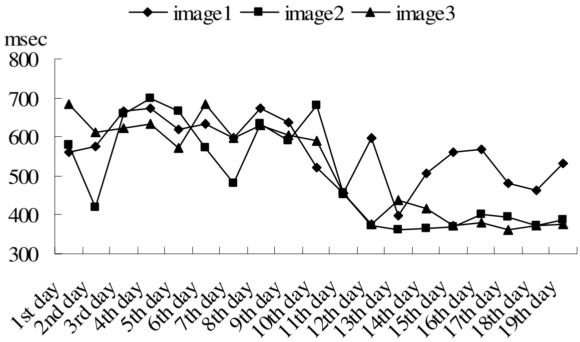

Fig. 12. Change of the latency for N_{400}

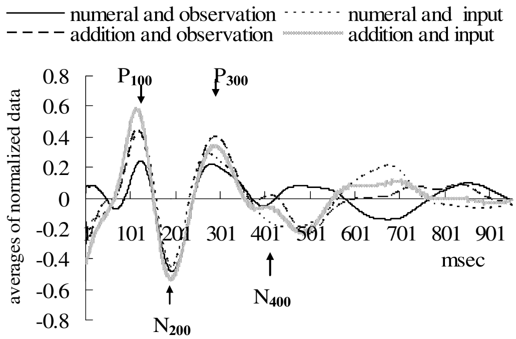

Fig. 13. Waveforms of ERPs for numeral displays and some actions of subject a

4 Discussions

To understand the cause of N_{400} and P_{500} in our experiments, we investigate the response of the subject to numeral displays. In the experiments to achieve this aim, given a number or the addition of numbers in the display, the subject is asked to take some actions. The waveforms given in Fig. 13 is to compare various cases. In Fig. 13, "*numeral and observation*" means that given a number in the display the subject just observes it, and "*numeral and input*" means that given a number in the display the subject inputs the same number to the computer. We mean by "*addition and observation*" that given the addition of numbers the subject just observe the addition. We mean by "*addition and input*" that given the addition of numbers the subject inputs the result of the addition to the computer.

In the experiments containing calculation work by *subject a*, we notice that some peaks appear at some later stages, such as N_{400} and P_{500} in the waveforms of ERPs. The waveforms of ERPs for image 1 of a chemical formula and for numeral input case resemble each other. However, there is the small difference between these waveforms. For image 1 of a chemical formula, a small swelling appears just after

P_{300} in the waveforms, but such a swelling does not appear in the numeral input case. We notice that this small swelling is caused by the calculation work for converting the chemical formula to its molecule weight. The calculation work for image 1 is almost trivial, and N_{400} does not appear in the waveforms for image 1. From this fact, we can consider that for simple tasks requiring just almost trivial calculation, N_{400} does not clearly appear in the waveforms. For image 2 and image 3 of chemical formulae, the subject converts each formula to its molecule weight. This is the main reason why N_{400}, P_{500} and N_{600} appear in the waveforms of ERPs for image 2 and image 3. In the case of *addition and input*, the subject need not the converting work. The latency for this case is shorter than the latency for image 2 and image 3 of chemical formulae. Since tasks for image 3 are harder than other tasks, the amplitude of ERPs for image 3 is larger than others.

We believe that N_{400} and P_{500} in Fig. 10 and Fig. 11 are caused by the addition work in the molecule weight calculation. This belief is based on the comparison among the waveforms shown in Fig. 13. These peaks appear more clearly while the subject engages in calculating molecule weights for image 2 and image 3 than in calculating numeral additions from the numeral values shown in the display.

5 Concluding Remarks

The experimental results discussed in this paper are summarized as follows:

(1) In the experiments, the calculation of the molecule weights consists of three stages (image 1, image 2, and image 3). The ERPs of the subjects are measured at each stage. We can notice some difference of the amplitude and the latency of the waveforms of ERPs among these stages.
(2) For the stages of image 2 and image 3, the subjects are involved in calculation work for addition. During each of these stages, multiple peak potentials appear in the time range between 300 ms to 600 ms from the start of the task.
(3) The order of hardness among the tasks at these stages is image 1, image 2 and image 3 in increasing order.
(4) We can observe eminent potentials, P_{100} and N_{200} in the waveforms of ERPs for image 1. These seem to be visual evoked potentials.
(5) The latency of P_{300} for image 1 is clearly improved by repeated learning. On the other hand, the effectiveness by repeated learning does not clearly appear at the improvement of the latency of P_{300} for image 2 and image 3. For these images, the subjects are involved in some work for numeral addition.
(6) From the discussions about the analysis of ERPs, we can predict that the level of achievement of the learner can be evaluated by his ERPs.

As described above, from ERP measurements in our experiments, we can observe some difference among achievements of learning chemical formulae by the subjects. Our experimental results suggest a possibility that information obtained from ERPs can be directly applied to the problem of how to know the brain status of the learner. This kind of information may be useful to develop the effective e-learning methods. However, our experiments shown in this paper have some serious problems. For example, we did not unify the hardness of the chemical formulae used in the tasks.

We did not also clarify the relationship between the hardness of a task and ERPs measured from subjects. It might be worthy to resolve these problems by further investigation.

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