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Procedia Computer Science 35 (2014) 1596 – 1604
Procedia Computer Science

18th International Conference on Knowledge-Based and Intelligent Information & Engineering Systems - KES2014

Learning system using simple electroencephalograph feedback effect during memory work

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Abstract

Simple electroencephalographs (EEG devices), which have recently been used commercially to an increasing extent, are portable and wearable to a degree that they do not restrict a wearer's actions. This convenience of use allows the ordinary use of electroencephalography inexpensively and widely. This study examines the construction of a simple EEG system that can feed back obtained EEG information for instruction assistance in distance learning. This paper presents an investigation of the relation between two wavelengths: low-γ that reacted during memorization work in the experiment last year, and θ waves that indicate a reaction in a short-term memory domain designated as working memory. Then a support system using the properties thereof was constructed. An experimental comparative analysis of correlation was conducted using electroencephalographically obtained data of students' memorizing work from actual electroencephalogram measurements. The results revealed synchronized behaviour of $(\theta + \alpha)/10$ and low γ. Furthermore, a prototype system using the properties of these two wavelengths was constructed. Change in memory by the existence of a support system has demonstrated the effectiveness of $(\theta + \alpha)/(10 \times \text{low\_}\gamma)$ as an index for measuring the extent of memorization.

Peer-review under responsibility of KES International.

Keywords: Simple electroencephalograph;θ wave , α wave and γ wave; Distance learning; Feedback system

1. Introduction

Electroencephalography (EEG), which provides biological information, is widely used as a performance index of information processing that takes place in the brain. Frequency response among EEG characteristics is known to be

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Peer-review under responsibility of KES International.
doi:10.1016/j.procs.2014.08.243

related closely to cognitive processes such as learning, language, and perception. By virtue of continued development of brain science and technology, electroencephalographs (EEG devices), which used to be expensive and bulky, have been miniaturized for portability. Simple EEG devices that are wearable and sufficiently compact to permit a wearer to have unrestricted movement have become commercially available recently. We specifically assess the merits of a simple EEG device and explain the construction of a system that feeds back EEG information for use with distance learning[1].

Distance learning systems are beneficial because the progress and results of learning can be fed back and checked immediately. However, there are shortcomings: student learning cannot be observed directly; and insufficient information such as the learning state and progress information can offer only limited support. It is therefore indispensable to observe the cognition and mental condition of user students with biological information obtained from the EEG devices, to enable the support of students in light of their actual conditions. Such a system for observation can be expected to improve distance learning shortcomings and to encourage instruction assistance and student learning. This study specifically examines the fact that θ waves reacted on working memory[2] and that low_γ reacted on memorization work in an experiment conducted last year[3]. Moreover, this study investigates the relation between these two wavelengths. A support system using the properties thereof was constructed. Then an experimental comparative analysis was conducted of correlation in the electroencephalogram data of students' memorizing work in actual electroencephalogram measurements.

2. Electroencephalography

Electroencephalography (EEG), which can measure an index of human information-processing steps, is widely used in medicine for integrative functional evaluation of a brain, and for investigation of brain disorders through epileptology and angiopathy. An electrical signal arises in the event of neural ignition or synaptic transmission in a brain. This biological signal can be recorded using an electrode placed on the scalp as it emerges as brain potential change. That recording is designated as an electroencephalogram[4]. The EEG data are classified into five types according to their frequency range. Listed below are the designation, frequency range, and typical mental state of the appearance of each wave.

- δ waves, 1–4 Hz, in sleep
- $\underline{\theta}$ waves, 4–8 Hz, in sleep/attention
- α waves, 8–12 Hz, relaxed/eyes closed
- β waves, 15–20 Hz, concentrated/moving
- γ waves, 30 Hz -, processing memory and vision

Fourier analysis of original collected EEG data yields the power spectrum of each frequency.

However, EEGs show many individual differences. The relation between EEG and the cognition state varies with circumstances, even for the same person. The emergence of α waves does not always imply that a subject is relaxed. Accordingly, it is necessary to perform repeated measurements and to compare data with EEG obtained in various circumstances.

3. Simple electroencephalograph

An EEG device measures and records electroencephalographic data. Conventional experimental studies of brain physiology use a large-scale apparatus. However, such an EEG device is unsuitable for ordinary use. Medical-grade instruments with many electrodes bother subjects because of their inconvenient requirements for wearing and restriction of movement, which burden subjects with stress. This situation might inhibit their learning, which is the objective of this study. When medical level precision is necessary for the acquisition of EEG data, EEG equipment should be used. However, small portable EEG devices that are easily available are desirable in cases where EEG information is used for applications, assuming a simple EEG input interface and ordinary use.

For these reasons, it is easy and effective to use a simple EEG device rather than the medical type of EEG device for introducing EEG devices to educational use, as in this study. Therefore, this study conducts EEG experiments using MindSet™ produced by NeuroSky, Inc.[5], which is inexpensive and wearable. MindSet transmits digital EEG data to a PC. The potential between a sensor on the forehead and an electrode on the ear is measured, collected EEG data are analyzed with an on-board chip built in an ear pad, and data are transmitted to a PC using Bluetooth, a wireless communication system. Figure 1 shows communication with a MindSet and a PC.

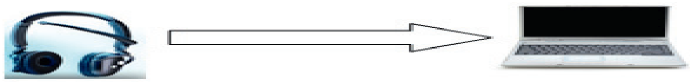

Fig. 1. MindSet^{TM} and communication.

Features of MindSet are listed below.

- Measurement point: at the frontal lobe with one sensor (international 10 / 20 system (Fp1))
- A reference point is set on an earlobe
- Dry sensor type EEG module
- A chip in the ear pad performs functions ranging from sensing to analysis
- Operable with most processors and DPS
- Data transfer to PC employs Bluetooth communication
- Sampling at 512 Hz
- Each frequency component is extracted using fast Fourier transform (FFT) for every second.

A sampling frequency of 512 Hz assures 512 original EEG data obtained every second. Frequency components are extracted by application of FFT to these data, which are then digitized and transmitted to a PC. Other signals are transmitted and received as data aside from these, including poor-sig-lev (noise intensity) and e-sense meter (original index of NeuroSky) such as the attention level and meditation level. Table 1 shows the range of each frequency component at FFT.

Table 1. Frequency component table of brain waves.

Type	Measurable data (Hz)	State of mind
δ waves	0.5–2.75	Deep sleep without dreaming, non-REM sleep, unconsciousness
θ waves	3.5–6.75	Intuition, creativity, remembrance, imagination, illusion, dreams
Low α waves	7.5–9.25	Relaxed but not lazy, peace, consciousness
High α waves	10–11.75	Formerly designated as sensorimotor rhythm (SMR), relaxed but concentrating, integrative
Low β waves	13–16.75	Contemplation, recognizing self and environment
High β waves	18–29.75	Alert, wakefulness
Low γ waves	31–39.75	Memorization, high-order cognitive activity
Mid γ waves	41–49.75	Visual information processing

There are libraries and applications accompanying the simple NeuroSky EEG device, which can facilitate users' research and development. The system environment of this study collects EEG data using an application provided by NeuroSky.

4. State of EEG and learning state

Previous research findings in psychology and brain science empirically teach that EEG waveforms are useful as an index of a mental condition if observed with a related event. The measurement of the following is regarded as effective to observe human mental conditions: the power spectrum of α and β waves obtained by discrete Fourier transform of obtained EEG, the fraction of α or β waves to the whole EEG, and the ratio of α waves to β waves[6,7]. α waves are a waveform that is generally observed during rest and wakefulness. The α wave amplitude is generally enlarged in a relaxed state, but it shrinks with tension and the appearance of β waves.

Particularly, β waves (13–30 Hz) are regarded as closely related to cognition states. Some reports describe studies that address the relation between intellectual tasks and EEG. Giannitrapani et al.[8] measured the EEG of healthy persons during an intelligence test. They discovered that the low-frequency component of β waves became predominant during reading tests, mathematics tests, and a figure alignment tests, but they are less dominant during other tests, which demonstrates that β waves are effective to some degree as an index for inferring a cognition state. In fact, γ waves (31 Hz -) have been known to show reactions during memorization work. Not so much relevance is observed with β/α, which is effective as an index for presuming a thinking state. Because γ waves are prone to be affected by muscle and eyeball motion, it is important that signals be separated carefully for identification. θ waves react on working memory during mental arithmetic.

4.1. Working memory

Working memory, located in the prefrontal area, serves a crucial role in thinking. It is a domain for conducting operations while maintaining information temporarily. It affects mental arithmetic, conversation, thinking capability, etc. For example, working memory is always in action when composing a formula in mind when performing mental arithmetic or when uttering words when talking with people in a conversation.

Forgetfulness occurs if working memory deteriorates. Such degradation is preventable by training such as that of the N-Back task.

4.2. N-Back task

An N-Back task is used for experimentation, investigation, and measurement of the "capability of a brain for using temporary memory", designated as working memory. Simple tests of memorization and forgetting are repeated, starting from a state where *n* easily memorable items, such as a number, a character, and a position, are memorized. The capabilities of working memory are measured using test results.

5. EEG measurement experiment

This experiment is aimed at analyzing the relation between an EEG and cognition state in a learning state under cognitive work with a simple wearable EEG device. Accordingly, an EEG under cognitive work is measured. Then the relations between the measured EEG, cognition, and frequency response are observed. The correlation between a learning state and an EEG is investigated.

EEG measurements were made of several student participants in our laboratory. Measurements were conducted in a seminar room. The attention of the participants was maintained by providing sufficient intermissions.

Power spectra at respective frequency ranges and sensor sensitivities were recorded during experiments. As a precondition of analysis, measurements were conducted only when sensor sensitivity was at its best. Unusual numerical values occurred, although rarely, among continuous and stable data, even given the best sensor sensitivity. Such cases were excluded as noise.

5.1. Experiment I: Electroencephalogram analysis in memorization work

5.1.1. System outline – EEG acquisition system –

It was necessary to construct an EEG acquisition system to record EEG in advance of EEG observation experiments in this study. Because the API of MindSet can acquire but not record EEG data, a Windows program that records EEG data was coded in Java and implemented. Figure 2 depicts the schematic diagram of the system.

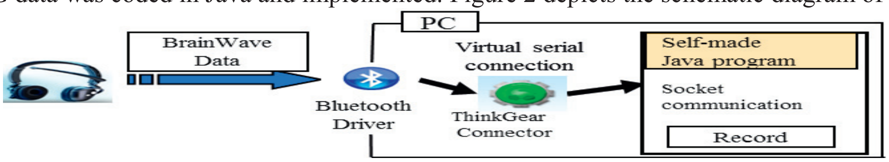

Fig. 2. Schematic diagram of EEG acquisition system.

MindSet transmits data to a PC through a Bluetooth Driver. A server program distributed by NeuroSky (Think Gear Connector) is accessed by TCP when extracting data from the PC. The Java program prepared in this study performs socket communication to the server program and receives data. A packet is transmitted every other second and the acquired packet is analyzed. This provides the numerical data, attention level, relaxation level, and sensor sensitivity of each frequency range. Because the received data are big endian, log data are written as a text file in little endian, floating point format for processing by this system.

5.1.2. Experiment outline

- Participants: Two men in their 20s (university students studying natural sciences)
- Measuring time: 300 s
- Cognitive themes: visual N-Back task (easy)

Cognitive themes are executed. Then relevance with a frequency component for memorizing low_γ is investigated.

5.1.3. Experimental procedure

A visual N-Back task (easy) with a 3 × 3 grid is given as a cognitive theme. A participant must memorize the position of squares displayed successively on the grid and to answer the position of a square displayed *n* steps ago. A new position is given upon answering. A correct answer is awarded with 1 point, while a penalty of -2 points is assigned to a wrong answer. The Number Back increases until ten points are reached, although it decreases inversely as the points become zero or fewer. However in the case of 1-Back, it does not change even if the points are zero.

5.1.4. Results

(1) Experimental results

Table 2-1 shows the points acquired by participant A, averaged over all frequency components and averaged for each Back number. Figure 3-1 shows low_γ and $(\theta + \alpha)/10$ for each Back number as a graph. Table 2-2 and Fig. 3-2 show the averages for participant B and the graph in the same way.

Table 2-1. Averages for Participant A.

Participant A	(θ+α)/(10×low_γ)	low_γ	(θ+α)/10
Overall	1.5193138	0.65212	0.757591
1-Back	1.4135361	0.485079	0.646004
2-Back	2.9197914	0.429495	1.029128
3-Back	1.8766496	0.553892	0.737322
4-Back	1.9674237	0.641104	1.07972
5-Back	1.2038010	0.684419	0.656136
4-Back	1.0442079	0.807794	0.670409
5-Back	1.5177073	0.719959	0.595562

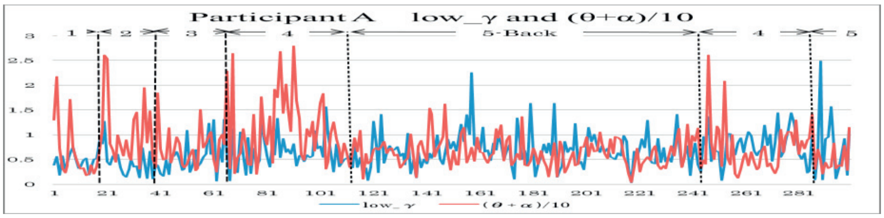

Fig. 3-1. $(\theta + \alpha)$ and low_γ for Participant A.

Table 2-2. Averages for Participant B.

Participant B	(θ+α)/(10×low_γ)	low_γ	(θ+α)/10
Overall	1.238932	0.987621	0.893527
1-Back	1.318315	0.709159	0.542955
2-Back	1.024247	0.990088	0.647465
3-Back	1.501329	1.654015	1.601736
4-Back	1.362321	0.759207	0.847896
5-Back	1.219325	0.662155	0.639523
4-Back	0.906946	1.054167	0.713125
5-Back	1.321904	0.922477	0.91737
4-Back	1.139217	0.825756	0.761471
5-Back	1.219454	1.240233	1.094536

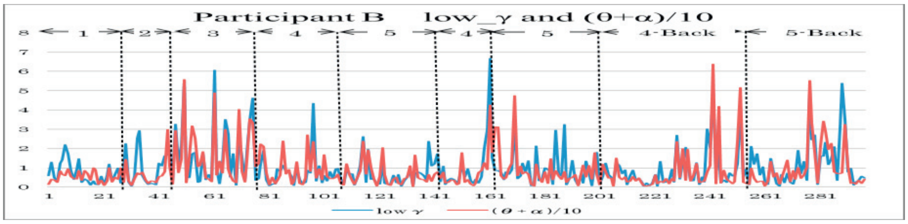

Fig. 3-2. $(\theta + \alpha)$ and low_γ for Participant B.

(2) Analysis and evaluation of results

The experimentally obtained results show the synchronous behaviour of $(\theta + \alpha)/10$ and low_γ. Although $(\theta/10)$ individually synchronizes with low_γ to some extent, $(\theta + \alpha)/10$ overlaps in more parts. Furthermore, we assumed to compute as an index the ratio of two synchronized components $(\theta + \alpha)/(10 * \text{low\_}\gamma)$ by the effectiveness of synchronous behaviour of α and β.

$(\theta + \alpha)/10$ and low_γ can be effective only as indices for comparison to the same participant, because of individual differences in the wavelengths of the electroencephalogram. However, $(\theta + \alpha)/(10 \times \text{low\_}\gamma)$ can be acquired as a normalized value in spite of individual differences in the magnitude of wavelength. Consequently, this method is considered effective for comparison of two or more people.

5.2. Experiment II: Comparison using feedback system

5.2.1. Electroencephalogram data feedback learning system

Functions for analysis and evaluation were added to the electroencephalogram acquisition system used in Experiment I. A system was constructed that gives feedback to a user according to the result. Figure 4 shows a schematic diagram of the feedback system.

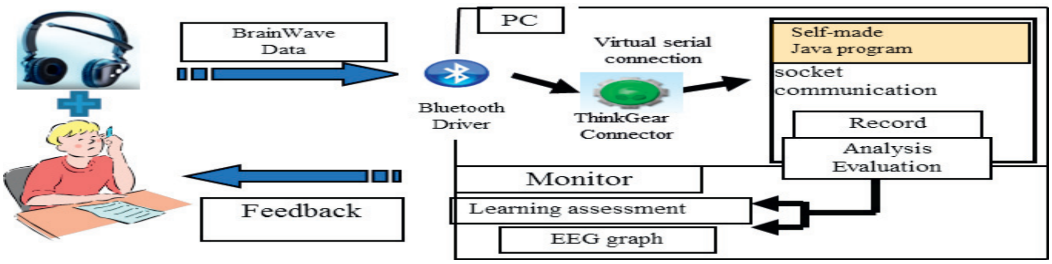

Fig. 4. Schematic diagram of the feedback system.

The averages of data designated for each definite period of time are compared. Then the brain activity intensity is determined and evaluated according to its increase or decrease.
Because a graph is displayed in the same fashion for every definite period of time, a participant's own electroencephalogram state can be comprehended easily.

5.2.2. Experiment Outline

- Participants: Four men in their 20s (university students studying natural sciences)
- Measuring time: until work completion
- Cognitive theme: visual N-Back task (hard)

Components that are regarded as effective are extracted from the result of Experiment I and are used. Cognitive themes are executed in two ways: with or without the evaluation system constructed. Then the results are compared.

5.2.3. Experimental procedure

As a support system, $(\theta + \alpha)/(10 \times low\_\gamma)$ is adopted as an index for presuming the extent of memory according to Experiment I. Its average is taken every 5 s and compared. When the average drops successively, it is judged as memory decline. A direction is displayed to a participant to restart on the screen with a beep. Then the participant suspends cognitive themes immediately, and restarts after refreshing the brain.

Cognitive themes are conducted using a 3 × 3 grid as a visual N-Back task (hard). Differences from Experiment I are the following.
- fixed at 4-Back.
- a square is displayed at an interval of 2.5 s.
- a theme finishes as 50 squares are displayed.
- a participant is to answer only when the positions of a newly displayed square and displayed *n* steps ago are the same.

5.2.4. Results

(1) Experimental results

Table 3 presents the percentage of correct answers with/without support, and the average of $(\theta + \alpha)/(10 \times low\_\gamma)$. Figures 5 indicate average $(\theta + \alpha)/(10 \times low\_\gamma)$ every 5 s with/without support. Whenever an average was acquired, it was compared with that at the last time, whether it decreased or increased was analyzed, and restart was directed. The timing of the restart was noted as R with broken lines in the graph with support. R displayed on the graph without support is denoted as a restart by manual direction.

Table 3-1. Percentage of correct answers and $(\theta + \alpha)/(10 \times low\ \gamma)$ for Participant A.

		Percentage of correct answers	$(\theta + \alpha)/(10 \times low\_\gamma)$
Participant A	without support	35%	1.2119
	with support	63%	1.2370

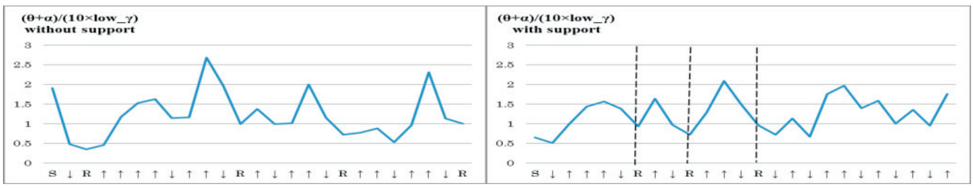

Fig. 5-1. $(\theta + \alpha)/(10 \times low\ \gamma)$ for Participant A.

Table 3-2. Percentage of correct answers and (θ + α)/(10 × low γ) for Participant B.

		Percentage of correct answers	$(\theta + \alpha)/(10 \times low\_\gamma)$
Participant B	without support	42%	1.033339
	with support	54%	1.077722

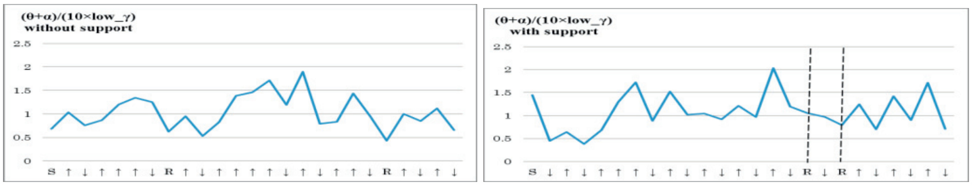

Fig. 5-2. (θ + α)/(10 × low γ) for Participant B.

Table 3-3. Percentage of correct answers and (θ + α)/(10 × low γ) for Participant C.

		Percentage of correct answers	$(\theta + \alpha)/(10 \times low\_\gamma)$
Participant C	without support	38%	1.28728928
	with support	64%	1.82339344

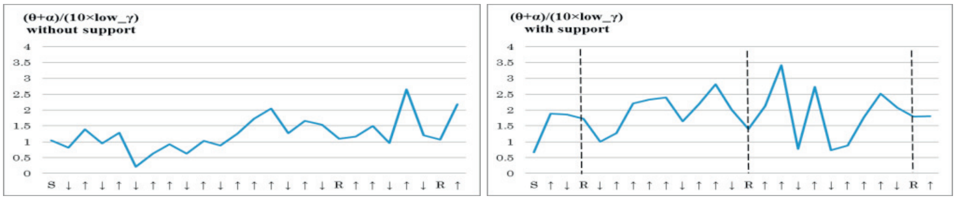

Fig. 5-3. (θ + α)/(10 × low γ) for Participant C.

(2) Analysis and evaluation of results

Comparison of cases with and without a support system revealed a high percentage of correct answers with support. Supported restart tended to raise the average. A questionnaire survey administered after the experiment suggested a state in which a participant's memorizing work could not be followed before and after the direction of restart. As a result, directions of restart were given at a good timing, participants were able to tackle themes efficiently, and the percentage of correct answers was encouraged.

However, one participant achieved exceptionally better results without support. In such cases, the timing of restart was too late, so that the support system was instead harmful.

6. Comprehensive evaluation and discussion

(1) Experiment I verified the synchronized behavior of $(\theta + \alpha)/10$ and low_γ. The effectiveness of the ratio of α and β waves β/α as an index for presuming a learning state suggests that the ratio of synchronized $(\theta + \alpha)/10$ and low_γ might be effective similarly as an index of memorization work. Because a normalized value can be acquired using a ratio from an electroencephalogram with individual differences in the wavelength magnitude, it is considered effective for comparison of two or more people. Consequently, the discussion presented above suggests the effectiveness of $(\theta + \alpha)/(10 \times low\ \gamma)$ as an index for presuming brain activity during memorization work.

(2) Experiment II indicated a higher percentage of correct answers in cases with support. The reply to the questionnaire and restart timing suggest that $(\theta + \alpha)/(10 \times low\ \gamma)$ affects a participant's memory capacity: average $(\theta + \alpha)/(10 \times low\ \gamma)$ increased at restart because the storage area of a participant's brain was initialized and the memory capacity was secured.

Consequently, the discussion presented above verifies the effectiveness of $(\theta + \alpha)/(10 \times \text{low } \gamma)$ as an index for presuming the degree of memory and the usefulness of a feedback support system.

7. Conclusion

This paper presented an investigation of the relation between two wavelengths: low_γ that reacts on memorization work and θ waves that indicate a reaction in a short-term memory domain designated as the working memory. A support system was constructed using the properties. An experimental comparative analysis of correlation was conducted using electroencephalogram data of memorizing work of participants in actual electroencephalogram measurements.

The results revealed the synchronized behaviour of $(\theta + \alpha)/10$ and low_γ. Moreover, experiments using a support system with $(\theta + \alpha)/(10 \times \text{low } \gamma)$ as an index showed improved percentages of correct answers. These findings suggest the effectiveness of $(\theta + \alpha)/(10 \times \text{low } \gamma)$ as an index for presuming the degree of memory, and underscore its usefulness as a feedback support system.

We will test increasing of participant in future. In addition, we will inspect about the reliability of the electroencephalographic sensor about this EEG's device.

Acknowledgement

This study was supported by a grant-in-aid for scientific research No. 24501219.

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