Proceedings of the 17th World Congress
The International Federation of Automatic Control
Seoul, Korea, July 6-11, 2008

Systematic Evaluation of Relaxation Circumstances Based on Bio-neurological Signals

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Abstract: The widespread use of relaxation technique amongst medicine community and sustained work environments makes a more complete understanding of its physiological effects. This research proposes a systematic evaluation for relaxation circumstances, which consists of subjective evidence and objective evidence. Innovative feature of this evaluation system is adding bio-neurological signals to support previous findings about relaxation circumstances. A work-rest schedule containing mental calculation and music relaxation is specially designed to reflect effect of prolonged cognitive work and relaxation in mental work environments. The results indicate that short period of music relaxation in sustained mental work is effective to counteract the accumulation of mental fatigue and improve work efficiency. This systematic evaluation method can be widely applicable, in medical fields, working environments and daily life for the purpose of prediction, detection and evaluation of human states.

1. INTRODUCTION

Relaxation is widely used to treat a variety of health problems, including hypertension, headaches, anxiety and insomnia. Besides the use amongst patient populations and medical community, relaxation technique can be applied into a variety of work environments. Regular relaxation breaks seem to be an effective way to control accumulation of accident risk in industrial manufactories (Tucker, 2003). Work-rest schedule including suitable relaxation factors and timing has widespread applications in shift work systems (Folkard, 2003, 2005).

In order to testify the effectiveness of relaxation technique, various kinds of methods such as questionnaire investigations (Milosevic, 1997), behaviour evidence (Dinges, 1995), bio-neurological signals (Gevins, 1990; Okogbaa et al., 1994; Boksem, 2005), psychological and biochemical measurements have been applied. However, previous literature has not provided a systematic evaluation for mental fatigue and relaxation circumstances. To maintain scientific validity, only subjective evidence or only objective evidence is not enough.

In this research, an integrated design and evaluation system based on the relationship between subjective and objective evidence has been proposed, which may improve the validity and reliability of research on relaxation circumstances. The paralleling analysis from subjective evaluation, behaviour performance and bio-neurological signals are used to testify the effectiveness of a short break of music relaxation (e.g. 15 minutes per hour) in sustained mental environments. This integrated system has widespread application in detection and evaluation of human mental states.

2. METHODS

2.1 Systematic Evaluation for Relaxation Circumstances

2.1.1 Integrated Design and Evaluation System

In order to give a systematic evaluation of mental fatigue and relaxation circumstances, an integrated design and evaluation system is created as shown in Fig. 1. This system consists of three components: subjects, inputs, and outputs. Subjects are the centre of this system. Inputs are the experiment tasks assigned to subjects, which comprise mental calculating task and music relaxation. Outputs are the evidence obtained from subjects, which include subjective evidence and objective evidence. Subjective evidence is self evaluation about subjective feelings, which is drawn as visual analogue scale (VAS). Objective evidence contains calculating performance and EEG signals.

2.1.2 Subjects Selection and Experiment Environments

Eight healthy male students, aged 22-25 years old, were recruited from Saga University of Japan. All the subjects were instructed to abstain from alcohol and caffeine 24 hours before experiments. Subjects were settled in a dimly lit, sound-attenuated, electrically shield room. Each experiment started at 10:00 a.m.. The room temperature was 24~26℃. Before each experiment, subjects had been trained once in order to be familiar with the experiment environments and task operation.

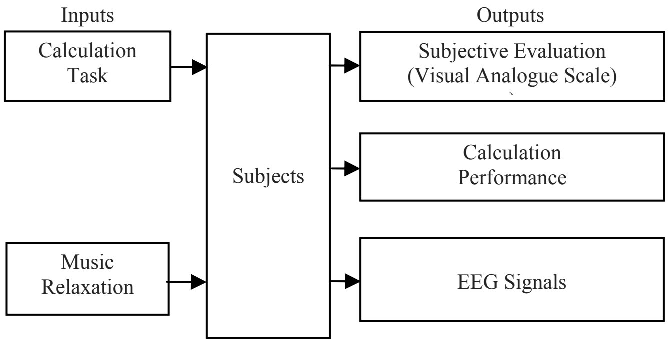


Fig. 1. Integrated design and evaluation system for relaxation circumstances

2.1.3 Inputs – Experiment Tasks

(1) Calculation task:

The calculating task is shown on a 17" PC monitor. The content of mental arithmetic is 0~99 two-digit integer addition. This calculation task is self-paced.

(2) Music relaxation:

Subjects are instructed to enjoy music with an earphone. The music is Mozart Eine Kleine Nachtmusik (Hughes 2001).

2.1.4 Outputs – Evidence Obtained from Subjects

(1) Visual analogue scale (VAS):

Subjects receive inquiry sheets about the level of subjective feelings. Subjects respond to this inquiry sheet by drawing visual analogue scale (VAS) with a minimum score of zero and a maximum score of 100. The level of subjective tiredness is descried as the following: 0 – energetic, 50 - normal situation, 100 - exhausted. The level of vigilance is descried as the following: 0 – sleepy, 50 - normal situation, 100 – vivid.

(2) Calculating performance:

During calculation task, calculating performance is recorded automatically. A real-time report for calculating performance is presented on computer monitor, which reports reaction time for each answer, total accomplish answers, correct answers, miss answers and false answers.

(3) Bio-neurological signals:

Electroencephalogram (EEG) signals are recorded simultaneously throughout the experiment. EEG signals are recorded using Ag/AgCl electrodes. The electrical impedance is under 10kOhms for all electrodes. Electrodes are placed according to the international 10–20 system and put at the following areas: Fp1, Fp2, F3, F4, Fz, Cz, O1, and O2 against ipsilateral earlobe electrode (A1 or A2). EEG signals are amplified by a digital EEG machine (Nihon-Koden EEG2110) with the sampling frequency of 200 Hz, a low-frequency cut-off of 0.5Hz, and a high-frequency cut-off of 30Hz. The record data are stored by segments. Each segment contains 1024 samples (5.12s).

2.2 Experiment Paradigm

In order to let subjects experience mental fatigue and relaxation, a work-rest schedule including mental calculating task and music relaxation is specially designed. This work-rest schedule consists of four sequential sections arranging as follows:

● Section 1: Normal state before experiment task (It lasts 5 minutes)

● Section 2: Calculation task 1 (It lasts for 120 minutes and divides into four stages. Each stage lasts for 30 minutes)

● Section 3: Music relax (It lasts for 15 minutes)

● Section 4: Calculation task 2 (It lasts for 30 minutes)

VAS is drawn down at four states: normal state, after calculation task 1, after music relaxation, and after calculation task 2.

2.3 EEG Signals Analysis

2.3.1 Visual Inspection of EEG Raw Data

During the experiment, there is no restriction for eye open or closure under music relaxation circumstances in order to reach a free relaxation state. The first step for EEG analysis is visual inspection of EEG raw data. In music relaxation section, the segments containing dominant alpha rhythm and with the maximum amplitude at the occipital regions are picked out as typical eye-closed wakeful music relaxation state and used for further analysis.

2.3.2 EEG Spectral Parameters

EEG amplitude is calculated in frequency bands. Artifacts caused by the movement of eyelids and eyeballs can be seen in frontal and central regions. Only the EEG signals derived from the occipital region are not contaminated. Previous fatigue and relaxation literature abounds with theta, alpha and beta activities (Kakizaki, 1985; Jacobs, 2004). Therefore, theta (4-8 Hz), alpha (8-13 Hz) and beta (13-25 Hz) activities in occipital region are analyzed in the current research. EEG amplitude A_z (x) is calculated by using (1), (Nakamura M. et al. 2005)

$$A_z(x) = 6\sqrt{S_z(x)}(\mu V), \qquad (1)$$

where x represents each channel; z denotes the respective EEG frequency bands. $S_z(x)$ is the amount of EEG components calculated by the summation of periodogram with the frequency band of z in channel x.

2.3.3 Percentage Increase of EEG Amplitude

To quantify the percentage increase of EEG amplitude over normal state, ratio is taken by using (2),

$$\text{Variation Ratio} = (A - A_{normal}) / A_{normal} \times 100\%, \qquad (2)$$

where A denotes average amplitude in each experimental section, A_{normal} denotes average amplitude under normal state.

3. RESULTS

With the assistance of this integrated design and evaluation system, the progressive mental fatigue and the effectiveness of music relaxation has been systematically analyzed by means of VAS, calculating performance and EEG spectral analysis. Besides, relationship between subjective evidence and objective evidence has been analyzed to explore the correlation among these estimators.

3.1 Visual Analogue Scare (VAS)

Subjective tiredness level and vigilance level were found highly related with effect of time. The mean value and standard derivation of tiredness level and vigilance level are illustrated in Fig. 2 (a) and (b).

After calculation task 1, significant increased tiredness level was shown. The effectiveness of music relaxation can be reflected by comparing the value after calculation task 1 and after calculation task 2. After calculation task 2, alleviated tiredness level and improved vigilance level were reflected.

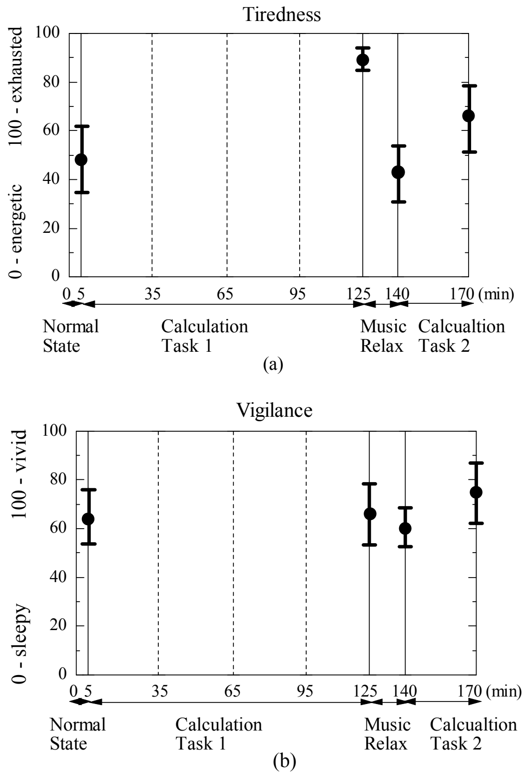


Fig. 2. VAS at four states: normal states, after calculation task 1, after music relaxation and after calculation task 2. (a) Mean tiredness level and standard derivation. (b) Mean vigilance level and standard derivation.

3.2 Calculating Performance

Reaction time and correct answers number were found highly related with effect of time. The variation of reaction time and correct answers each half an hour during calculation tasks were illustrated in Fig. 3.

During calculation task 1, gradually increasing reaction time and decreasing correct answers were recorded. The effectiveness of music relaxation can be reflected by comparing the record in calculation task 1 and calculation task 2. In calculation task 2, shorter reaction time and larger correct answers were recorded compared with the value in the last half an hour in calculation task 1.

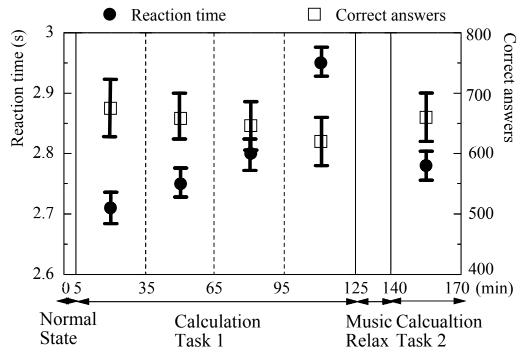
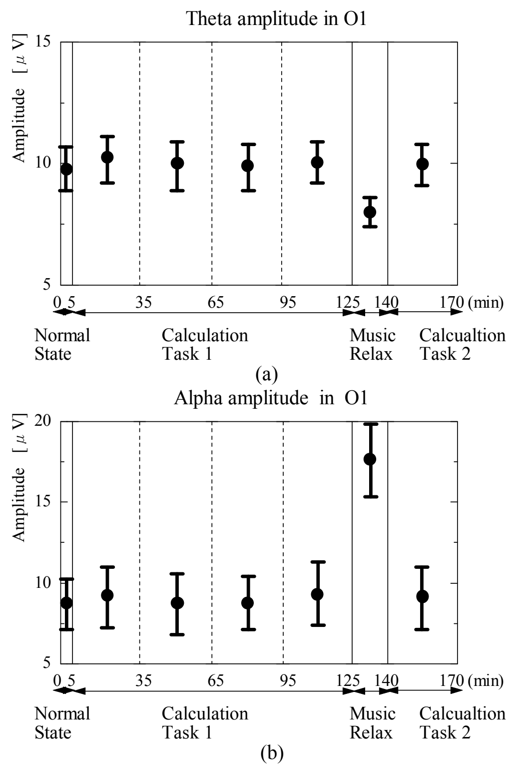
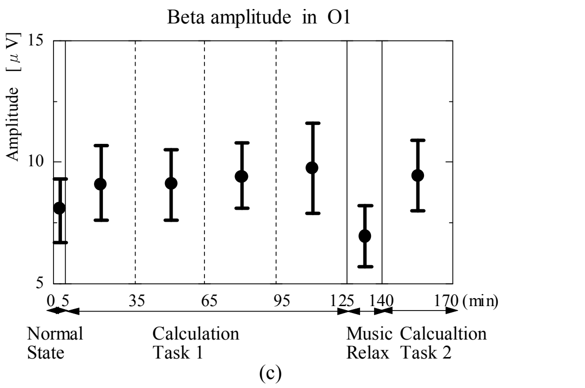


Fig. 3. Calculation performance each half an hour. Mean reaction time, mean correct answers and their standard derivations are illustrated.

3.3 EEG Signals Analysis

Besides the variation of subjective evaluation and calculation performance, the change of occipital EEG frequency components was illustrated in Fig. 4. Clear decrease of theta wave, increase of alpha wave and decrease of beta wave in occipital region were observed under eye-closed wakeful music relaxation state.





(c)

Fig. 4. Mean O1 EEG amplitude and standard derivations. (a) Theta rhythm (4-8Hz), (b) Alpha rhythm (8-13Hz), and (c) Beta rhythm (13-25Hz).

3.4 *Relationship between Subjective Evidence and Objective Evidence*

The analysis above has shown the evidence from VAS, calculating performance and EEG spectral analysis respectively. The following shows the relationship among subjective evidence and objective evidence.

The relationship between subjective tiredness level and percentage increase of O1 EEG amplitude over normal state (%O1EEG) is illustrated in Fig. 5. The subjective tiredness level increased following this order: music relaxation state, calculation task 2 and the last stage of calculation task 1. Tiredness level was positively correlated with %O1EEG. Correlation coefficient with %O1beta was 0.91. Correlation coefficient with %O1theta was 0.68. It suggests %O1EEG can be good indicators for evaluation of subjective tiredness level.

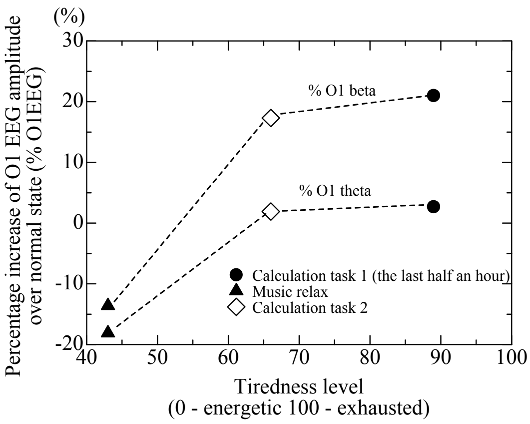


Fig. 5. Relationship between subjective tiredness level and percentage increase of O1 EEG amplitude over normal state (%O1EEG).

The relationship between reaction time and percentage increase of O1 beta amplitude over normal state (%O1beta) is shown in Fig. 6. Each marker shows the average value each half an hour. During calculation task 1 (5-125 min), gradually increasing reaction time was accompanied with gradually increasing %O1beta. The correlation coefficient between reaction time and %O1beta during 5-125 min was 0.98. In calculation task 2 (140-170 min), smaller %O1beta was accompanied with shorter reaction time.

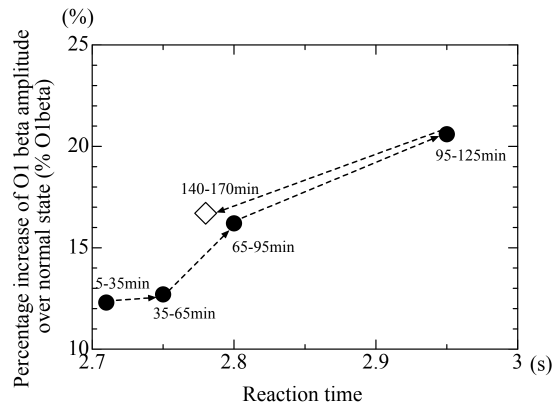


Fig. 6. Relationship between reaction time and percentage increase of O1 beta amplitude over normal state (%O1beta).

4. DISCUSSIONS

4.1 *Merits of Systematic Evaluation Method*

The objective of this research is to give systematic evaluation for mental fatigue and relaxation by using subjective evidence, behaviour evidence and bio-neurological findings.

Previous literature used large database from industry manufactories and shift work system to testify the effectiveness of regular breaks in sustained activities. (Tucker, 2003; Folkard, 2003, 2005). The previous research was based on a large database and was convincing. However, the evidence was only subjective questionnaires or accident record. To give a comprehensive interpretation about mental fatigue and relaxation technique, an integrated design and evaluation system is proposed in this research.

This systematic research shows some merits compared with previous research. First, more objective evidences are accompanied with subjective evidences for verification of human state. Bio-neurophysiology measure is used to provide physical interpretation, which is central to human fatigue and relaxation state. Second, moment-to-moment evaluation is realized because calculating performance and bio-neurological signals are recorded simultaneously throughout the experiments. Third, not only respective characteristics of each estimator but also correlation among subjective and objective estimators are explored. Correlation analysis is important to explore underlying relationship among subjective feelings, behaviour performance and bio-neurological mechanisms. With assistant of this integrated evaluation system, consistent evidences from subjective measures and objective measures provide rich information about mental fatigue and relaxation circumstance.

Such integrated system has widespread applications in research of human state. Three components (inputs, subjects and outputs) of the system can be defined variably depending on research objective. More estimators such as psychological evidence and biochemical measures can be additive outputs of this system.

4.2 *Bio-neurological Characteristics of Mental Fatigue and Relaxation State*

In this integrated system, the variation of EEG signals parallels the change of subjective evaluation and calculating performance. While numerous physiological indicators are available to measure level of alertness, EEG signals may be one of the most predictive and reliable (Makeig et al., 1993, 1995). Relaxation technique is related to acute changes in alpha and theta activity. (Delmonte, 1984; Jacobs, 2004). EEG amplitude is sensitive to workload and work difficulty. EEG variation especially occipital beta wave is highly related to workload and mental fatigue. (Kakizaki, 1984).

In this research, decrease of theta wave, increase of alpha wave and decrease of beta wave in occipital region are observed under eye-closed music relaxation state, which is highly related to comfortable and wakeful relaxation feelings.

The percentage variation of O1 EEG is found highly related with subjective feelings and calculation performance, which can be viewed as good indicators for human fatigue and relaxation state.

4.3 Effectiveness of Music Relaxation Circumstances in Sustained Mental Work

The effectiveness of music relaxation circumstances can be seen from subjective measures and objective measures. First, music relaxation relates with a comfortable subjective evaluation. After music relaxation, subjects reflect that they can use less effort to maintain attention and keep an alert cognitive state. Second, music relaxation leads to shorter reaction time and higher correct rate. After music relaxation, subjects reflect quicker response and more efficient calculation performance. Furthermore, music relaxation in eye-closure states causes clear alpha dominance in occipital region. EEG analysis supplies bio-neurological evidence for effectiveness of music relaxation.

Subjective evidence and objective evidence testify the effectiveness of short period of music relaxation in sustained mental work. Music relaxation can be practically applied into work environments to alleviate mental fatigue and improve work efficiency.

5. CONCLUSIONS

Relaxation technique has widespread application amongst both patient and normal populations. Relaxation circumstances can be practically applied into variety of work environments in order to reduce impact of workload and improve work satisfaction. The integrated design and evaluation system proposed in this research provides comprehensive evaluation for relaxation based on the relationship of subjective evidence and objective evidence. With assistance of this systematic evaluation, the effectiveness of short period of music relaxation in a work-rest schedule has been testified. This evaluation system is very flexible and expandable depending on research objective and experiments requirements. The concept of this integrated system can be widely applicable into the predication, detection and evaluation of human state.

ACKNOWLEDGMENT

The authors would like to express gratitude to H. Hatazaki from Laboratory, Kyushu Electric Power Co., Inc. for meaningful discussion about the necessity of relaxation in control halls of power station. This research is supported by Nation Nature Science Foundation of China 60543005, 60674089; and Shanghai Leading Academic Discipline Project, B504

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