Self-Identification of Mentality and Self-Control through Indirect Biofeedback

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ABSTRACT

This paper describes a possibility of a new scheme for a user with mental health problems so that the user can identify his/her own mentality and self-control it not by visiting specialists passively as usual but by proactively confronting his/her symptoms. For that purpose, the scheme should provide the user with functions not only to externalize and objectify the user's mental state but also for the user itself to self-control the mental state. Here, we propose an indirect biofeedback system which represents a user's mental state with color and shape, and enables the user to grasp his/her mental state and to proactively change and control it through methods of breathing.

KEYWORDS

Indirect biofeedback, heartbeat, autonomic nervous system, breathing, mental disease

1 INTRODUCTION

The number of patients with stress and mental problems has been gradually increasing in Japan. On the other hand, however, there is a fact in reality that the situation could not have been improved even if such patients have consultation with a specialist like psychiatry and psychosomatic medicine.

What should the patient do by him/herself for a complete recovery from mental disease? We speculate that if visiting and consulting psychotherapist is a merely passive experience, the treatment would not be very effective [1]. In contrast, we think that pursuing the patient to approach the symptoms of the disease in a voluntary and proactive way is one of the most important factors for the success of treatment.

The first step towards achieving a proactive behavior of patient is allowing him/her to be self-aware of his/her current mental condition. Based on the recognition of this condition, the patient would act appropriately to maintain his/her self-control [2]. That is, a device or mechanism must be needed to externalize the internal state of the self, and to keep a sense of unity between the entity externalized and him/herself.

In this research, we propose an indirect biofeedback system that helps the patient to be self-aware of his/her current mental condition by monitoring an object with visual features that vary according to the patient's heart rate [3]. That is, the object with visual features is the entity which not only externalizes the mental state of the self but also keeps a sense of unity with the self. Also we investigate how effectively we could control our mental condition through the ways of breathing such as abdominal and costal for self-controlling.

Eventually we would like to clarify a possibility for us to identify our mental state and to control it through the ways of breathing casually and easily.

2 BIOFEEDBACK FOR IDENTIFYING THE SELF AND SELF-CONTROL

In this research, we are aiming to provide a system through which ordinary users can use to identify their mental state and control the self easily and on a daily basis. For that purpose, we propose an indirect feedback which enables users to understand their inner state intuitively with a user friendly representation of physiological data.

2.1 Concept

It has been already reported that the autonomic nervous system (ANS) can be controlled by biofeedback to some extent. Concretely, the report says that a user's physiological functions could be improved for the expected direction such as decrease of anxiety symptom and of physical disorder through biofeedback disciplines [4].

Most of such biofeedback systems are used at medical institutions as a medical treatment

which should be executed under a medical doctor's supervision. It is quite usual that acquired physiological data are represented numerically and/or with waveforms. That is to say, those systems are not originally supposed to be used by ordinary users on a daily basis.

In this research, we are aiming to provide a system through which ordinary users can use to identify their mental state and control the self easily and on a daily basis. For that purpose, we propose an indirect feedback which enables users to understand their inner state intuitively with a user friendly representation of physiological data.

In addition, in this research, we employ way of breathing as way of self-controlling the inner state, since it is well known that we can control our ANS only by way of breathing [5].

2.2 Acquisition of information on Balance of Autonomic Nervous System from Heartbeat Fluctuation

In this research, we estimate the balance of the autonomic nervous system (ANS) from the frequency analysis of heartbeat fluctuation. Heartbeat fluctuation can be measured simply and non-invasively, and the frequency analysis of heartbeat fluctuation tells us some index of the stress of heart ANS. It is well known that heartbeat can be changed by regulatory control of nervous and endocrine systems as well as physical position and movement [6].

The autonomic nervous system (ANS) works autonomously and is automatically regulate, so we cannot control it intentionally, different from the motor nerve which we can control intentionally. ANS consists of the sympathetic nervous system (SNS) and the parasympathetic nervous system (PNS). SNS mainly works for activating and tensing the body, for example, when we have sweaty palms and a racing heart. The activation of SNS constricts blood vessel and increases heartbeats. As a result, blood pressure goes up, and then blood flow to peripheral organisms is increased. On the other hand, PNS works for activating internal organs, and for giving the body a rest.

If ANS gets imbalanced, it causes unpleasant symptoms such as high heartbeats even in resting, having poor digestion, feeling hot all of sudden, and so on. Also, in some cases in which stress to the body is over the limit, the balance on ANS and hormonal system are sometimes badly affected, and then such imbalance causes unpleasant symptoms above-mentioned, and then the unpleasant symptoms promotes anxiety and stress more, and eventually the symptoms get worse in a vicious circle. Pilling up of even a tiny cause sometimes results in big stress.

ANS should be originally a mechanism to well regulate our body and mind, however, ANS happens to be related to unpleasant symptoms such as pains and anxiety. So, it should be expected that we can relax ANS intentionally by getting rid of stress through methods for relaxation and biofeedback.

In this research, we focus on the above-mentioned fact that we can keep our body and mind in good situations by intentionally controlling ANS and by recovering the good balance of ANS [7]. The following knowledge concerning relationship between ANS and heartbeat fluctuation should be available:

- The low frequency (LF) of heartbeat fluctuation is observed when both the sympathetic nervous system (SNS) and the parasympathetic nervous system (PNS) are activated
- The high frequency (HF) of heartbeat fluctuation is observed when PNS is superior to SNS, and it reflects breath fluctuation.

Based on such knowledge, we calculate LF and HF of heartbeat fluctuation and LF/HF (divide the LF in HF). And we measure L/H ($\log_{10}$L/H) as indexes to know the balance of ANS. Here, we set LF : 0.04～0.15Hz and HF : 0.15～0.4Hz. The concrete procedures to get L/H, and to use them are as follow [8]:

1) To get LF and HF as power spectrum through frequency analysis of heartbeat concerning the minimum, maximum and mean of RRI (RR Interval) of heartbeat fluctuation and their changes
2) HF can be observed when PNS is superior

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to SNS, so we use the value of HF as the degree of PNS activation.

3) LF can be observed both SNS and PNS are active, so we divide the LF in HF (L/H).
4) We use L/H (log10L/H) as the degree of ANS activation, i.e., the degree of stress.

2.3 Indirect Biofeedback

In this research, we get physiological information with a heartbeat sensor pasted on a user's chest, and use its fluctuation for biofeedback. And then, we analyze the heartbeat fluctuation, calculate the balance of ANS with SNS and PNS, and represent its situation with changes of color and shape of a circle.

The reasons why we do not employ numerical feedback directly but feedback the change of color and shape of a circle are to provide a user with user-friendly representation which the user can easily perceive, understand and feel a sense of unity with, and to avoid negative feedback caused by unfamiliar numerical flow-based representation which sometimes displays drastic changes and might give negative feeling to the user. Here is ideas on its design:

- The 3 kinds of colors are prepared for the circle; red shows active situations with SNS superiority, green shows mood-stabilizing situations, and blue shows depressive situations with PNS superiority
- The shape of circumference of the circle can be changed by the switching rate of superiority of SNS and PNS in heartbeat fluctuation
- If the switching rate is high, it means that the user's mental condition is not stable. And at such time, the shape of circumference of the circle becomes distorted largely.

Fig. 1 shows the example of indirect biofeedback representation which we propose here.

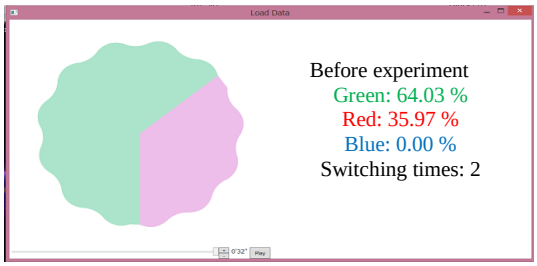

Fig.1: Example of Indirect biofeedback Representation

2.4 Related Works

The term of feedback is originally a concept coined in the research field of Cybernetics, and it means that the output of a system is gone back to the system in order to modify the output. Such mechanism is indispensable for a system to automatically control system itself. That is, in a broad sense, feedback is a method to control a system, i.e. a machine or human, by re-inputting the result of past performance of the system.

The first step to control the self, in the case of human, is to intend to be in desirable mental state for the self, and the second step is to change its intension into self-confidence by using response of body and mind. When biological, psychological and/or physiological responses which appear in relaxation practices are fed back to a client, if the client can perceive them as external stimuli, those feedback result in effective influence on the client's body and mind.

The term of biofeedback is used in the cases where some device or equipment such as electroencephalograph, electrocardiograph, galvanic skin reflex, blood-pressure gage, and electromyography is used for measuring bodily and mental responses and for displaying them as numerical data to a user. So, it is important for a user to properly grasp his/her mental state in biofeedback so that the user can be aware of when and in what situation he/she feels stress or relaxed.

The biofeedback as a method is a way for a user to create relaxation by him/herself, so one of its advantages is that the user can get used to do so in a daily basis and then can get relaxed even in any environment. For example, the biofeedback method is now widely used as a method of mental training for sport professionals, and also used for medical

mental care in U.S.A. where the effect of biofeedback is highly appreciated. In addition to the fields of sports and mental care, the method can be available for human's mental activities such as capability development, self-fulfillment, goal achievement, and so on.

Autonomic nervous system is important to maintain vital homeostasis, and respiratory sinus arrhythmia (RSA) is known as a selective index of cardiac vagal activity. Kotani's team researched into evaluation of errors in the amplitude of RSA, and proposed a method to reduce them. They applied the proposed method for the real-time CG interaction and tested whether it could extract the amplitude of RSA in real-time. They found that an elastic chest band is suitable under resting conditions, and that the Berger's interpolation method was the best for detecting instantaneous heartbeat intervals in real-time signal processing [9].

As one of studies regarding relationship between biofeedback and breathing, there is a research aiming to investigate effectiveness of biofeedback on breathing exercise as a mental support for elite athletes [10]. Four Japanese national team members participated in mental training to acquire breathing techniques as one of the relaxation skills. Stress Eraser manufactured by Helicor Inc, a small real-time biofeedback device, was used to visualize the transition of dominant points of PNS during the training. As the result, 3 out of 4 athletes consistently improved their dominant points of PNS, even if it was the first time for them to have this training. It means that monitoring the progress with real-time feedback was useful for them to master the adequate breathing such as its rhythm and length. The athletes' reflections were also recorded over the course of 10 sessions. It showed that they all realized the advantage of using real-time biofeedback while acquiring a breathing skill during mental training. These outcomes suggest that real-time biofeedback should be a very powerful tool for mental control support for both athletes and consultants.

While biofeedback as a method is highly appreciated and expected, existing biofeedback systems have displayed biological information measured by some device or equipment as numerical data and/or waveform image to a user. In general, it is quite difficult for an ordinary user to properly understand the meaning of changes of such numerical data and/or waveform image, and this should be a problem in the second step of changing the user's intension into self-confidence to control the self. There happens to be a possibility to induce the user's too sensitive and negative response and then to result in opposite effect.

Thus, in this research, we have introduced indirect biofeedback so as to keep a sense of unity between an entity which externalizes the internal state of the self, and the user him/herself. Concerning how to keep a sense of unity between the entity and the user, you may assume that the circle itself represents the user him/herself as a system, the color coding inside the circle represents the balance between the sympathetic nervous system (SNS) and the parasympathetic nervous system (PNS) of the user's internal state, and the change of circumference which is a sort of boarder between the self and others represents whether the user's mental state is stable or not.

We think that biofeedback in representation should be simple and easily understandable especially for mental patients, because some of them who have chemotherapy sometimes suffer cognitive dysfunction related to the ability to think, reason, concentrate, or remember. The proposed system models user's own mental state with the balance between SNS and PNS in ANS, and represents it as color distribution within a simple circle. We expect that users can see their mental state with such the simple representation, and try to self-control it through breathing so that the balance between SNS and PNS could become good and improved by using the proposed system. In this research, we would like to clarify a possibility for a user to how easily and casually identify user's mental state and to self-control it through breathing.

3 INDIRECT BIOFEEDBACK

3.1 Indirect Biofeedback System

Fig.2 shows the configuration of the proposed system in this research.

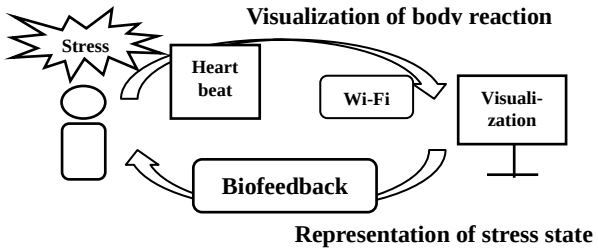

Fig.2 System Configuration

The change of L/H calculated based on heartbeat fluctuation is mapped to the change of color and shape of the circle. And the system displays the change of color and shape of the circle to a user.

- The analysis algorithm of L/H

In mapping the index of L/H on the color of red, green, and blue, we conducted preliminary experiments, and then determined the following mapping rules;

- Red: L/H>+0.4
- Green: -0.4 <=L/H<=+0.4
- Blue: L/H<-0.4

When the value of L/H is zero, it means that the superiority between the sympathetic nervous system (SNS) and the parasympathetic nervous system (PNS) in the autonomic nervous system (ANS) is switched. When the number of switching times increases, the shape of the circle goes distorted. To calculate the L/H from RRI of the heartbeat, the following process and calculation should be needed.

RRI data => Abnormal value removal => Spline interpolation => Direct-current ingredient removal => Window function it buries => 0. => FFT => LF, HF=>L/H

3.2 Display Method of Indirect Biofeedback

Fig. 3 shows the indirect biofeedback system result. How to view the result is as follows;

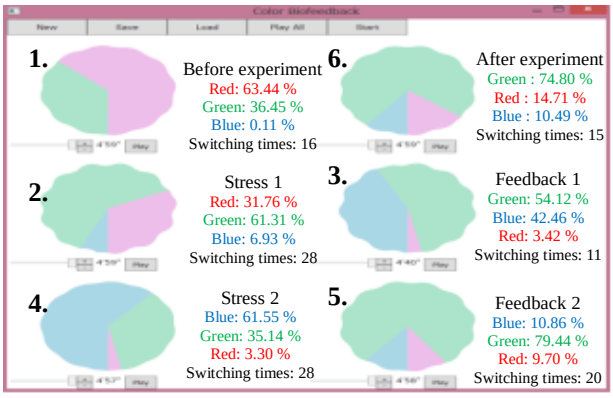

Fig.3 Indirect Biofeedback System Result

The therapeutic result of normal times measured at the first and last time is arranged in a row. It was arranged easy to see in comparison.

4 EXPERIMENTS

In our research, in our research, in order to verify the feasibility of the proposed self-identification and self-control, we conducted experiments with 16 subjects.

Then we calculated RRI of these subjects and inferred the possibility of being under mental stress again.

The detailed explanation of the experimental procedures is as follows:

- Types of Stress:
  *1 : The subject is recalls an unpleasant past experience,
  *2 : The subject iteratively calculates the results of the subtraction of $N_{i+1}:=N_i-7$ ($N_0=1111$) for 5 minutes.
- Control method:
  A : Abdominal breathing, and
  B : Thoracic breathing.

Thus, for different amount of stress and different method of control, we conducted four patterns of experiments.

- patterns of experiments
  Pattern #1: *1→A→*2→B,
  Pattern #2: *1→B→*2→A,
  Pattern #3: *2→A→*1→B, and
  Pattern #4: *2→B→*1→A.

- The experimental procedure:

1) Measuring the hearth rate in normal condition of the subject,
2) The subject identifies his (or her) own mental state by means of using the proposed software system,
3) The subject is influenced by either *1 or *2 of above described types of mental stresses.
4) After identifying his (or her) own mental state by means of using the proposed software system, the subject applies either A or B of the above mentioned stress control methods.
5) Repeating Steps 3)〜5) two times. During the second iteration, both the stress type and the control method alternate,
6) Finally, the subject is allowed to return to his (or her) normal condition.
7) Calculating the difference (if any) between the initial (Step 1) and final (Step 6) normal conditions of the subject.

Each of the above mentioned 4 patterns of the experiment is conducted with 4 subjects, respectively. Therefore, total number of subjects participating is all 4 patterns of experiments, is 16.

4.2 Experimental Results

After conducting the experiment, the subjects were asked to answer questionnaires.

4.2.1 Subjective evaluation

By analyzing the answers in questionnaires, provided by subjects who participated in the experiments, we evaluated the amount of tiredness and relaxation, respectively, as shown in Fig. 4 and 5. The red bars represent the amount of tiredness, while the blue bars show the amount of relaxation.

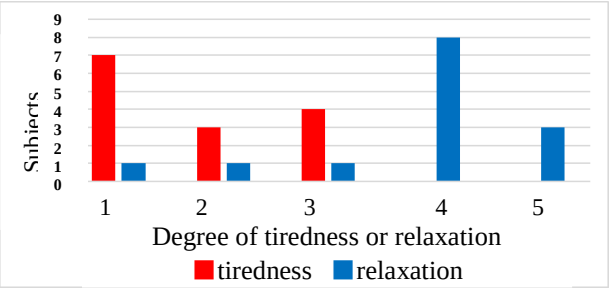

Fig.4 Amount of tiredness *before* experiments (normal condition of subjects)

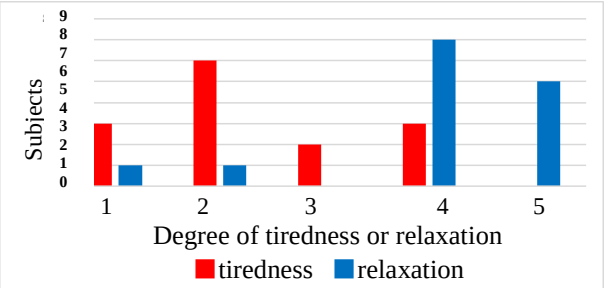

Fig.5 Amount of tiredness *after* the experiments (normal condition of subjects)

As Fig. 4 and 5 indicate, the degree of both tiredness and relaxation increases as a result of the conducted experiments. The opinions of the subjects, as expressed in the questionnaire, are shown below:

- **Could you relax (compared to the stressed condition) by applying the self-control methods (breathing)?**
  - I was too conscious about breathing,
  - As a result of breathing, I was able to relax,
  - As a result of breathing, I was able to feel easy.
- **Did the representation of biofeedback as circular graph influence your mental state?**
  - I felt anxious if the green (good) area of the graph did not increase.
- **Compared to the relaxation by breathing only, does an additional use the proposed biofeedback system allow to relax even better?**
  - I was able to relax,
  - I was able to confirm my relaxation by observing the circular graph visualized by the proposed system.

4.2.2 Objective evaluation

Fig. 6 shows the experimental result, obtained from the experimental patterns #2. The blue bars illustrate the parasympathetic dominance, the green ones – the balance between the sympathetic and parasympathetic, and red bars indicate the sympathetic dominance, respectively.

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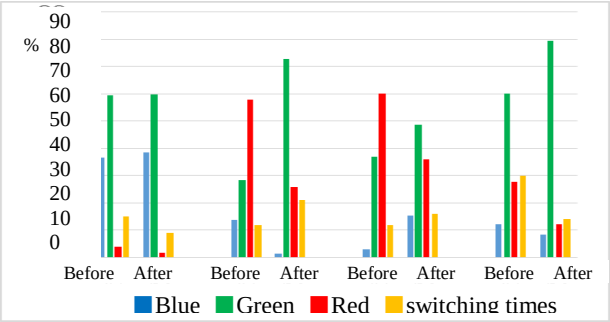

Fig.6 Results of experiments of pattern #2

The reason for relaxation of the subjects is that after being affected by recalling an unpleasant past experience, they did abdominal breathing, which, in turn, promotes an excitement. Then, after conducting calculations, the subjects relaxed as a result of the following thoracic breathing.

In addition, the comparison between the relative size of green (good) circle after and before the experiment indicates a result of T-test, as illustrated in Fig. 7 below.

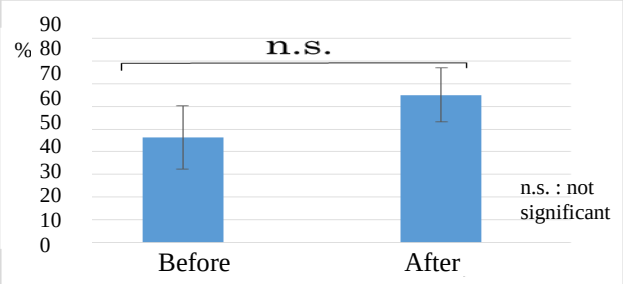

Fig.7 T-test Results of the Experiment
(i.e. Relative size of the green area)

As shown in Fig. 7, since it was p> 0.1 in p=0.136, the experimental result of this time was UN-more significant than the result of the T-test of the pattern #2.

From the presented experimental data we could conclude that choosing the recalling unpleasant past experience as a first method for stress load contributes to the increased tiredness of the subjects. Conversely, choosing arithmetical calculations as a first stress-inducing method facilitates a reduction of the amount of their stress.

Selecting recalling unpleasant past experience and arithmetical calculations as the first and second stress-inducing method, respectively, is associated with the sympathetic dominance. However, reversing the order of these two stress-inducing methods is associated with the parasympathetic dominance.

The final mental state of subjects (either tired or relaxed) depends on the sequence of both stress-inducing and stress-controlling methods.

Because the subject that participated in our experiments were mentally very healthy, achieving a good level of self-control was relatively easy. In addition, even if the subjects were initially stressed, their stress reduced quickly and to very low levels as a result of the exercised self-control.

According to the results of subjective evaluation (via questionnaire), some subjects said to be able to relax by using the proposed biofeedback system. On the other hand, the results of objective evaluation indicate that there were no significant differences in the mental states of subjects before and after the experiments.

In this research, objective experimental results in this research did not become better state. But subjects felt relaxed. So it is a possibility that the proposed system causes a Placebo effect. Placebo effect in this research is to feel relaxed by the system regardless to objective experimental results.

5 DISCUSSION

In this research, objective experimental results did not indicate an improvement of the subject's mental state. However, the subjects felt relaxed. We think the discrepancy between the subjective and objective results indicates that the proposed system causes a Placebo effect. Placebo effect in this research is to feel relaxed by the system regardless to objective experimental results.

Some of the subjects wanted to see the balance of mental state with a graph rather than circle. Some of the subjects seemed to be too sensitive to be relaxed. Depending on a user's background, the system should provide a user with option selection on displaying the balance.

As for the method of controlling the self,

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we employed 2 ways of breathing this time. Since it depends on an individual which is superior the sympathetic nervous system (SNS) or the parasympathetic nervous system (PNS) depending on situations, we should seek for a possibility to provide a user with a much suitable method of controlling the self.

6 CONCLUSION

In this research, we have proposed an indirect biofeedback system. This system enables not only to externalize and objectify the user's mental state but also for the user itself to self-control the mental state.

The indirect biofeedback which we have introduced here is to keep a sense of unity between an entity which externalizes the internal state of the self, and the user him/herself. For that purpose, we designed the system so that the circle itself represents the user him/herself.

We conducted 4 type subject experiments which have 2 different loads of stress and 2 different ways of breathing. And we evaluated the measured data as well as the questionnaire result carried out after the experiments. This would indicate that the subject could well control their mental states after the loads of stress, since they are healthy. This would indicate that the subject could well control their mental states after the loads of stress, since they are healthy.

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