Self-Identification of Mental State and Self-Control Through Indirect Biofeedback

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Abstract

This paper describes a possible new scheme for a user with mental health problems to identify his/her own mental state and control it. For that purpose, we propose an indirect biofeedback system which encodes physiological information in terms of color and shape, and enables the user to grasp his/her inner state and to proactively change and control it by using breathing techniques. Those methods facilitate the user to self-control his/her autonomic nervous system. Here, we discuss indirect representation and placebo effect.

Introduction

The number of people with stress and mental problems has been gradually increasing in Japan. However, their mental health is often not improved by consultations with psychiatry or psychosomatic medicine specialists. We hypothesize that consulting these specialists is not very effective because it is merely a passive experience. We believe that if the patients are instead asked to approach the symptoms of their disease in a voluntary and proactive way, the treatment is more likely to succeed. To elicit proactive behavior from the client, he/she must become aware of their current mental condition. The client can then act appropriately to maintain his/her self-control. A device or a mechanism is needed to externalize the internal state of the client, while establishing a sense of unity between the external device and him/herself.

Here, we propose an indirect biofeedback system that helps the client to become self-aware of his/her current mental condition by monitoring a device with visual features that vary according to the client's heartbeat. That is, the device not only externalizes the mental state of the self but also keeps a sense of unity with the self. We also investigate how effectively the clients could control their mental condition by using breathing techniques such as abdominal and costal breathing.

We would ultimately like to determine whether it is possible for an individual to learn to easily and automatically identify his/her own internal state and control it through breathing.

Biofeedback for Identifying the Self and Self-control

Concept

It has already been reported that individuals can, to some extent, control their autonomic nervous system (ANS) by using biofeedback. Specifically, one report claims that individuals can use biofeedback to produce useful improvements in their physiological functions, such as decreases in anxiety symptoms and physical disorders.

Biofeedback systems are generally used at medical institutions and are considered as medical treatments to be executed under a medical doctor's direct supervision. Acquired physiological data are usually represented numerically and/or as waveforms. Such systems are not designed to be used by ordinary clients on a daily basis.

In the research reported here, we aim to develop a system using which ordinary users can identify their physiological state and exercise self-control on a daily basis. For this purpose, we propose that an indirect feedback enables the users to understand their internal state intuitively with a user-friendly representation of physiological data.

In addition, in this research, we employ breathing techniques as a means of exercising self-control over the users' internal state, since this is the only known means by which individuals can control their ANS.

Acquisition of Information on the Balance of Autonomic Nervous System from Heartbeat Fluctuation

In this work, we estimate the balance of the autonomic nervous system (ANS) by analyzing the frequency of heartbeat fluctuation. Heartbeat fluctuation can be measured simply and non-invasively, and the frequency analysis

of the heartbeat fluctuation yields an index of stress, manifesting itself by way of the influence of the ANS on the heart. It is well known that heartbeat can be changed by regulatory control exerted by the nervous and endocrine systems, as well as by physical position and movement. ANS works autonomously and regulates itself automatically. Unlike motor nerves, it is not possible to control the ANS intentionally. The ANS consists of the sympathetic nervous system (SNS) and the parasympathetic nervous system (PNS). The SNS mainly activates and tenses the body (e.g., sweating palms and a racing heart). The activation of the SNS constricts blood vessels and increases the heartbeat rate. As a result, the blood pressure goes up, and the blood flow to peripheral areas increases. On the other hand, the PNS activates the internal organs, and puts the body into the state of rest.

Imbalanced ANS is associated with unpleasant symptoms such as a high heartbeat rate (even at rest), poor digestion, and sudden heat sensation. In addition, in some cases, when the body stress is sufficiently great, the balance of the ANS and the hormonal system is sometimes severely affected, leading to the above-mentioned unpleasant symptoms. The symptoms promote anxiety and stress, resulting in a vicious circle. Because these effects accumulate, even a relatively weak event may ultimately result in a large stress. The ANS is typically capable of properly regulating our body and mind, but it is also related to the unpleasant symptoms of pain and anxiety. We believe that an individual can relax the ANS intentionally by using relaxation and biofeedback techniques to relieve the stress.

This research is focused on the hypothesis that our bodily and mental health can be maintained by intentionally controlling the ANS and recovering its proper balance. The relationship between the ANS and heartbeat fluctuation is as follows:

- The low frequency (LF) component of the heartbeat fluctuation is observed when the SNS and the PNS are activated.
- The high frequency (HF) component of the heartbeat fluctuation is observed when the PNS is more active than the SNS, and this state is reflected in the breath fluctuation.

Using this knowledge, we calculate the LF and HF of the heartbeat fluctuation as well as the LF/HF ratio. We will use L/H log-ratio ($\log_{10}$(LF/HF)) as an index of the ANS balance. Here, we define LF as 0.04–0.15 Hz and HF as 0.15–0.4 Hz. The actual procedures for computing the L/H log-ratio and for analysis are as follows:

1) We compute the LF and HF values, expressed as a power spectrum, by performing the frequency analysis of heartbeat rate series by using the minimum, maximum, and mean of the RR Interval (RRI) of the heartbeat fluctuation and its changes.
2) HF can be observed when the PNS is superior to the SNS; thus, we use the value of HF as a measure of the extent of the PNS activation.
3) LF can be observed when both the SNS and the PNS are active; thus, we divide the LF by the HF (L/H).
4) We use L/H ($\log_{10}$(LF/HF)) as a measure of the extent of the ANS activation, i.e., the level of stress.

Indirect Biofeedback

Physiological information is acquired by using a heartbeat sensor on a user's chest, and heartbeat fluctuations are used as the basis for generating a biofeedback signal. To generate this signal, the heartbeat fluctuation is analyzed. A measure of the balance of the SNS and PNS within the ANS is calculated and displayed to the user as changes in the color and shape of a circle. Fig. 1 shows an example of the indirect biofeedback representation which we propose here.

Fig. 1 Example of indirect biofeedback representation.

There are many reasons for using indirect biofeedback represented by changes of color and shape. First, direct numerical feedback might induce negative feelings in the user, because he/she is perceiving unfamiliar data that may exhibit dramatic changes in numerical values. Second, the user might be negatively impacted if he/she is shown data indicating an adverse physiological condition. We designed the indirect biofeedback display as follows:

- Feedback was provided via a circular display that could assume one of three colors. Red was used to indicate active situations with the SNS superiority. Green encoded mood-stabilizing situations. Blue encoded depressive situations with the PNS superiority.
- The shape of the display varied from a circle to a flattened ellipse, depending on the rate of switching from a SNS- to a PNS-dominated condition. This was inferred from the heartbeat rate fluctuations.
- Higher switching rate indicated less stable mental condition. In this case, the display became more elliptical.

In the three-color mapping, red represents an SNS-dominated condition, blue represents a PNS-dominated condition, and green represents a condition of balance between the SNS and PNS. These choices are based on color psychology, in which red is associated with strong energy of passion or excitement, blue with calmness and tranquility, and green with ease and comfort.

Related Work

The concept of feedback control was originally formulated in the field of cybernetics. It describes a situation in which the output of a system, or the consequences of that output, is fed back into the system as an input, which can act to modify its future output. Such a mechanism is indispensable for a system that is to automatically control itself. In a broad sense, feedback is a method to control a system, i.e., a machine or human, by re-inputting the results of past performance to the system.

The first step toward self-control, in the case of a human, is to intend to be in the desired physiological state. The second step is to change this intention into an actual influence of the mind over the body. When the biological, psychological, and/or physiological responses that are produced by relaxation practices are fed back to a client and the client can perceive them as external stimuli, the feedback can help the client to exert a more effective influence over his/her physiological and psychological state.

The term biofeedback is used when a certain device, such as an electroencephalograph, an electrocardiograph, a galvanic skin reflex measuring device, a blood-pressure gauge, or electromyography, is used for measuring bodily and mental responses and for displaying them to a user as numerical data. Therefore, it is important that the presented biofeedback data will allow the user to properly grasp his/her inner state. This allows the user to become aware of when and in what situation he/she feels stressed or relaxed.

Biofeedback is a method for a user to create relaxation by him/herself. One of its advantages is that the user can get used to eliciting biofeedback on a daily basis and then can learn how to relax in any environment. Biofeedback is now widely used for mental training of sport professionals, and is also used for medical mental care in the U.S.A., where the effect of biofeedback is highly appreciated. In addition to the fields of sports and mental health care, the method may be of use for enhancing human mental activities such as the development of mental capabilities, self-fulfillment, and goal achievement.

The ANS is important to the vital process of homeostasis, and respiratory sinus arrhythmia (RSA) is known as a selective index of cardiac vagal activity. It is thus a measure of the autonomic activity. Kotani and his collaborators studied the RSA amplitude measurement errors, and proposed a method for reducing them. For the sake of a real-time computer graphics (CG) display, they tested whether their method could be used for extracting the RSA amplitude in real-time. They found that an elastic chest band is suitable for measuring breathing under resting conditions, and that Berger's interpolation method was optimal for detecting instantaneous heartbeat intervals in real-time signal processing.

One study of the relationship between biofeedback and breathing investigated the effectiveness of biofeedback on a breathing exercise as a mental support for elite athletes. Four Japanese national team members participated in mental training to acquire breathing techniques as a relaxation skill. A small real-time biofeedback device (Stress Eraser, manufactured by Helicor Inc.), was used for visualizing the transitions into training periods during which the PNS activity was dominant. As a result, 3 out of 4 athletes consistently improved their PNS dominant points, even if they were using the training for the first time. Monitoring their own progress with real-time feedback was useful for them in mastering breathing techniques associated with breath rhythm and length. The athletes' reflections were also recorded over the course of 10 sessions. These reports show that all athletes 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 the importance of biofeedback as a method is now widely appreciated, existing biofeedback systems display biological information to the user in the form of numerical data and/or waveform images. In general, it is quite difficult for a lay person to properly understand the meaning of changes in numerical data or in waveform images. Such lack of understanding is a problem for the second step, in which the user should be given a capacity to confidently control the self. There is a possibility that displaying biofeedback information in a wrong format will cause the user's response to be too sensitive, leading to the effect opposite to that of reaching a proper balance. In the present research, we have introduced indirect biofeedback as a means to keep a sense of unity between a device that externalizes the internal state of the self, and the user him/herself. In our display, the circle represents the user as a system, and the color coding inside the circle represents the balance between the user's sympathetic nervous system (SNS) and parasympathetic nervous system (PNS). The border of the circle represents the boundary between the user's self and others. If the user's physiological response is less stable, the circle will shrink along one axis into an increasingly eccentric ellipse. Especially for psychiatric clients, we think that biofeedback representations should be simple and easily understandable, because some of them are receiving psycho-pharmaceutical treatment and sometimes exhibit cognitive dysfunction related to the ability to think, reason, concentrate, or remember. The proposed system models the user's own physiological state indicating the balance between the SNS and the PNS in the autonomic nervous system as a color distribution in a simple circle. We expect that such a simple representation will help users to see their inner state, and try to self-control it by breathing, so that they can improve the balance between their SNS and PNS. Our goal here is to determine whether the users can easily and casually identify their inner state and self-control it by breathing.

Indirect Biofeedback System

Fig. 2 shows the configuration of the proposed system.

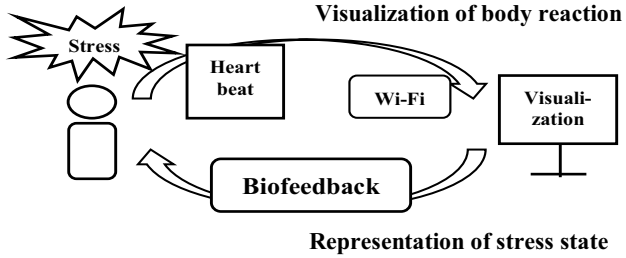

Fig. 2 System configuration.

A change in the L/H log-ratio, calculated based on the heartbeat fluctuation, is mapped onto a change in the color and shape of the circle. The system displays the change in the color and shape of the circle to a user.

- The analysis algorithm of the L/H log-ratio

For determining the mapping of the L/H log-ratio index onto the colors of red, green, and blue, we conducted preliminary experiments, and empirically derived the following mapping rules. We indeed derive these rules based on some experimental data:

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

The zero value of L/H implies that the user is switching from a physiological state in which one of the ANS components dominates (i.e., the SNS or the PNS), to a state in which the opposite component dominates. When the number of switching times increases, the circle elongates into an ellipse, and the algorithm for calculating the L/H log-ratio from the RRI data of the heartbeat is as follows:

Obtain RRI data →Remove abnormal values → Perform spline interpolation → Remove direct-current ingredient → Eliminate noises with window function → 0 insertion → FFT → LF, HF→L/H.

Experiments and Results

Self-identification of Mental State and Self-control: Indirect Biofeedback

Using the proposed system, we conducted 4 different types of experiments involving human participants. For each experiment, we considered 2 different loads of stress and 2 different ways of breathing with 16 study participants. The results indicate that the study participants properly controlled their inner states after being subjected to the considered loads of stress; this ability was attributed to the fact that all of the study participants were healthy (questionnaire-based).

The detailed sequence of the performed experimental procedures is as follows:

- The participant was exposed to one of the following types of stress:
  *1: The participant recalled unpleasant past experiences.
  *2: The participant was asked to iteratively perform the calculation $N_{i+1}=N_i-7$ ($N_0=1111$) for 5 min.
- The participant was asked to use one of the following stress control techniques:
  A: Abdominal breathing.
  B: Thoracic breathing.

We considered the following patterns of experiments:

- Experimental patterns:
  Pattern #1: *1 → A → *2 → B
  Pattern #2: *1 → B → *2 → A
  Pattern #3: *2 → A → *1 → B
  Pattern #4: *2 → B → *1 → A

According to the results of subjective evaluation (questionnaire-based), some participants reported that they were 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 inner state of the participants, before and after the experiments.

In this study, objective experimental results did not indicate an improvement in the study participants' physiological condition induced by the use of biofeedback. However, the participants reported that they felt more relaxed. We attribute the discrepancy between the subjective and objective results to a placebo effect that is caused by the proposed system. Here, we define a placebo effect as reporting feeling relaxed regardless of the actual objective experimental results. In addition, some of the participants wanted to see the balance of physiological information displayed as a graph, rather than a circle.

Effects of Fake Biofeedback: Placebo Effect

Experiments

We conducted an additional experiment in which the participants evaluated both real and fake biofeedback. In the case of fake biofeedback, the user evaluated the data provided by another healthy participant.

We designed this experiment as follows. The participant should use the following 2 systems:

*1: Real biofeedback system
*2: Fake biofeedback system

By using the real feedback system, the participant acquires his/her own biological information. On the other hand, by using the fake feedback system, the participant is provided with the biological information of another healthy participant. The participant is asked to use abdominal breathing as a stress control technique.

Subjective Evaluation

In the subjective evaluation, 17 out of 23 participants judged the real biofeedback to reflect their mental state better than the fake biofeedback.

Objective Evaluation

For the objective evaluation, after the participants exerted self-control by using both real and fake biofeedback, we compared the effectiveness of the real and fake biofeedback in increasing the green area (that represents the balanced situation between the SNS and the PNS). The result is shown in Fig. 3.

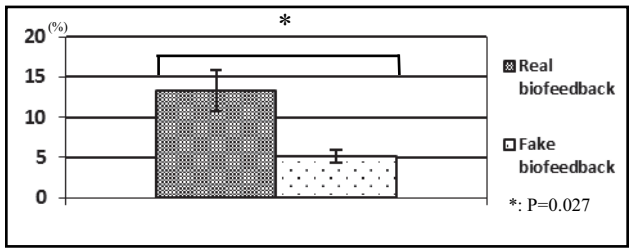

Fig. 3 T-test analysis results of the placebo effect (i.e., an increase in the good balance of the ANS).

As shown in Fig. 3, the real biofeedback was significantly better at producing a balanced situation in the ANS, compared with the fake biofeedback. Some participants doubted the performance of the fake biofeedback readout because it changed even when they almost reported not feeling stressed. The participants felt that the real biofeedback system better reflected their mental states.

Comparison with Existing Methods of Biofeedback

Experiments

In addition, we conducted an experiment in which we compared the proposed indirect biofeedback display with a conventional direct biofeedback display with the waveform representation.

We designed this experiment as follows. The participant should use the following 2 systems:

*1: Indirect feedback system

*2: Direct feedback system

By using the indirect feedback system, the participant acquires his/her own biological information as a form of circular representation proposed in this study. On the other hand, by using the direct feedback system, the participant acquires his/her own biological information in the waveform representation. The participant is asked to use abdominal breathing as a stress control technique.

Subjective Evaluation

Twenty out of 23 study participants reported, in the subjective evaluation, that the indirect biofeedback display was better than the direct one.

Objective Evaluation

For the objective evaluation, we compared the ability of participants using the circle image and a conventional waveform display to achieve a good balance of their ANS. The result is illustrated in Fig. 4, which shows that the indirect feedback system was much more effective than the direct one. The result ($p=0.04$) was determined to be significant based on a T-test with $p<0.05$.

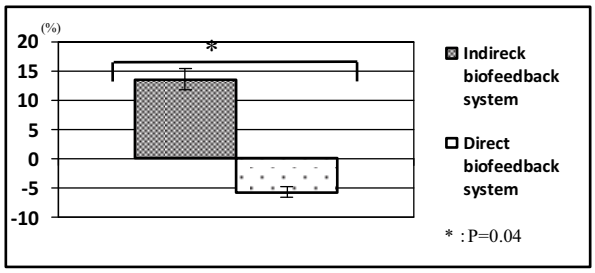

Fig. 4 T-test analysis results of representation (i.e., an increase in the good balance of the ANS).

We can explain this result as follows:

- Direct Biofeedback
  1) It might be difficult for the subjects to grasp their inner state during the given time.
  2) The waveform image sometimes seemed to cause negative reactions in the subjects through straight expressions.
  3) The direct biofeedback system induces stress in the participants, with certain tense or irritation, thereby reducing their level of ANS balance.
- Indirect Biofeedback
  1) The subjects can easily grasp their inner state through expressions that are easy to understand.
  2) The circular image and easily understandable expressions do not cause negative reactions that are likely to appear in the case of direct biofeedback.

We conclude that users can control themselves more easily by using the proposed indirect biofeedback, compared with the direct biofeedback that is common to existing biofeedback systems.

Discussion

In the placebo effect experiment, most of the participants doubted the fake feedback image. Even if the participants observed an increase in the green area on the display, it was usually hard for them to believe that the data reflect their own mental state.

From the comparative experiment on the representation of feedback information, the participants preferred the circular representation proposed here to the previous means of representation, namely, waveform representation.

Conclusion

In this research, we developed an indirect biofeedback system. This system externalizes and objectifies the users' physiological state for the purpose of allowing the users to self-control their inner state.

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

We evaluated the measured data and the questionnaires that were administered after the experiments. The results indicate that the study participants could properly control their inner states after being subjected to the considered loads of stress; this ability was attributed to the fact that all of the study participants were healthy

Moreover, we conducted two additional experiments, 1) on the placebo effect and 2) on the representation of biological information. In the experiment on the placebo effect, when the participants were provided with fake information, we confirmed no placebo effect; however, when the participants were provided with the real information, we observed the placebo effect.

In the comparative experiment on the representation of biological information, we confirmed that the indirect biofeedback yields better results compared with the direct one.

References

Fumiaki, I.; Kiyoshi, K.; Tomohiro, A. et al. 2007. Development of the method for estimating cardiac vagal activity in real-time during body motion and Ggeneration of the interactive CG. *IEEJ Trans EIS*, 127(10): pp1762-1769.

Haruo, S. and Ikuko, S. 2014. Effectiveness of biofeedback on breathing exercise as part of mental support for elite athletes. *Japanese Society of Biofeedback Research*, 41(1): pp.27-36.

Katsuki, Y. 2010. Influence of the mental stress on heart rate variability. *Kagoshima Academic Repository Network*: pp.1-10.

Keiji, H. 2011. Religions and Others --- Study on Language and Reality---. SHUNJUSHA Tokyo.

Kiyoshi, M. 1989. The Effects of relaxation training using biofeedback system on physiological and psychological functions. *The Annual Reports on Educational Science*, 52: pp51-67.

Mariko, T. 2003. PORM Theory and Practice -Trauma Deletion and Process of Self-Expression-. SHUNJUSHA Tokyo.

Mieko, O and Taishi, A. 2006. Breath inducing system for relaxation, *Japanese Society of Biofeedback Research* 33: pp.61-62.

Nobuaki, M.; and Yoshiaki, M. 2010. Study of mental stress evaluation based on analysis of heart rate variability, *Life-Support* 22(3): pp.106-113.

Satoshi, K., and Tsutomu, M. 2003. Extraction of Kansei-information from color images. *The Institute of Image Information and Television Engineers*, Vol.27(22): pp5-8.

About medical plan (mental disease). 2015. Available: http://www.mhlw.go.jp/seisakunitsuite/bunya/kenkou_iryou/iryou/iryou_keikaku/dl/shiryou_a-3.pdf

Autonomic imbalance. 2015. Available: http://www.japha.jp/doc/byoki/019.pdf. accessed 2015-7-6.

Heartbeat fluctuation and autonomic nervous system function. 2015. Available: http://www.take-clinic.com/psm/hrv/hrv_autonomic2.htm, accessed 2015-7-6.