On the Feasibility of Patient-Motivated Remedy via Indirect-Biofeedback

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Abstract

The number of people in Japan with stress and mental problems, including sleep disorders, has gradually been increasing. However, their situation is often not improved by consultation with specialists in psychiatry or psychosomatic medicine. A consultation with a specialist may not be very effective if it is a passive experience for the patient; if the patient is asked to approach the symptoms of his/her disease in a voluntary and proactive way, however, the treatment is more likely to succeed. To elicit proactive behavior, the patient must be made aware of their current mental state so that they can then act appropriately to maintain control.

The objective of our research is to introduce indirect biofeedback and verify a possibility for a user to self-identify his/her mental state and to self-control it through indirect biofeedback. We focus on seeking a possibility of a patient-motivated remedy not only with self-identification and self-control of their mental state by his/herself, but also with sharing the information among his/her family members and medical staff through indirect biofeedback.

In this research, we developed indirect biofeedback system that is aimed for enabling patient-mediated remedy and improving the patients' quality of autonomic nervous system and their sleep. The proposed system brings patients the following effects; 1) patient-motivated remedy effect for pharmacotherapy and 2) improvement of their own natural healing ability.

We designed the following two frameworks for Indirect biofeedback. 1) To test the efficacy of our proposed methods of indirect biofeedback and intentional breathing exercises, we proposed an indirect biofeedback system that helps the patient be aware of their current mental condition by monitoring a device with visual features that vary according to the heart rate of the patient. The device not only externalizes the mental state of the self but also keeps a sense of unity with the self. 2) What we emphasize as an aim of introducing indirect biofeedback is to seek a possibility for patient-motivated remedy through sharing indirect biofeedback information, but not to provide information useful for disease treatment with a doctor, nor to provide a useful care tool with care workers. The patient sleep scores were obtained from a mattress sensor, and visualized on his/her own virtual plant. The patient and his/her support members saw the patient's virtual plant every day, and using this tried to talk to them more effectively; the virtual plant system can work as a good trigger for communications.

To clarify its usefulness of sharing indirect-biofeedback information, we have conducted the following two experiments. Firstly, to test the efficacy of our proposed methods of indirect biofeedback and intentional breathing exercises, we conducted experiments with 16 study participants. Secondly, we conducted experiments with five elderly persons as subjects as well as family members and medical staffs in a senior care home. The results indicated that the study participants could properly control their inner states. Moreover, we attempted to verify whether or not patients, their family members, and medical staffs could deepen their mutual understanding and mutual acceptance by sharing the indirect biofeedback information. Also, we evaluated whether or not the patients could improve their own conditions through the proposed indirect biofeedback. We confirmed that patients, their family members, and medical staff could deepen their mutual understanding and mutual acceptance by sharing the indirect biofeedback information. This effect was partially verified using subjective and objective evaluation.

In the future work, we will develop an update system in which we can evaluate patients' conditions depending on their age, gender and disease so that patients and their support members can deepen mutual acceptance and understanding.

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Chapter 1

Introduction

1.1 Mental Health and Biofeedback

1.1.1 Background of Mental Health

The number of patients with stress and mental problems has been gradually increasing in Japan [1][2]. 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.

Why is the case in which a patient is completely recovered from the disease so rare in spite of consulting to such a specialist? An idea says that both a doctor and a patient are preoccupied with passive type of communications confine their selves even at the time of mental treatment. A doctor as one of vocation is an entity who earns a hospital fee by facing a patient and asking him/her about the condition as business. In the field of remedy, the doctor might aim only to relax the symptoms and pains which the patient is now suffering, but might not at least set a goal of removing the cause of disease. The patient, on the other hand, might think it enough to just visit the hospital so that they can get some direction and medicine for relaxing the symptoms, and can improve the condition by practicing the remedy for the disease.

As far as both the doctor and the patient play a sort of language game in which both of them are preoccupied with passive type of communications without having common clear objective of finding and treating the fundamental causes of the mental condition of the patient, it should be natural that the treatment is often inefficient, and it should be difficult to heal the disease completely [3][4][5][6].

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. 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 their current mental condition. Based on the recognition of this condition, the patient would act appropriately to maintain their self-control. 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.

1.1.2 Concept of Biofeedback

Biofeedback is the process of gaining greater awareness of many physiological functions primarily using instruments that provide information on the activity of those same functions, with a goal of being able to manipulate them at will [7].

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 [8][9].

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 wave forms. That is to say, those systems are not originally supposed to be used by ordinary users on a daily basis [10].

In this research, we propose an indirect feedback which enables users to understand their inner state intuitively with a user friendly representation of physiological data. And we verify a possibility for a user to self-identify their mental state and to self-control it through indirect biofeedback. We focus on seeking a possibility of a patient-motivated remedy not only with self-identification and self-control of their biotic state by their selves, but also with sharing the information among their family members and medical staff through indirect biofeedback.

1.1.3 Research Issues and Challenges

To sum up, there are several research issues and challenges on Indirect biofeedback.

Indirect Biofeedback

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

The reasons why we do not employ numerical feedback directly but feedback the change of color and shape of a circle or virtual plants 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.

For solving this challenge, we used the techniques of autonomic nervous system analysis and color psychology.

Indirect Representation

Direct biofeedback is a direct feedback via changing numerical values or waveforms. Indirect biofeedback is an indirect feedback via changing color and shape of a circle or virtual plants. The indirect information is designed to be displayed in a way that anybody can understand and feel. We adapted the technique of environmental engineering design.

Self-identification and Self-control

To some extent, individuals can control their autonomic nervous system (ANS) through biofeedback. Specifically, reports claim that individuals can use biofeedback to produce useful improvements in their physiological functions, such as a decrease in anxiety symptoms and physical disorders [11][12].

Biofeedback generally is used at medical institutions and is seen as a medical treatment to be executed under the direct supervision of a medical doctor. Acquired physiological data are usually represented as numerical data or a waveform image. Such systems are not designed for use by ordinary clients on a daily basis [13][14][15].

The goal of our research is that ordinary users can identify their physiological state and exercise self-control on a daily basis through the proposed system. An indirect feedback system enables users to understand their internal state intuitively via a user-friendly representation such an indirect biofeedback of physiological data. We employed the techniques of breathing technique.

Information Sharing

The indirect information through the proposed system in this research is represented using by the techniques of sleep analysis and evaluation and the end of average and their information is shared with patients' support members such as family members, doctors, and medical staff for the interactions and communications with the patient.

1.2 Motivations of Research

Based on the limitations and challenges of current research, we would like to propose an approach based on biological data such a heartbeat, sleep data and investigate a model of indirect biofeedback mechanism that helps with patient awareness of their own self and their sleep quality, through use of a device with visual features that vary according to the heartbeat and the sleep data of the patient.

Finally, we would like to suggest a mechanism through which the patient, their family members, and medical staff can share the indirect biofeedback information.

1.3 Objectives of Research

The objective of our research is to introduce indirect biofeedback and verify a possibility for a user to self-identify their state through indirect biofeedback.

We focus on seeking a possibility of a patient-motivated remedy as well as a possibility of self-identification.

1) Patient-motivated remedy effect alternative to pharmacotherapy and

2) Improvement of their own natural healing ability.

1.4 Thesis Overview

Self-identification of Mental State and Self-control through Indirect Biofeedback (Chapter 3)

In this thesis, the proposed indirect biofeedback model is presented. The environment for experiments and data acquisition, as well as preliminary results is elaborated. We investigate how effectively clients control their mental condition through breathing techniques such as intentional abdominal breathing and intentional costal breathing.

Indirect Representation and Placebo Effect (Chapter 4)

This thesis presents the usefulness of the proposed indirect biofeedback system, based on the results of two experiments as follows.

1) Find the effects of fake biofeedback: placebo effect

The subjects evaluate both real and fake biofeedback. For the latter, the user evaluated data provided by a healthy subject.

2) Compare existing biofeedback methods

The proposed indirect biofeedback display is compared with a conventional direct biofeedback waveform display.

Multiple and Recursive Indirect-Biofeedback for Enabling Patient-Motivated Remedy (Chapter 5)

This thesis describes a possible indirect biofeedback model of mutual acceptance between a patient, their family members, and medical staff, by sharing information through indirect biofeedback. We attempt to verify whether or not patients, their family members, and medical staffs could deepen their mutual understanding and mutual acceptance by sharing the indirect biofeedback information.

1.5 Thesis Organization

This thesis is organized as follows:

In Chapter 2, the background of the research is described. Chapter 3 presented several literary and experimental evidences. Chapter 4 focused on the Placebo effect and on representation of biological information of indirect biofeedback. Chapter 5 focused on an indirect biofeedback model that helps with patient awareness of their sleep quality and condition, through use of a device with visual features that vary according to the sleep data of the patient. Finally, Chapter 6 concludes this thesis.

Chapter 2

Research Framework for Indirect Biofeedback

This chapter presents the concepts and definitions that lay the foundation for this thesis. First, a brief description on fundamental knowledge for the current research is introduced.

2.1 Mental Health and Language Game

By the time Wittgenstein wrote The Philosophical Investigations he rejected the three assumptions of his early period namely that language is used for one purpose the presenting of facts, that sentence acquires meaning in one way that is through picturing and that language essentially has a clear and firm structure of the formulae in a logical calculus. In the later development of his thought Wittgenstein seems to repudiate the earlier notion of the uniformity of language, which would restrict the word to a rigid and demarcated use, a use which would suit all cases. He came to think that language is flexible, subtle and multiform.

Wittgenstein's remarks on "Games and Definitions" could be applied to aesthetics. The nature of art is like that of the nature of games. If we look carefully and see what it is that we called 'art' we will find no common properties but discern strands of similarities.

Knowing what art is not discovering some manifest or latent essence but being able to recognize, describe and explain those things we call art by virtue of these similarities. The basic resemblance between these concepts is their open texture.

In elucidating them certain (paradigm) cases can be given to which we conveniently apply the word 'art' or game but no exhaustive set of cases can be given. It is so because one can always envisage new cases, which can be added to it.

There is a view to postulate that a patient and the doctor play the “language game”, a philosophical concept advocated by Ludwig Josef Johann Wittgenstein, where the doctor “plays” the role of a doctor rather than understand the patient, and the patient “plays” the role of patient rather than reveal their true nature to the doctor.

For example, in the current state of psychiatric care, a patient might think it is enough to just visit the hospital /so that they can get some directions and medicines for relaxing the symptoms. And patients can improve the situation by practicing the remedy for the disease. On the other hand, a doctor might aim/ only to relax the symptoms and pains by medicines which a patient is now suffering from. The doctor might not at least set a goal of removing the cause of disease.

The viewpoint of this research is to get freedom break free from a passive communication. In the medical field, if the doctor and patient wants to understand each other, an intervention of a third party is necessary. Presence of the third party would be able to collect the objective indicators between doctor and patient. Based on the third party’s information, doctor and patient would share the information and communicate successfully. If the patient learns of treatments other than pharmacotherapy, and if the patient can choose their own suitable treatment themselves, they can face the symptoms of disease in a proactive way and the effect of medical treatment can be improved. Our study attempts to answer this challenge.

2.2 Biofeedback Technics

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 [7][8].

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 [9][10]. So, it is important for a user to properly grasp their mental state in biofeedback so that the user can be aware of when and in what situation they feel 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 [16][17].

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 wave form 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 wave form 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 [18], 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.

2.3 Autonomic Nervous System and Heartbeat

The autonomic nervous system can be controlled by ourselves through heartbeat using by breathing technics. An excerpt from the books are shown below:

The autonomic nervous system (ANS) regulates involuntary (not under conscious control) activities. It consists of the sympathetic and parasympathetic nervous systems. These work in opposition to each other in order to maintain homeostasis (balance) within the body.

Sympathetic nervous system Output from this system steps up internal bodily activity. It is sometimes called the "fight or flight" system because it stimulates the body to react to emergencies by increasing the heart rate, dilating the pupils, and switching blood supply from the intestines to the muscles and brain.

Parasympathetic nervous system, this system decreases the heart rate, contracts the pupils, and feeds blood away from the brain and muscles to the intestines. Tables 1 and 2 below are some of the organs affected by the ANS and the effects produced by stimulation by the sympathetic and parasympathetic systems [19].

Table 1. Relationship between Organ affected and autonomic nervous system (1).

Organ affected	**Sympathetic stimulation**	**Parasympathetic stimulation**
Heart	• Accelerates the heartbeat	• Slows the heartbeat
Eye	• Dilates the pupils	• Constricts the pupils
Sweat glands	• Stimulates sweat secretion	• Generalized secretion
Tear glands	• Inhibits secretion	• Stimulates normal or excessive secretion
Salivary glands	• Decreases secretion	• Stimulates secretion
Gastric fluids	• Inhibits secretion	• Stimulates secretion
Intestinal fluids	• Inhibits secretion	• Stimulates secretion
Lungs (bronchial tubes)	• Dilates	• Constricts

Table 2. Relationship between Organ affected and autonomic nervous system (2).

Blood vessels in skin in skeletal muscle in digestive tract	• Constricts • Dilates • Usually inhibits defecation	• Dilates • Dilates • Increases peristalsis (wave-like muscular contractions)
Liver	• Releases glucose; and decreases bile secretion	• Increases bile secretion
Stomach	• Decreases activity	• Increases activity
Intestines	• Decreases activity	• Increases activity
Kidney	• Decreases volume of urine	• None
Pancreas	• Inhibits secretion	• Promotes secretion
Bladder	• Relaxes the bladder	• Contracts the bladder
Hair follicles	• Produces “goose pimples.”	• None

When not any neuro-humoral influence, the inner HR is about 90 to 120 beats/min. The two changing of the autonomic nervous system work in a synchronized way on HR.

In a healthy unblocked person, the HR at any time represents the effect of parasympathetic nervous system activity and sympathetic nervous system activity. Under resting conditions, while taking the rests, parasympathetic nervous system's activity prevails and the variations in HR period are largely dependent on parasympathetic nervous change of the tone.

The effect of parasympathetic nervous effect is slowing down or even stop the heart. The latency of the sinus node response is very short. After a single stimulus, the maximum response has been reported to occur within 400 milliseconds. Therefore parasympathetic nervous change results in a peak response either the first or the second beat after its onset. After the end of parasympathetic nervous change, HR rapidly turns back to its original level. The rate of recovery is somewhat slower than that of onset, but HR usually recovers in less than 5 to 10 seconds [20].

Baroreflex has been proposed to be mainly a vagally mediated control system between HR and blood pressure, where the R-R interval is changed in response to changes in arterial pressure. Any rise in blood pressure is sensed by the baroreceptors, which are pressure-sensitive nerve endings mainly found in the wall of aortic arch and in the carotid sinuses. The baroreceptor reflex is stimulated, which results in a reduction of HR and cardiac contractility and, thus, a drop in blood pressure. An initial decrease in blood pressure has opposite effects [21][22].

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:

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 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.

2.4 Breathing Technics

The heart rate variability (which is called HRV) is an indicator of the cardiac autonomic regulate.

We can usually record two spectral components such high frequency (0.15-0.50 Hz), which is due to parasympathetic nervous system activity and a low frequency component (0.05-0.15 Hz) due to sympathetic nervous system activity. Sympathetic superiority in the power spectrum obtained from short- and long-term HRV recordings predicts a convalescence in a number of heart diseases.

Heartbeat variability is sometimes recorded without measuring breath respiration, slow breathing might increase low frequency power in RR interval and falsely mimic sympathetic nervous system activation.

The sympathetic nervous system works, your heart rate and your breathing is speed up, and stress hormones like cortisol start pumping through your bloodstream and they are preparing your body to face the stresses.

The parasympathetic nervous system controls your rests such relax. When the parasympathetic nervous system is superiority, your breathing slows and your heart rate decreases, also your blood pressure lowers as the blood vessels relax, and your body is put into a calm and healing state.

From these mechanism, we can control our own nervous system such as sympathetic nervous system and parasympathetic nervous system through using by breathing technics in a part [23].

The following Figure 1 is relationship between breathing technique and the autonomic nervous system.

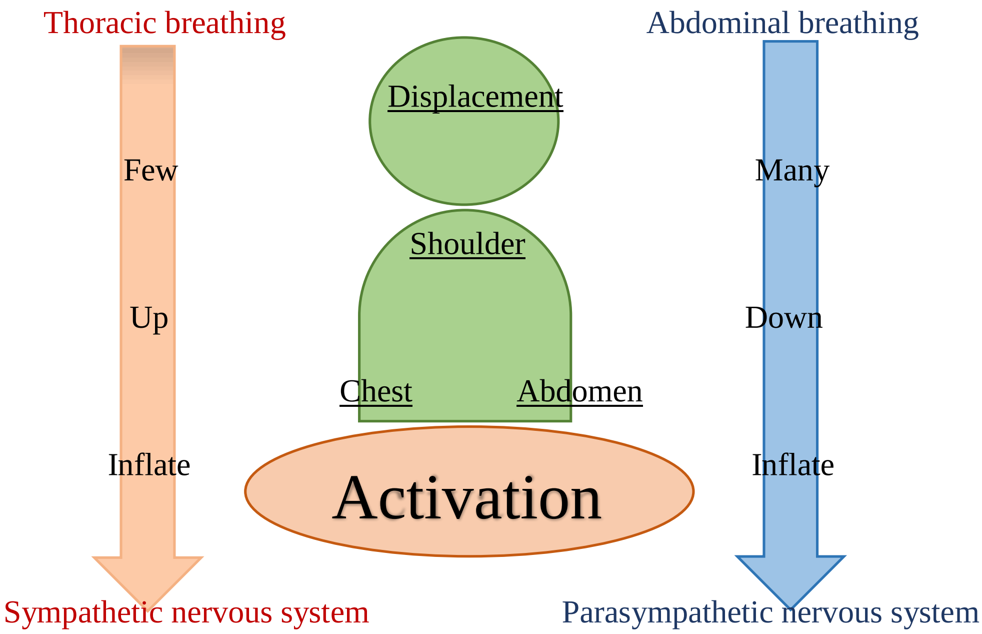

Figure 1. Relationship between autonomic nervous system and breathing.

2.5 Sleep Analysis and Evaluation

On basis, the sleep can be measured by some indicators. An excerpt from the book is shown below:

The main states of vigilance are wakefulness, REM sleep and non REM sleep. Non REM sleep is further divided into four Stages from the lightest Stage 1 to the deepest Stage 4. Stages 3 and 4 are referred to as slow wave sleep (SWS). The frequency of sleep Stages alters during the night - in the early hours of sleep SWS dominates, whereas REM sleep occurs more often in the second part of sleep. The portion of REM sleep during night alters with age - in newborn babies REM sleep lasts for 50%, in adults for 20%.

An essential method in human clinical and basic sleep research is polysomnography. It is composed of measuring electroencephalogram (EEG), electro *oculogram (EOG) and electromyogram (EMG), see Figure1. Electroencephalography is the basic method with an excellent temporal resolution and lower spatial resolution of electrical activity of cerebral cortex. The quality of EEG recording depends on some technical parameters* [24].

The sleep state and/or sleep quality are determined by numerous factors. If the aim of this research is to exactly determine a patient's sleep state and/or sleep quality, it is indispensable for us to investigate how and what a factor affects sleep state and/or quality. However, the aim of this research is to seek a possibility for patient-motivated remedy through sharing indirect biofeedback information. For that purpose, we focused on how effective indirect representation can reflect some change of a patient's biotic information, and how effective such representation influences on information sharing. In other words, we determined the evaluation criteria on a patient's sleep state and/or quality depending on how effective indirect representation achieves information sharing.

Thus, on this occasion we employed the sleep score calculated by some algorithm developed by TANITA, based on the length of deep sleep, the ratio of deep sleep, the number of nocturnal awaking and some sleep indicators, obtained through a mattress sensor.

On the other hand, TANITA's algorithm to compute sleep score seems to be tuned for healthy adults but not for the elderly people. As one of further studies, we should develop an algorithm suitable for the elderly people.

2.6 The End of Average: General and Uniqueness

The End of Average proposed a paradigm where the idea of average actually never fits any. An excerpt from the book is shown below:

"In 1950, researchers at Wright Air Force Base in Ohio measured more than 4,000 pilots on 140 dimensions of size, including thumb length, crotch height, and the distance from a pilot's eye to his ear, and then calculated the average for each of these dimensions.

Everyone believed this improved calculation of the average pilot would lead to a better-fitting cockpit and reduce the number of crashes — or almost everyone.

Out of 4,063 pilots, not a single airman fit within the average range on all ten dimensions (height, shoulders, chest, waist, hips, legs, reach, torso, neck, and thigh).

One pilot might have a longer-than-average arm length, but a shorter-than-average leg length. Another pilot might have a big chest but small hips. If you picked out just three of the ten dimensions of size--- say, neck circumference, thigh circumference, and wrist circumference---less than 3.5 percent of pilots would be averaged sized on all three dimensions [25]. *There was no such thing as an average pilot."*

The paradigm suggested that, for a complex and multi-dimensional system such as human, it is not safe to simply use data of many people to calculate a fit-for-all method.

2.7 Color Sociology

The color affects human be many things both consciously and subconsciously.

An excerpt from the book is shown below [26]:

Color is one of the important things that human can percepts. Everyday objects and things have been designed to pass along a message through colors.

In psychological field, colors effects psychological processing has not been fully explained. Particularly some past studies on the effect of color on cognitive tasks have presented wrong results. These studies have often only evaluated two of the three original colors and still results are contradiction. The focus of most studies is comparing red to either blue or green. In the results, the studies have been a mixing with some of the studies showing red to enhance performance over blue or green and the other studies showing the opposite effect.

Different colors raise different achievement motivations which can affect the performance on different types. On cognitive tasks, for color to affect the performance, Elliot and Maier say the six premises. The followings are for example,

1) Colors might be able to carry a specific meaning.

   If color were only for art and beauty purposes then it would not have influence over psychological functioning.

2) The meaning of colors is based both on learned associations and on biological responses.

   For example, in an academic, red is sometimes the meaning of mistakes and a teacher corrects a paper is a red pen. This case is a learned association. Biologically red can be danger signals for animals such ape or cow. Blue is more often associated with openness and peace instead of danger.

3) The perception of color alone will cause evaluative processes.

   Processes of evaluation are defined as deeming whether a stimulus makes an injurious effect or not to human.

4) The evaluative processes which are caused by the perception of color, influence motivated behavior.

   Colors with a positive relation would makes an approach motivation, while colors with a negative relation would causes an avoidance motivation.

5) The influence of color on psychological functioning is implicit and automatic.

   The activates of the motivation behavior takes place subconsciously.

6) The meaning and effects of color are based on context.

   In different contexts a color can have different relations. If you are in a achievement situation, red is related with danger and mistakes. If you are in a social context, red can be related with romance and will then have more positive relations. Based on these six premises, in an achievement situation, red would be caused an avoidance motivation and blue would be caused an approach motivation. Red would cause negative relations, which would cause the avoidance motivation and blue would evoke positive relations, which would make the approach motivation.

The following Table 3 is the relationship between color and human feeling.

Table 3. Relationship between color and human feeling 1.

	Color	Positive image	Negative image
	Green	• Fresh • Youthfulness • Peace	• Conservative • Passive • Immature
	Blue	• Refreshing • Intelligence • Coolness	• Cold • Melancholy • Loneliness
	Violet	• Tradition • Mystery • Exalted	• Frustration • Pathological • Death
	Pink	• Cute • Sweet • Soft	• Weak • Unstable • Childish
	Blown	• Calmness • Sincere • Astringent	• Sober • Conservative • Country-like
	White	• Forever • Cleanliness • Sacred	• Tension • Emptiness • Unreliable
	Gray	• Urban • Calmness • Conservative	• Sad • Anxiety • Ambiguous
	Black	• High class • Chic • Looks cool	• Fear • Resistance • Dark
	Red	• Dynamic • Passion • Vitality	• Garish • Danger • Flashy
	Orange	• Bright • Homely • Warm	• Vulgar • Cheesy • Self-indulgence
	Yellow	• Hope • Joy • Happiness	• Infantile • Caution • Rash

Robert Plutchik arranges emotions in concentric circles where inner circles are more basic and outer circles more complex. Illustration of Plutchik's Model can be found at Figure 2 below [27].

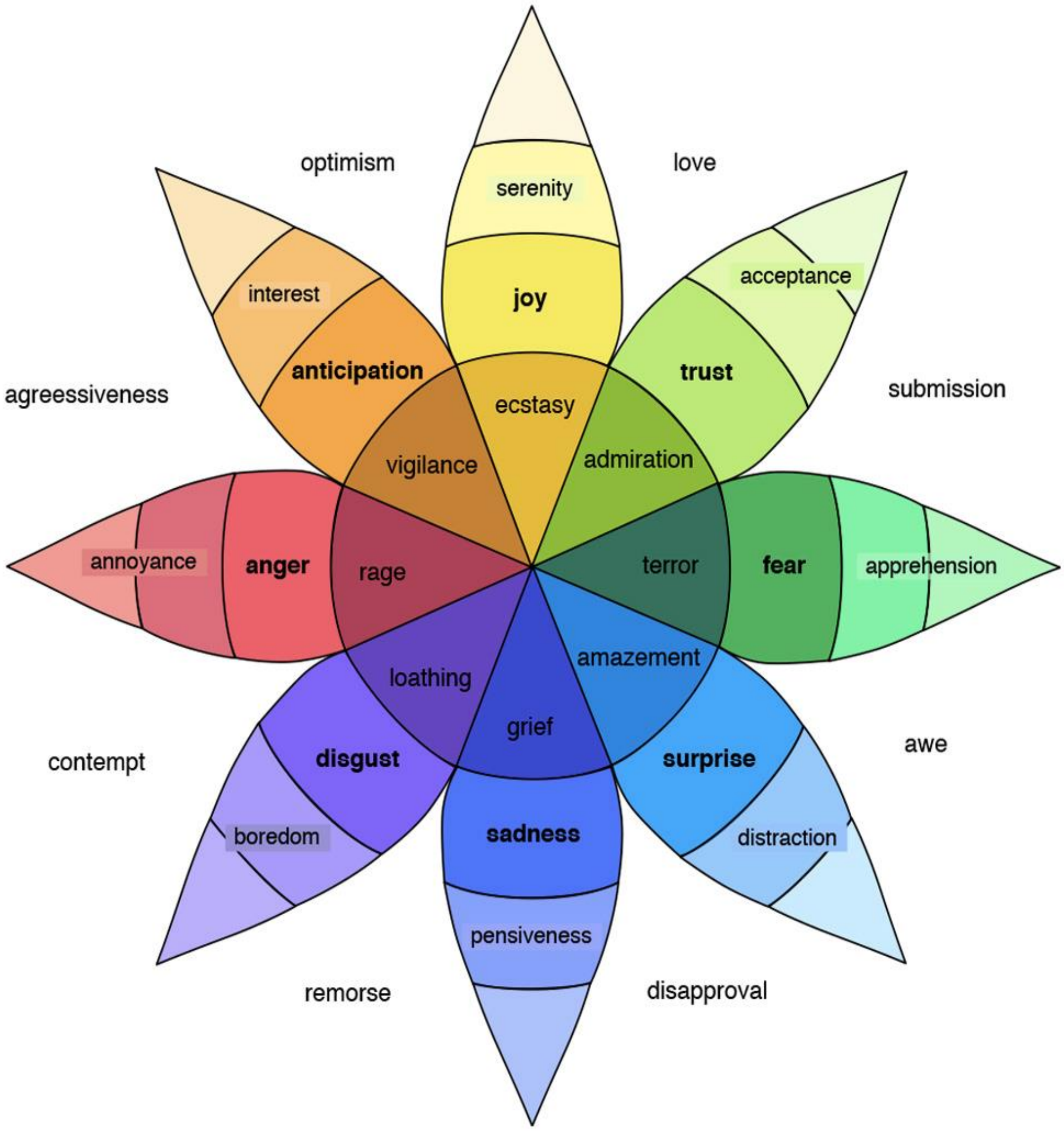

Figure 2. Plutchik model (or Plutchik's Wheel)

From the above references, we chose red, blue and green as the colors of representation and used to the proposed system.

2.8 Environmental Engineering Design

We can summarize the requirements for indirect biofeedback as follows: A representation of indirect biofeedback should exist as a familiar thing in our daily life, and could make some change depending on a person's biotic information and their inner state. In addition, it is quite important for people to easily and intuitively understand the meaning of the change. In considering senior patients this time, moreover, it should be natural even if it is displayed near their bed sides, and whether or not they can be aware of and/or interested in it.

In this paper, thus, employ virtual plants and their changes as a representation of indirect biofeedback. Also some environmental studies support our intuition of employing virtual plants: As the objective results, plants elicit increase of Alpha waves in human brains, decrease of heart rate, increase of disease resistance and refreshment in both human's body and mind. As the subjective results, plants are effective in making people relaxed and relieved, and in increasing their motivation. Even fake plants can help people to be comfortable [28].

The plant affects human be many things both consciously and subconsciously. There are increasing evidences to support the conception that plants would be able to play an important role in providing a higher quality living environment.

When there is a plant, it refreshes the indoor environment, relax the minds of the people and advance comfort. Through anticipation of these effects, plants are becoming more commonly placed in indoor environments such as homes and offices, which is called as "green amenity".

There are four effects on green amenity 1) thermal regulation and comfort improvement, 2) psychological effects and alleviation 3) healing of visual fatigue,

4) air purification. In addition, recently there is the increasing attention on horticultural therapy, which is primarily used for elderly people.

The following Figure 3 is the effects of the plants in the room to human.

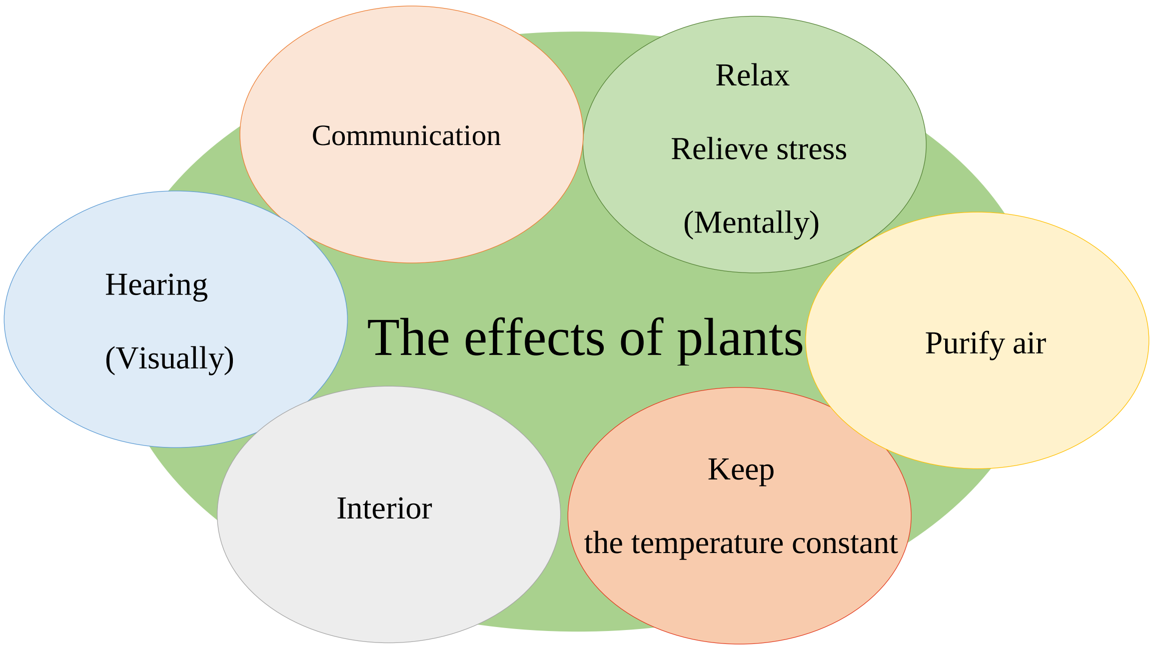

Figure 3. The effects of the plants in the room to human.

Even The artificial plant also affects human be many things both consciously and subconsciously.

Some study has compared the impression of the resting room in a commercial building where a foliage plant or an artificial plant was placed, impressions both of amenity and naturalness in the room were improved by the artificial plant as well as the natural plant. On the other hand, when the property of artificial or natural of plants were informed to the participants, the evaluation score of the room of the artificial plant decreased while that of the foliage plant increased. These results show that artificial plants are able to give the same effect as foliage plants and recognition of the plant property may control a spatial impression evaluated by the people.

In the study, amenity effect of ornamental foliage plants, imitation plants and photograph on human psychology were analyzed. As a result, higher ratio of alpha wave to beta wave was observed in plant for the subjects, indicating the amenity effect of ornamental foliage plants on human psychology [29].

Chapter 3

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

This chapter describes a possibility of a new scheme for a user with mental health problems so that the user can identify their own mental state and self-control it by proactively confronting their symptoms through the proposed system, different from the usual passive role of visiting specialists.

3.1 Introduction

The number of people with stress and mental problems has been gradually increasing in Japan. However, their situation is often not improved by consultation with specialists in psychiatry or psychosomatic medicine.

There is a view to postulate that a patient with schizophrenia and the doctor play the "language game", a philosophical concept advocated by L. J. J. Wittgenstein, where the doctor “plays” the role of a doctor rather than understand the patient, and the patient “plays” the role of patient rather than reveal their true nature to the doctor. In the current state of psychiatric care, a patient might believe it is sufficient to visit the hospital to get some instructions and prescriptions to allay the symptoms. And patients can improve the situation by practicing the remedy for the disease. On the other hand, the goal of the doctor might be to just ease the symptoms and pain from which the patient is suffering and not remove the cause of the disease.

A consultation with such a specialist could not be very effective if it is a passive experience for the patient. However, if the patient is 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, the client must be made aware of their current mental condition so they can then act appropriately to maintain self-control. A device or mechanism is needed to externalize the internal state of the client, while the client establishes a sense of unity with the external device.

Here, we propose an indirect biofeedback system that helps the client be aware of their current mental condition by monitoring a device with visual features that vary according to the heart rate of the client. 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 clients control their mental condition through breathing techniques such as intentional abdominal breathing and intentional costal breathing.

Moreover, differently from our previous papers, this paper clarifies the usefulness of the proposed indirect biofeedback system, based on the results of two additional experiments as follows.

1) Find the effects of fake biofeedback: placebo effect

The subjects evaluated both real and fake biofeedback. For the latter, the user evaluated data provided by a healthy subject.

2) Compare existing biofeedback methods

The proposed indirect biofeedback display was compared with a conventional direct biofeedback waveform display.

3.2 Biofeedback for Identifying the Self and Self-control

3.2.1 Concept

To some extent, individuals can control their autonomic nervous system (ANS) through biofeedback. Specifically, reports claim that individuals can use biofeedback to produce useful improvements in their physiological functions, such as a decrease in anxiety symptoms and physical disorders.

Biofeedback generally is used at medical institutions and is seen as a medical treatment to be executed under the direct supervision of a medical doctor. Acquired physiological data are usually represented as numerical data or a waveform image. Such systems are not designed for use by ordinary clients on a daily basis.

The goal of our research was to provide a system by which ordinary users can identify their physiological state and exercise self-control on a daily basis. For that purpose, we propose an indirect feedback system that enables users to understand their internal state intuitively via a user-friendly representation of physiological data.

To this end, we adopted the technique of intentional abdominal breathing, which is reported to result.

1) Change in alpha waves in the brain,

2) Activation of the nervous system, and

3) Change in the balance of the parasympathetic nervous system (PNS) in the ANS.

Thus, intentional abdominal breathing can help to maintain relaxed mental and physical states. In addition, we had the user perform intentional abdominal breathing as a means of exercising self-control over the internal state because this is the only known means by which individuals can control their ANS.

3.2.2 Acquisition of Information on Balance of ANS from Heartbeat Fluctuation

In this research, we estimated the balance of the ANS by analyzing the frequency of the heartbeat fluctuations, which can be measured simply and noninvasively. Frequency analysis provides an index of stress manifesting itself as the influence of the

ANS on the heart. It is well known that the heartbeat can be changed by regulatory control of the nervous and endocrine systems, as well as by physical position and movement. The ANS works autonomously and regulates itself automatically; unlike motor nerves, it cannot be intentionally controlled. The ANS consists of sympathetic nervous system (SNS) and the PNS. The SNS mainly activates and tenses the body; for example, when the palms sweat and the heart races. Because activation of the SNS constricts blood vessels and increases the heart rate, blood pressure goes up and blood flow to peripheral areas increases. On the other hand, the PNS activates the internal organs and puts the body in a resting state.

An unbalance in the ANS causes unpleasant symptoms such as a high heart rate even while resting, poor digestion, and sudden heat sensations. In addition, in some cases, when the body is under sufficiently great stress, the balance between the ANS and the hormonal system are sometimes severely affected, and this imbalance causes the unpleasant symptoms mentioned above. The symptoms promote anxiety and stress and eventually a vicious cycle develops. Since these effects accumulate, even a small cause may ultimately result in a large stress. The ANS usually is 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 through relaxation and biofeedback techniques to get rid of stress.

Therefore, our research focused on the proposition that we can keep our body and mind in good condition by intentionally controlling the ANS and thus recover its proper balance. The relationship between the ANS and heartbeat fluctuation is as follows:

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

Using this knowledge, we calculated the LF and HF of heartbeat fluctuation and their ratio (LF/HF). We used L/H ($\log_{10}$LF/HF) as an index of the balance of the ANS, where we set LF = 0.04–0.15 Hz and HF = 0.15–0.4 Hz. The procedures used to compute L/H and use the result are as follows:

1) We computed LF and HF expressed as a power spectrum by performing a frequency analysis of the heart rate using the minimum, maximum, and mean of the RR Interval (RRI) of the heartbeat fluctuation and its changes.
2) HF is observed when the PNS is superior to the SNS, so we used the value of HF as a measure of the degree of PNS activation.
3) LF is observed when both the SNS and the PNS are active, so we divided the LF by the HF (L/H).
4) We used L/H ($\log_{10}$LF/HF) as the degree of ANS activation, i.e., the degree of

stress.

3.2.3 Indirect Biofeedback

Physiological information is acquired through a heartbeat sensor pasted on the chest of the user, and heartbeat fluctuations are analyzed to generate a biofeedback signal. The L/H ratio is calculated and displayed to the user as changes in the color and shape of a circle.

Figure 4 shows an example of direct biofeedback represented as a waveform and Figure 5 shows an example of indirect biofeedback represented as we propose here.

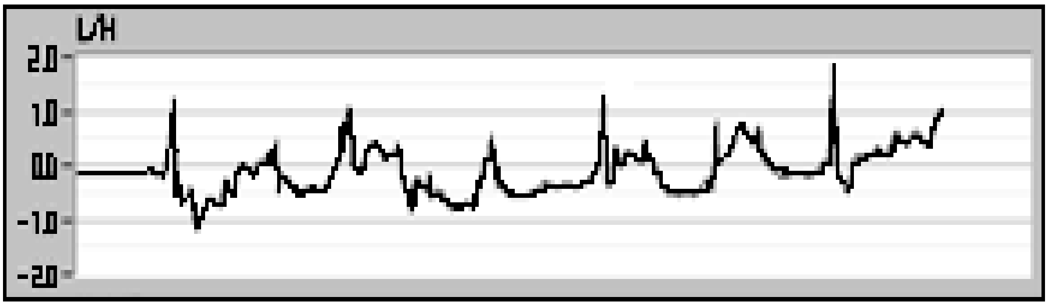

Figure 4. Example of direct biofeedback representation.

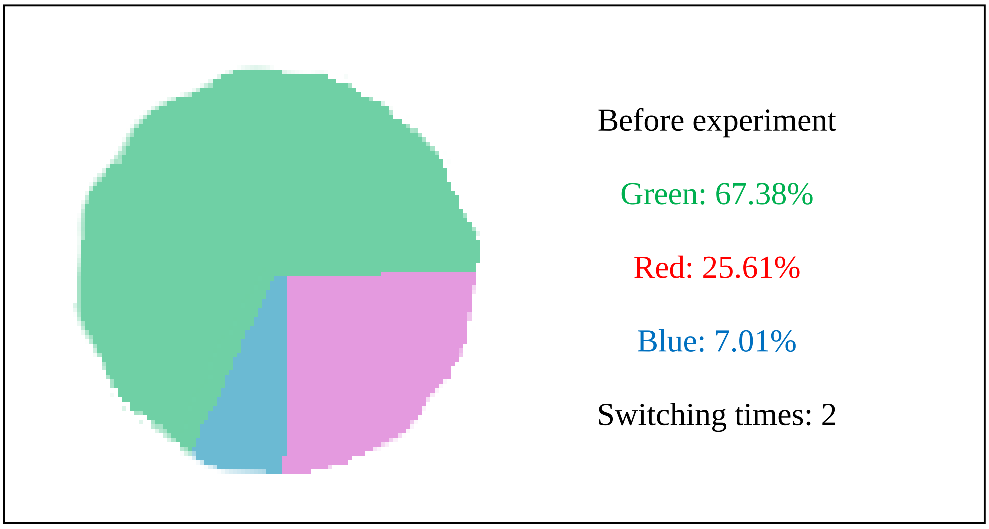

Figure 5. Indirect biofeedback representation corresponding to the direct one in Figure 4.

Figure 4 is a conventional waveform display of direct biofeedback, whereas we propose an indirect biofeedback display comprising a circle that changes color and shape. There are many reasons for representing indirect biofeedback in this way. First, direct numerical feedback might give the user a negative feeling because the unfamiliar data may be perceived as exhibiting drastic numerical changes. Second, the user might be negatively impacted if shown data indicating an adverse physiological condition.

We designed the indirect biofeedback display based on color psychology as follows:

- Feedback is provided via a circular display of one of three colors. Red indicates active situations with SNS superiority. Green shows a stable mood with a balance between the SNS and the PNS. Blue shows depressive situations with PNS superiority.

- The shape of the display can vary from a circle to a flattened ellipse depending on the rate of switching from an SNS- to a PNS-dominated condition. This is inferred from heart rate fluctuation.
- If the switching rate is high, the display becomes strongly elliptical, indicating that the mental condition of the user is not stable.

3.3 Related Works

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

The first step to controlling the self, 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 having the mind actually influence the body. When the biological, psychological, and physiological responses that are produced by relaxation practices are fed back to a client and the client perceives them as external stimuli, that feedback can help the client exert a more effective influence over their physiological and psychological states.

The term biofeedback is used when a device such as an electroencephalograph, electrocardiograph, electromyography, galvanic skin reflex-measuring device, or blood-pressure gauge measures bodily and mental responses and displays them as numerical data to a user. Therefore, it is important that the presented biofeedback data help the user properly grasp their inner state so they can become aware of when and in what situation they feel stressed or relaxed.

Biofeedback is a way for a user to self-create relaxation. One can use biofeedback on a daily basis and learn to relax in any environment. Biofeedback is now widely used for mental training by sport professionals and for mental healthcare in the U.S., where the effect of biofeedback is highly appreciated. In addition, the method could be used to enhance 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 and thus is a measure of autonomic activity. Kotani and his collaborators studied errors in the measurement of the amplitude of RSA and proposed a method to reduce them. For the sake of a real-time computer graphics (CG) display, they tested whether their method could extract the amplitude of RSA in real time. They found that an elastic chest band is suitable for measuring intentional breathing under resting conditions and that Berger’s interpolation method was the best at detecting instantaneous heartbeat intervals in real-time signal processing.

One study of the relationship between biofeedback and breathing investigated the effectiveness of biofeedback in intentional breathing used as mental support by elite athletes. Four Japanese national team members participated in mental training to learn intentional breathing for relaxation. A small real-time biofeedback device was used to visualize the transitions into periods where PNS activity was dominant during training. Three athletes consistently improved their PNS dominant points, although they were using the training for the first time. Monitoring their own progress with real-time feedback helped the athletes master intentional breathing techniques having to do with breath rhythm and length. Reflections of the athletes, recorded over the course of ten sessions, showed that they all realized the advantage of using real-time biofeedback while acquiring an intentional breathing skill during mental training. These outcomes suggest that real-time biofeedback could be a very powerful tool for mental control support for both athletes and consultants [30].

While the importance of biofeedback as a method is now widely appreciated, existing biofeedback systems display biological information to the user as numerical data, a waveform, or both. In general, it is difficult for a layperson to properly understand the meaning of changes in numerical data or a waveform. This lack of understanding is a problem that affects the second step of giving the user the ability to confidently control the self. There is a possibility that displaying biofeedback information in the wrong format could cause the user to over respond, resulting in the opposite effect, rather than yielding a proper balance. In our study, we have introduced indirect biofeedback as a way to keep a sense of unity between the device that externalizes the internal state and the user. In our display, the circle represents the user as a system and the colors inside the circle represent the balance between the SNS and the PNS. The circumference of the circle represents the boundary between the self and others. If the physiological response of the user is less stable, the circle will shrink along one axis into an increasingly eccentric ellipse. The proposed system models the physiological state of the user, indicating the balance between the SNS and the PNS in the ANS as a color distribution in a simple circle. Such a simple representation should help users see their inner state and control it through intentional breathing to improve the balance between their SNS and PNS. The goal of our research was to learn whether a user could easily and casually identify their inner state and control it through intentional breathing.

The visualization method that we employ here is similar to methods used in other fields where graphical representation promotes understandability. In general, it should be easy for *a third person*, as an observer or the one who takes the measurements, to perceive and understand some phenomenon. On the other hand, our proposed method enables the user, not a third person, to observe their own inner state. Because observing the inner state can, in turn, affect the inner state, the effectiveness of this framework should be investigated in a different manner than the usual cases in which a third person is involved. We found no research that utilizes this sort of indirect representation of biofeedback information and as indication for self-control.

3.4 Proposed Model with Indirect Biofeedback

We used WHS-1 which Union Tools Corp. provides as a wearable heartbeat sensor, as shown in Figure 6.

Figure 6. WHS-1 wearable heartbeat sensor.

Figure 7 shows the configuration of the proposed system in this research, and Figure 8 shows the flow of processing.

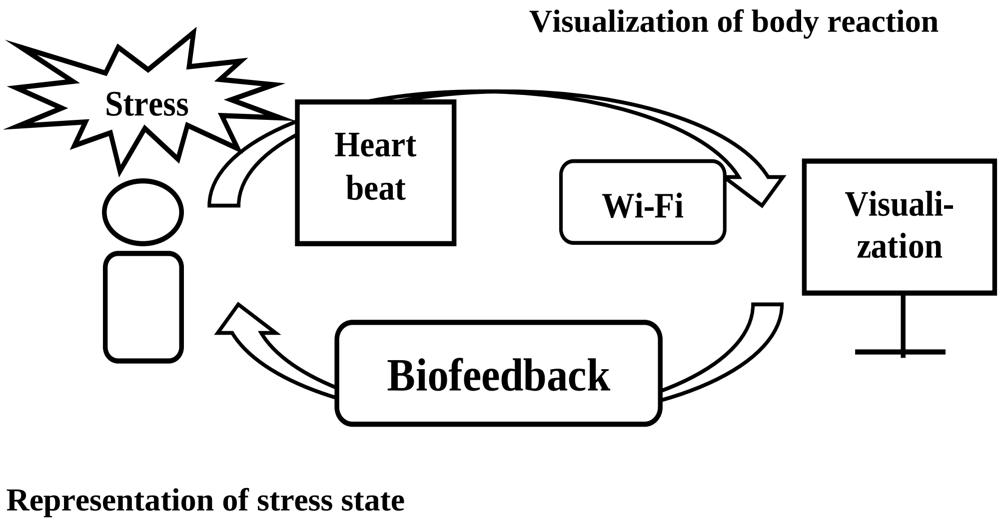

Figure 7. Indirect biofeedback system configuration.

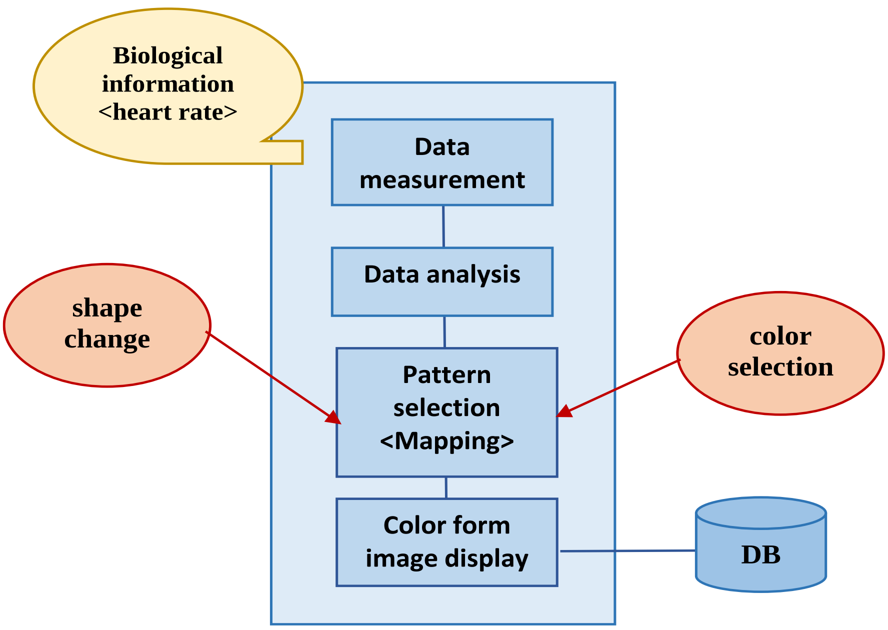

Figure 8. Flow of processing.

The system executes frequency analysis of results measured by WHS-1, calculates L/H, and compares the L/H with the one measured at the first time. If there is some changes in the comparison, the system changes the circle representation. In the case in which the circle representation is changed, the measured result on L/H is saved in DB so that the system can check it at any time.

The change in L/H, calculated on the basis of heartbeat fluctuation, is mapped as the change of color and shape of the circle that the system displays to a user.

- The analysis algorithm of L/H

To map the index of L/H into red, green, and blue sections of the circle, we conducted preliminary experiments and then based on the fact that LF/HF represents a balance between SNS and PNS in ANS and the results from the preliminary experiments, we obtained the following mapping rules [31][32];

- L/H > 0.4: SNS is more active than PNS, which corresponds to a tense or excited mental state that is represented by red.
- –0.4 ≤ L/H ≤ +0.4: SNS and PNS are in good balance, which corresponds to the best condition mentally and is represented by green.
- L/H < –0.4: PNS is more active than SNS, which corresponds to a sleepy or melancholy state and is represented by blue.

In addition, based on the results from the preliminary experiments, we decided to allow 5 min for data acquisition and processing to obtain a reliable value. Data acquisition and processing included

1. Acquisition of heartbeat data of a subject every minute.
2. Calculation of L/H.

3. Averaging the data obtained from the beginning of the experiment to the end (maximum of 5 min).

When L/H is zero, the user is in the process of switching from a physiological state in which one component of the ANS dominates (i.e., the SNS or the PNS) to one in which the opposite component dominates. As the number of switching times increases, the circle flattens into an ellipse. The L/H is calculated using the RRI of the heartbeat as follows:

RRI data => Abnormal value removal => Spline interpolation => Direct-current ingredient removal => Eliminate noises with window function => 0 => FFT => LF, HF=> LF/HF => L/H

3.4.1 Software Structure

Color biofeedback system is a system that visualizes the test person's body information as a circle based on the heart beat data got from the test person. The structure of the software is illustrated as Figure 9.

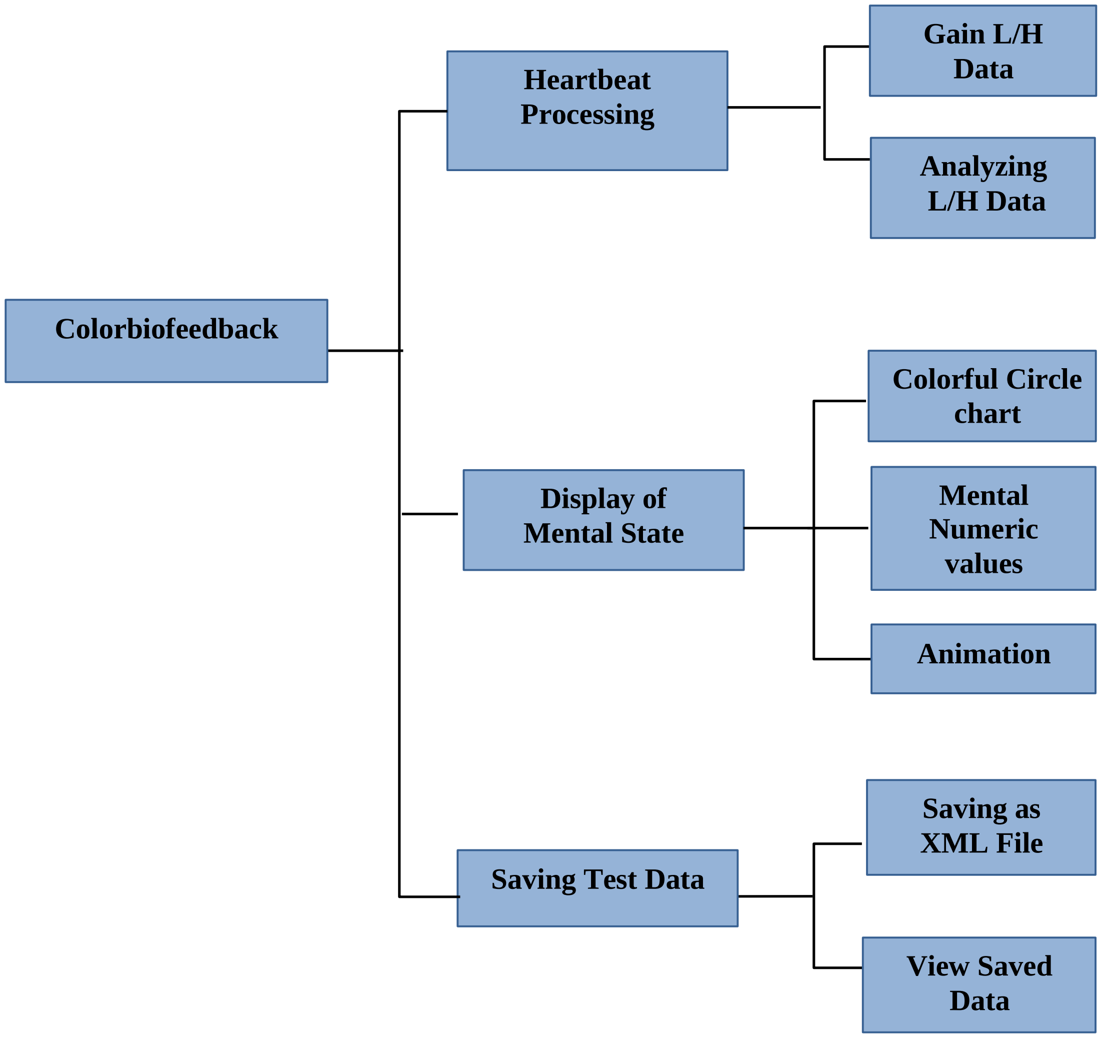

Figure 9. Structure of the software.

“Heartbeat Processing” is to implement gaining data from the sensor and analyzing the area of circle, exchange count of the sympathetic nervous system (SNS) / the parasympathetic nervous system (PNS) these two functions. “Display of Mental State” is to implement the function of displaying the colorful circle and numeric values in GUI. “Saving Test Data” is to implement saving the test data as XML file and displaying the saved data in GUI again these two functions.

The data flow diagram is illustrated in Figure 10.

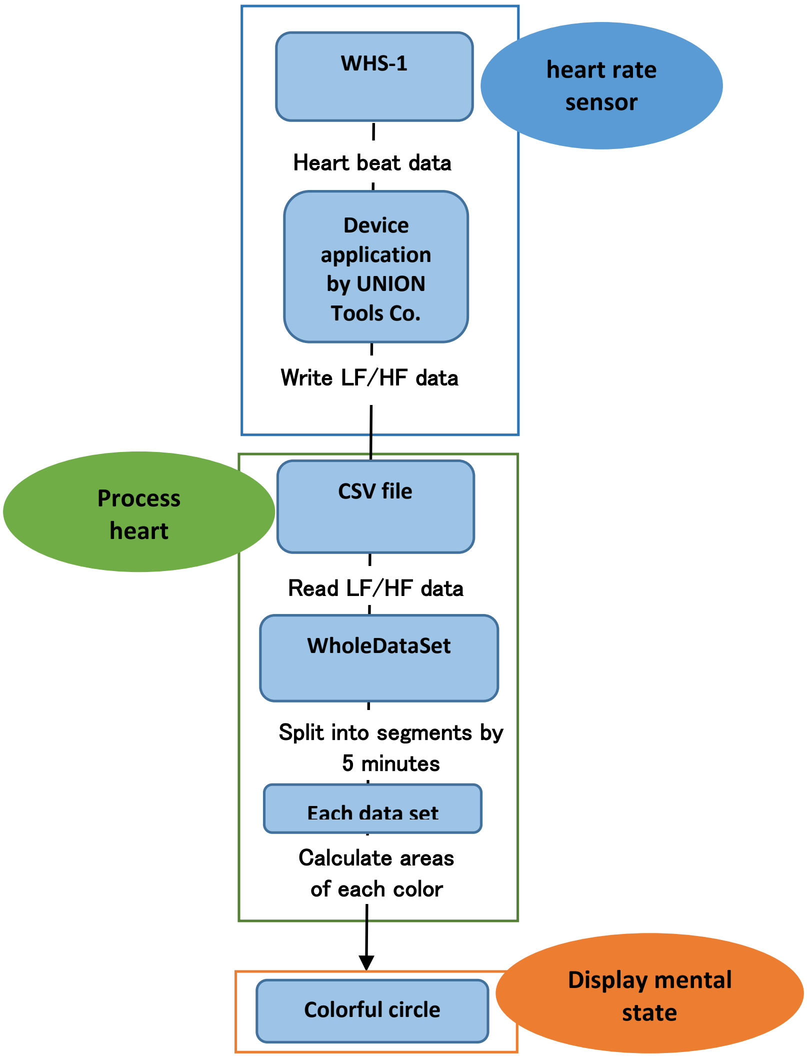

Figure 10. Data flow diagram.

3.4.1.1 Heartbeat Processing

We configured the following mechanisms as heartbeat processing.

- Saving L/H data

An example of gaining data is illustrated as Figure 11.

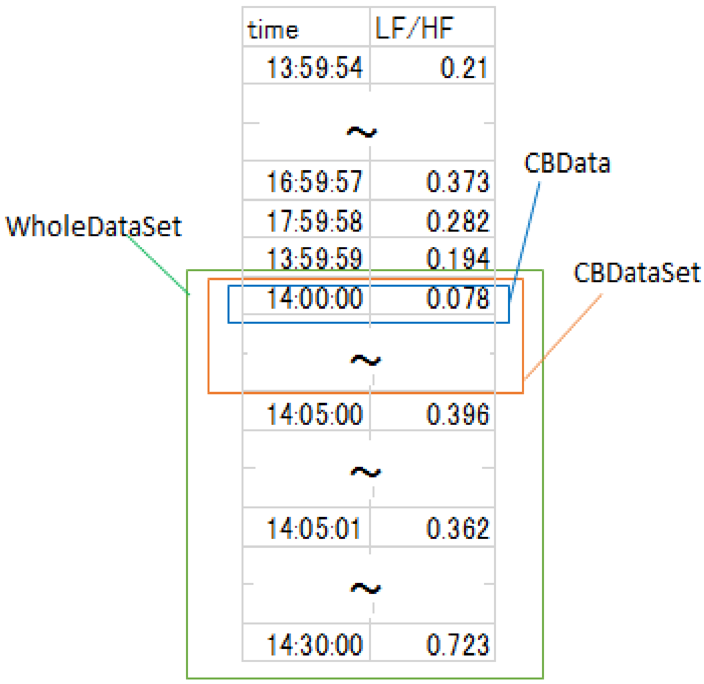

Figure 11 Gaining data example.

- Reading CSV file

The software reads the CSV file and creates the data including time and L/H values. There is a pattern in the data saved in CSV file. By following this pattern, the software reads the start time of the test in fourth line and reads time and L/H values from seventh line. The time and L/H value pair in one line is saved to one CBData class and all the CBData classes make up a CBDataSet class which means a collection of many pairs of time and L/H values. The data read from CSV file will first all be saved to one CBDataSet object of which the name is “WholeDataSet”. The “WholeDataSet” object includes all the data gained in one test. Then the “WholeDataSet” will be split into segments (sub data sets) by 5 minutes length.

- Analyzing L/H data

The data analysis flow chart is illustrated as Figure 12.

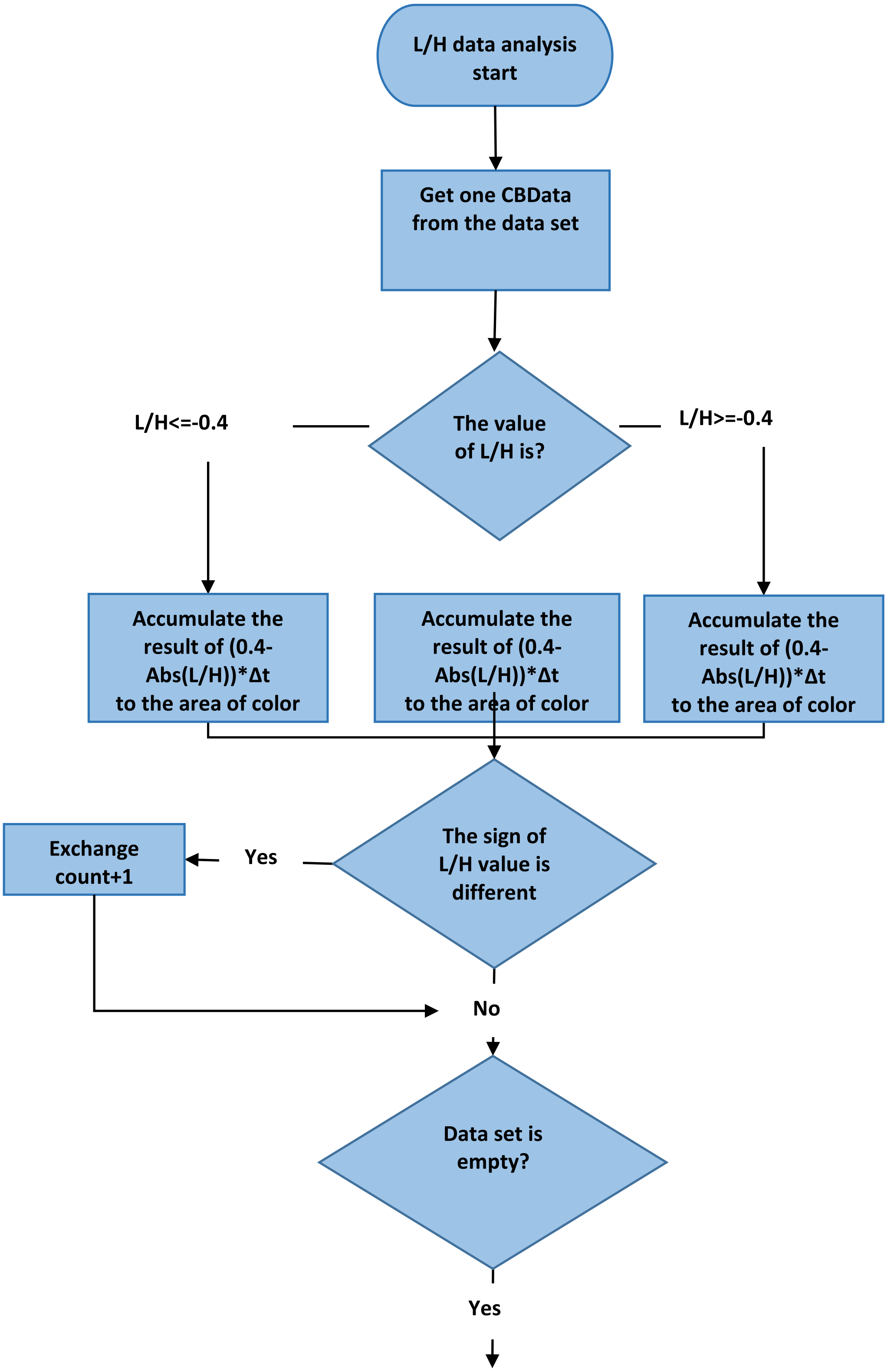

Figure 12 L/H data analysis flow chart.

In one CBData class, there is one pair of time and L/H value and data set is the collection of CBData objects. CBData objects are taken out from the data set and processed in sequence.

The area of each color is calculated according to the following function:

$$f_{area}()=(0.4-\text{Abs}(L/H))*\Delta t$$

Where Abs denotes absolute value and Δt denotes the difference of time to pervious CBData.

After all the data in data set is processed, the colorful circle chart and numeric values are displayed based on the accumulated area of three colors and the exchange count.

3.4.1.2 Display of Mental State

We designed the following functions as display of mental state for the patients.

- Procedure of display

The layout of display module is illustrated as Figure 13.

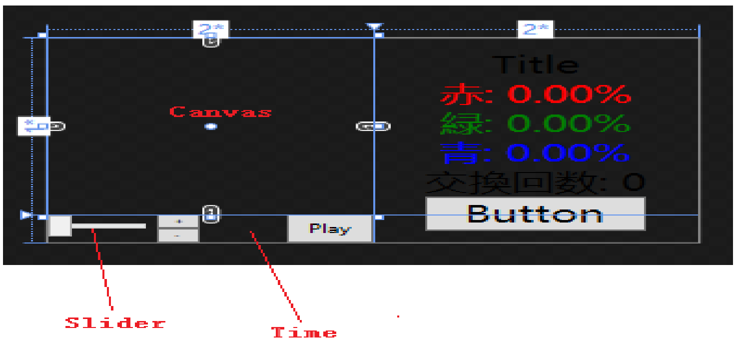

Figure 13. Layout of display module.

The “Canvas” grid is the place for drawing the circle which consists of three circular sectors of three colors. The numeric values are displayed on the right side according to the analysis result of test data.

The main procedure of drawing the colorful circle is illustrated as Figure 14.

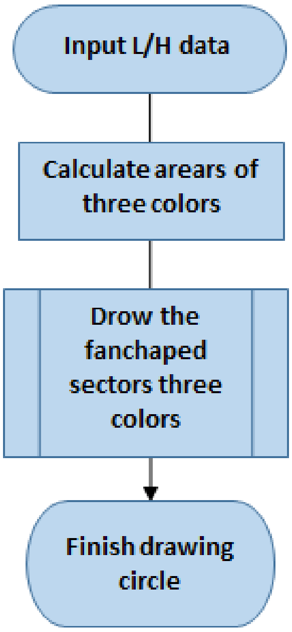

Figure 14. Main procedure of drawing circle.

To draw the circular sector of the circle, first draw a straight line in the position of begin degree. Then draw a wave line from begin degree to end degree and draw another straight line in the position of end degree so that the two straight line and the wave line can compose a circular sector. Finally fill the color in the circular sector. The procedure of drawing a circular sector is illustrated as Figure 15.

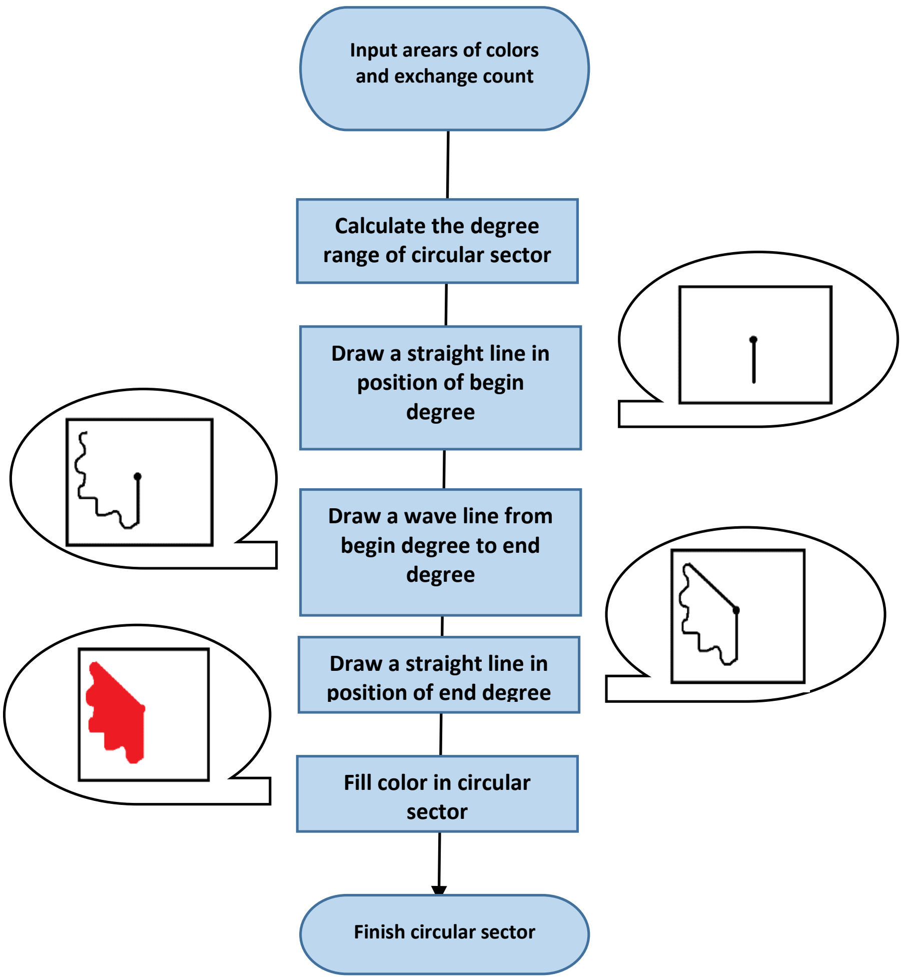

Figure 15. Procedure of drawing circular sector.

- Animation

The animation is implemented by refreshing the colorful circle chart and all the numeric values. While gaining data from sensor, the circle chart and numeric values are refreshed when getting new data from the CSV file. While replaying the test, the circle chart and numeric values are drawn according to the data recorded one by one in sequence with a time interval.

3.4.1.3 Test Data Saving

We developed the following functions as test data saving.

- Save as XML file

This function is to save the data gained in the test as a XML file. The data gained from CSV file is saved as CBData and CBDataSet objects in memory, so XML serialization is used to convert objects into XML text. The “Serialize” method of “System.Xml.Serialization.XmlSerializer” class is used for XML serialization.

- View test data

This function is to load test data from saved XML file. The “Deserialize” method of “System.Xml.Serialization.XmlSerializer” class is used for XML deserialization. By XML deserialization, the data saved in XML file is converted into CBData and CBDataSet objects and then the converted objects are put into display module of the software to replay the procedure of the test.

3.5 Initial Experiments and Results

To test the efficacy of our proposed methods of indirect biofeedback and intentional breathing exercises, we conducted experiments with 16 study participants (8 males and 8 females, between 19 and 22 years of age). Afterward, we calculated the RRIs of these participants and inferred the likelihood of their being under mental stress again.

3.5.1 Design of Experiments

For the experiment, the participants were asked to perform one of the following stresses:

*1: Recall unpleasant past experiences

*2: Iteratively perform the calculation $N_{i+1} = N_i - 7$ ($N_0 = 1111$, $i = 0, 1, 2, \ldots$) for 5 min

- Then the participant was asked to use one of the following stress control techniques:

  A: Intentional abdominal breathing

  B: Intentional thoracic breathing

We conducted four experiments using different patterns of the four items listed above:

- Pattern #1: *1 => A => *2 => B
- Pattern #2: *1 => B => *2 => A
- Pattern #3: *2 => A => *1 => B
- Pattern #4: *2 => B => *1 => A

- The experimental procedure was as follows:

1) The heart rate was measured when the participant was in a normal condition.
2) The participant identified their inner state using the proposed system.
3) The participant was exposed to mental stress *1 or *2.
4) After identifying their inner state using the proposed software system, the

participant used stress control method A or B.

5) Steps 3) through 5) were repeated twice while alternating the stress type and the control method.

6) The participant was allowed to return to his or her normal condition.

7) The difference (if any) between the initial (Step 1) and final (Step 6) normal conditions of the participant was calculated.

Each of the four patterns of the experiment was performed by four participants. Therefore, the total number of persons participating is all four patterns of experiments was 16.

3.5.2 Display Method of Indirect Biofeedback

Figure 16 shows the results of the use of the indirect biofeedback system.

Figure 16. Indirect biofeedback system results.

The therapeutic results of normal times measured before and after the experiment are arranged in a row for easy comparison.

3.5.3 Experimental Results

After the experiment, the study participants were asked to complete questionnaires.

3.5.3.1 Subjective Evaluation

By analyzing the answers provided by the study participants in their questionnaires, we evaluated reported tiredness and relaxation; the results are shown in Figure 17 and 18.

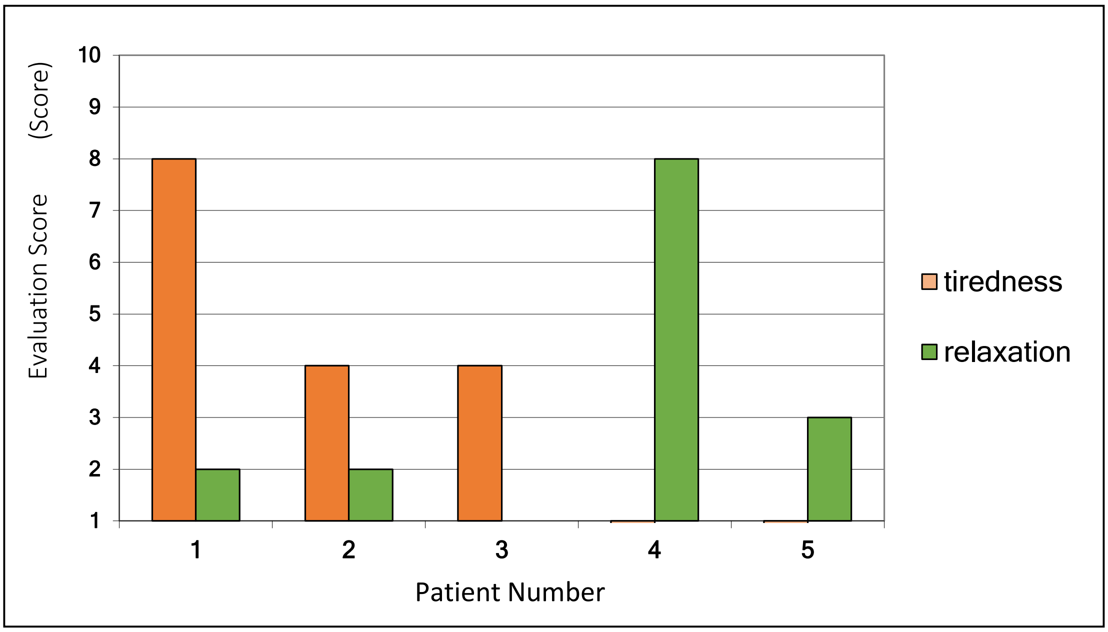

Figure 17. Amount of tiredness *before* the experiments.

(normal condition of subjects)

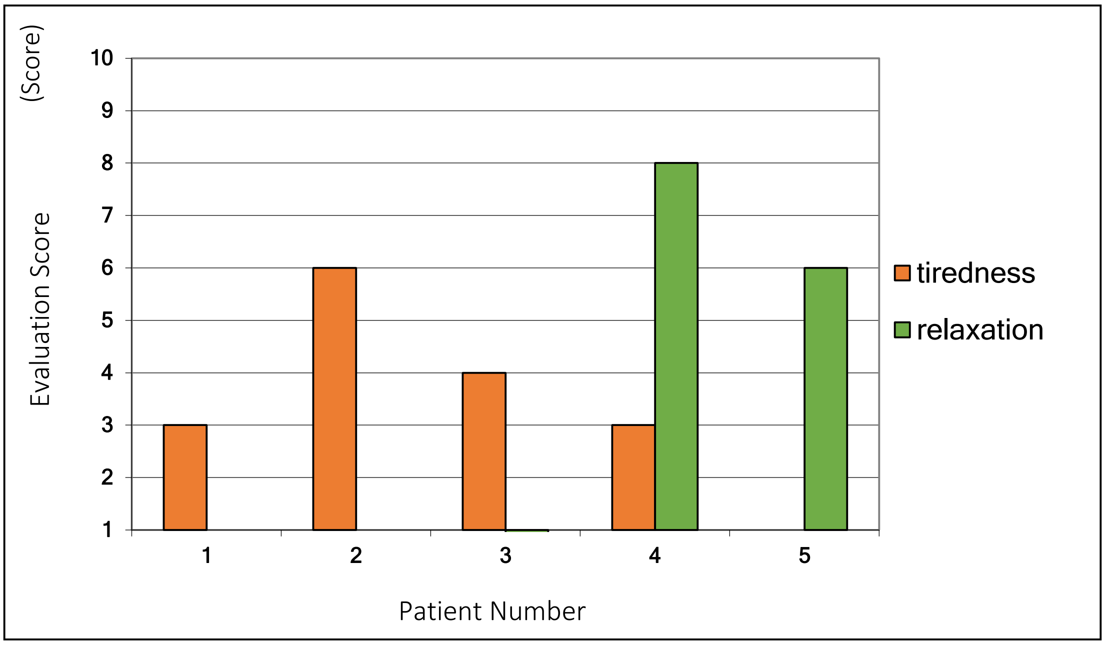

Figure 18. Amount of tiredness *after* the experiments

(normal condition of subjects).

Figure 5 and 6 show that the degree of both tiredness and relaxation increased as a result of the conducted experiments. The opinions of the subjects given in the questionnaire are presented below:

- **Could you relax (compared to the stressed condition) by applying the self-control methods (intentional abdominal and thoracic breathing)?**

  ・I was too conscious of the breathing.

  ・As a result of breathing, I was able to feel relaxed.

  ・As a result of breathing, I was able to feel refreshed.

1) **Did the representation of biofeedback as a circular graph influence your inner state?**

・I was able to confirm my relaxation by observing the circular graph visualized by the proposed system.

2) **Compared to relaxation by intentional breathing only, does the use of the proposed biofeedback system in addition to the intentional breathing allow you to achieve a more relaxed state?**

・I was able to relax.

・I was able to confirm my relaxation by observing the circular graph visualized by the proposed system.

3.5.3.2 Objective Evaluation

Figure 19 shows the green area percentages of patients' before the experiment.

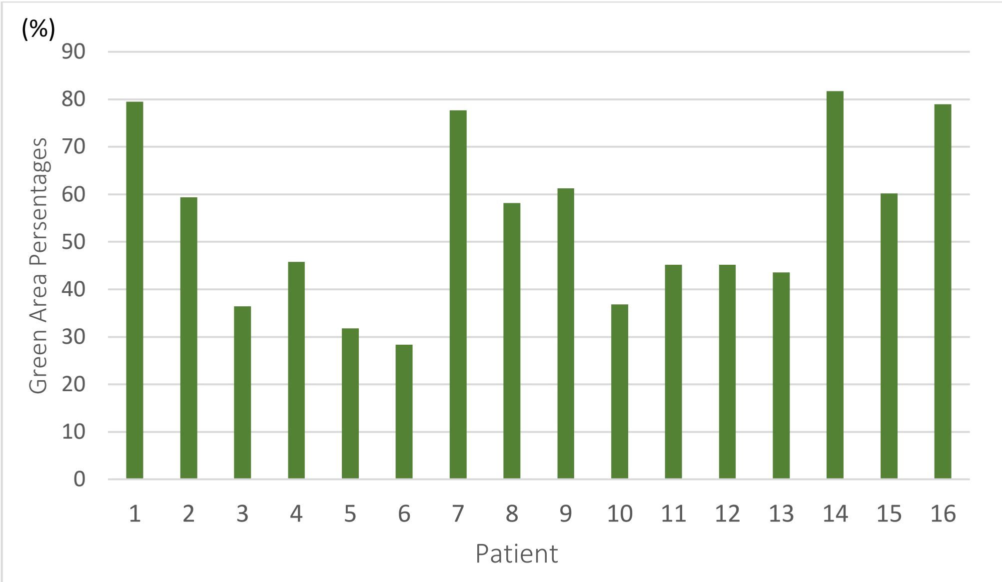

Figure 19. Green area percentages of patients' *before the experiment*.

Figure 20 shows the experimental results obtained for experimental pattern #2, which were more significant than those for the other patterns. The crosshatched bars illustrate parasympathetic dominance, the light stippled bars indicate a balance between the sympathetic and parasympathetic systems, and the dark stippled bars indicate sympathetic dominance.

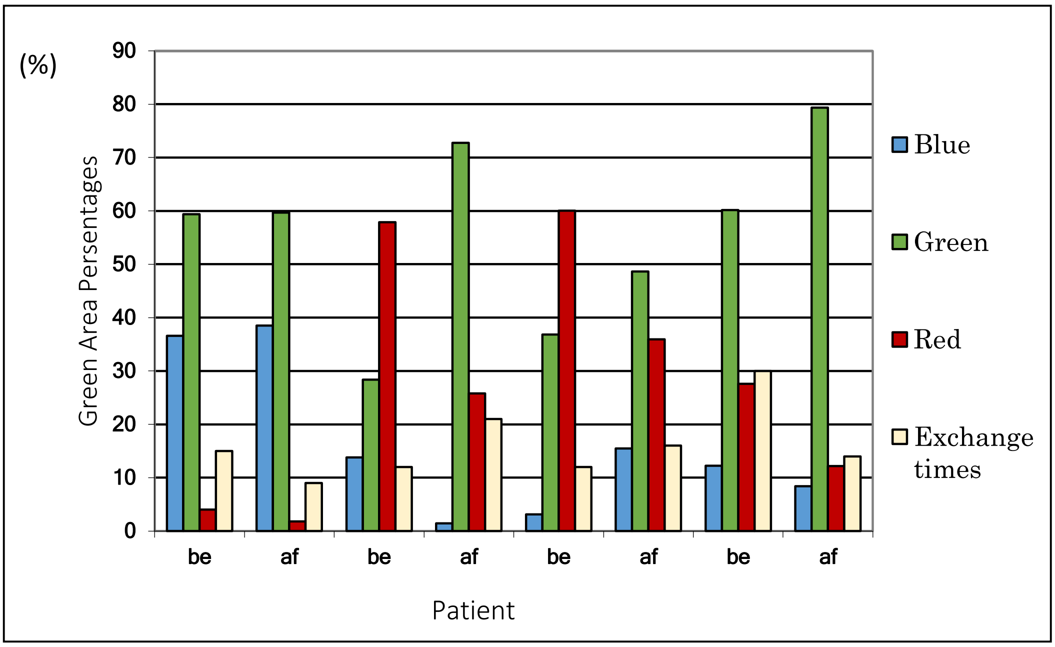

Figure 20. Results of the experiments of pattern #2.

The participants relaxed after recalling an unpleasant past experience by performing intentional thoracic breathing, which promotes excitement. Then, after performing mental calculation exercises, they relaxed through intentional abdominal breathing.

The relative size of the green (good) section of the circle before and after the experiment is compared in Figure 21. We evaluated the averaged difference of the ANS before and after the experiment using the ANOVA, which can identify a significant difference in a small amount of data with the same population.

Then determined the following value "*p*" rules in the Wilcoxon test [33][34]:

- $p>0.1$: not significant
- $0.05<p<0.10$: marginally significant
- $p<0.05$: significant

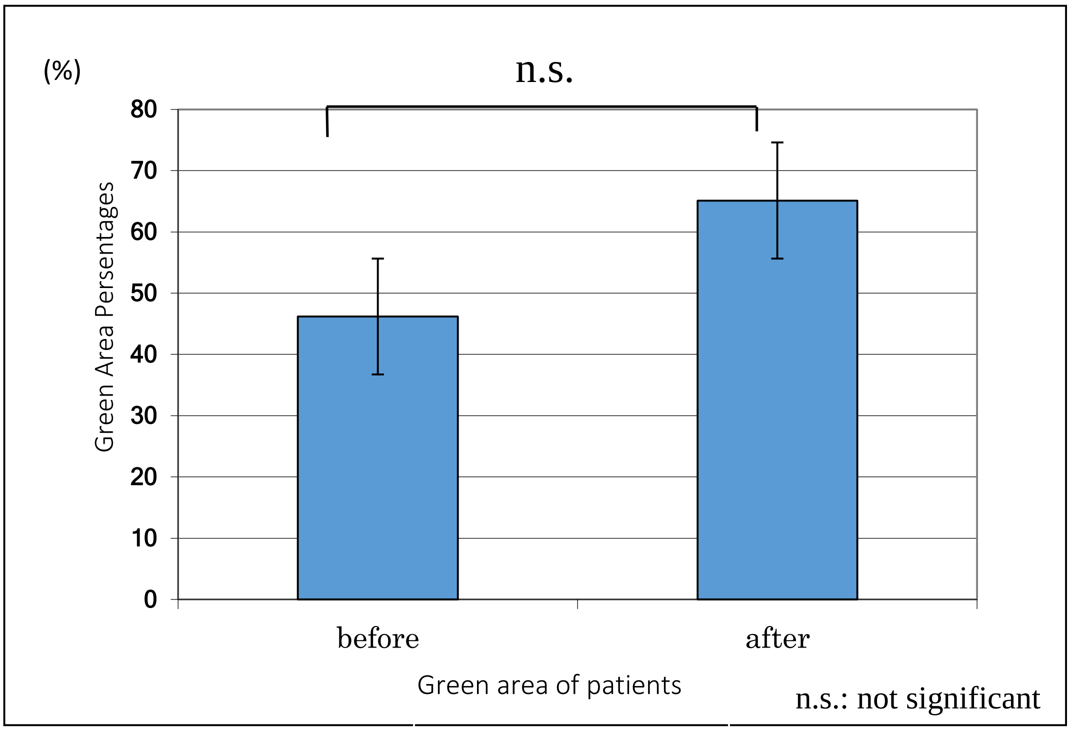

Figure 21. Test results of the experiment

(i.e., relative size of the green area).

Figure 21 shows that from $p = 0.136$, the experimental result was less significant than the T-test result for pattern #2.

From the experimental data, we concluded that recalling an unpleasant past experience as a stress load contributed to the increased tiredness of the participants.

Conversely, performing arithmetic calculations as the first stress-inducing method facilitated a reduction in the amount of stress.

The sequence of recalling an unpleasant past experience and doing arithmetic calculations as the first and second stress-inducing methods, respectively, is associated with sympathetic dominance. However, reversing the order of these two stress-inducing methods is associated with parasympathetic dominance.

The final physiological state of the study participants (either tired or relaxed) depended on the sequence of both stress-inducing and stress-controlling methods.

Because the participants in our experiments were mentally healthy, achieving a good level of self-control was relatively easy. In addition, even if a participant was stressed initially, the stress was reduced quickly and to very low levels because of the self-control exercises.

3.6 Discussion

The objective experimental results of our study indicated that there was no improvement in the physiological condition of the participants from the use of biofeedback. However, the subjects reported that they felt more relaxed. We think the discrepancy between the subjective and objective results indicates that the proposed system caused a placebo effect, wherein the user reported feeling relaxed regardless of the actual objective experimental results.

Some subjects wanted to see the balance of physiological information displayed as a graph rather than as a circle. Some subjects were too sensitive for the relaxation techniques to work. The feedback system should provide the user with several options for displaying the balance.

As for the method of controlling the self, we employed two intentional breathing techniques. The superior technique for controlling the balance between the SNS and the PNS depended on the situation and the individual. A future goal should be to provide the user with a more suitable method of controlling the self.

A certain amount of time is needed for training in self-control through biofeedback. However, we were able to get good results in subjective experiments when our subjects self-controlled for the first time. Thus, our evaluation of the proposed system showed that it achieved the functionality of a biofeedback system.

In a future study, we will conduct an experiment in which the participants use this proposed system and self-control for a certain period.

3.7 Conclusions

We developed an indirect biofeedback system that externalizes and objectifies the physiological state of the users to allow them to self-control their inner state. Indirect biofeedback allows the user to have a sense of unity with the device that externalizes the internal state of the self. For that purpose, we designed the system so that a circle represents the user.

We conducted four different experiments using human subjects. Each experiment included two different loads of stress and two different intentional breathing methods. We evaluated the measured data as well as the answers to a questionnaire filled out after the experiments. The results indicated that the study participants could properly control their inner states after the stress loads because they were healthy. In the indirect biofeedback system that we proposed, the subjects can easily grasp their inner state by observing circular representation with color and shape than direct biofeedback. In addition, indirect biofeedback does not cause any negative reaction that we noticed in the subjects with the direct biofeedback.

Thus, we conclude that users can self-control more easily using the proposed indirect biofeedback than the direct biofeedback common to the existing biofeedback systems.

In recent years, healthcare has become an important field on a global scale, and we will be entering an era in which we manage our own healthcare. Our proposed system could be used to manage and promote health by enabling users to self-control their inner state. It is helpful for general users who want to know their mental state that only the balance between the SNS and the PNS in the ANS, instead of a complex relationship between various indexes, is used in this proposed system.

In one of our future works, we will change the current stand-alone system into a network-based system that can collect user metadata, analyze it, and provide users with more useful information for their personal mental healthcare.

Chapter 4

Indirect Representation and Placebo Effect

This chapter describes a possible new scheme for a user with mental health problems to identify their own mental state and control it. For that purpose, we propose an indirect biofeedback system which represents physiological information with color and shape, and enables the user to grasp their inner state and to proactively change and control it through methods of breathing. Those methods facilitate the user to self-control the autonomic nervous system.

4.1 Indirect Representation and Placebo Effect

In the previous study, objective experimental results did not indicate an improvement in the study participants' physiological condition due to the use of biofeedback. However, the participants reported that they felt more relaxed. We think the discrepancy between the subjective and objective results indicates that the proposed system causes a placebo effect. Here we define a placebo effect as reporting feeling relaxed regardless of the actual objective experimental results. And some of the participants wanted to see the balance of physiological information displayed as a graph rather than a circle. Thus we conducted the following two experiments.

4.2 Experiments and Results

We conducted the following two experiments.

1) Effects of fake biofeedback: Place effect

2) Comparison with existing method of biofeedback

4.2.1 Effects of Fake Biofeedback: Placebo Effect

We conducted the experiment in which the participants evaluated both real and fake biofeedback. In the fake biofeedback, the user evaluated the data provided by another healthy participant with 23 study participants (12 males and 11 females aged between 19 and 22).

We designed this experiment as follows. The participant should use the following 2 kinds of systems;

*1: Real biofeedback system

*2: Fake biofeedback system

In the real feedback system, the participant gets their own biological information. On the hand, in the fake feedback system, the participant gets another healthy participant’s biological information as the feedback. The participant is asked to use the intentional abdominal breathing as the stress control techniques.

4.2.1.1 Subjective evaluation

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

4.2.1.2 Objective evaluation

As an objective evaluation, after the participants self-controlled using both real and fake biofeedback, we compared the effectiveness of the real and fake biofeedback in increasing of the green area that represents the balanced situation between SNS and PNS. The result is illustrated in Figure 22.

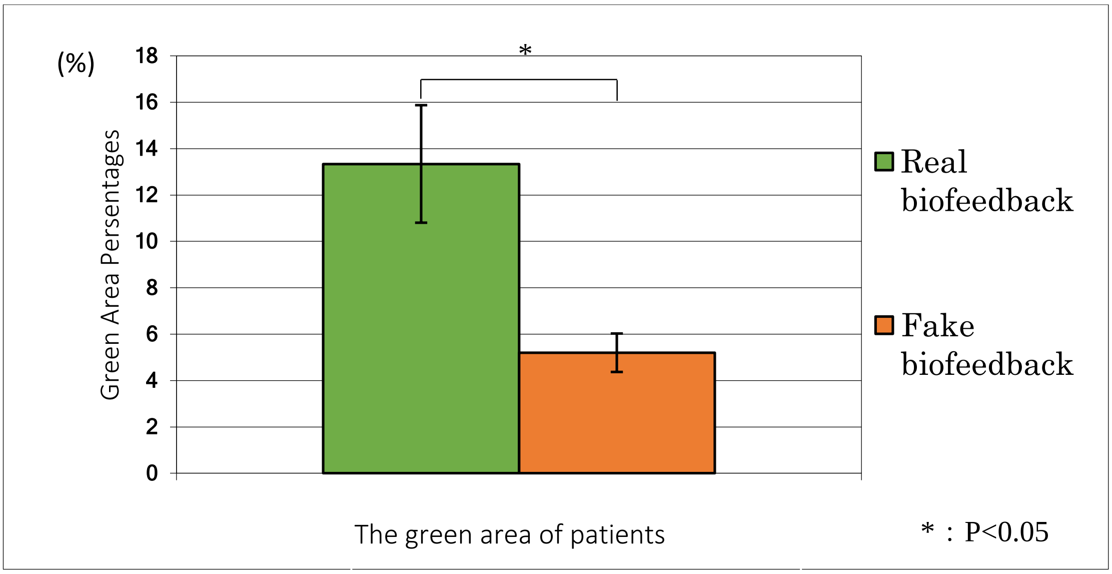

Figure 22. Test results of the placebo effect

(i.e., increase in the good balance of ANS).

As shown in Figure 22, the real biofeedback was significantly better at producing a balanced situation in ANS than was the fake biofeedback. Some participants doubted the behavior of the fake biofeedback readout because it changed even when they were not feeling anything. The participants felt that the real biofeedback reflected their mental states more closely.

4.2.2 Comparison with Existing Methods of Biofeedback

We conducted the experiment comparing the proposed indirect biofeedback display with a conventional direct biofeedback display with waveform representation with 23 study participants (12 males and 11 females aged between 19 and 22).

We designed this experiment as follows. The participant should use the following 2 kinds of systems;

*1: Indirect feedback system

*2: Direct feedback system

In the indirect feedback system, the participants get their own biological information as a form of circular representation proposed in this study. On the other hand, in the direct feedback system, the participants get their own biological information with waveform representation. The participant is asked to use the intentional abdominal breathing as a stress control technique.

4.2.2.1 Subjective evaluation

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

4.2.2.2 Objective evaluation

As an 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 Figure 23, which shows that the indirect feedback system was much more effective than the direct one. The result (p=0.04) was significant by the Wilcoxon test with p<0.05.

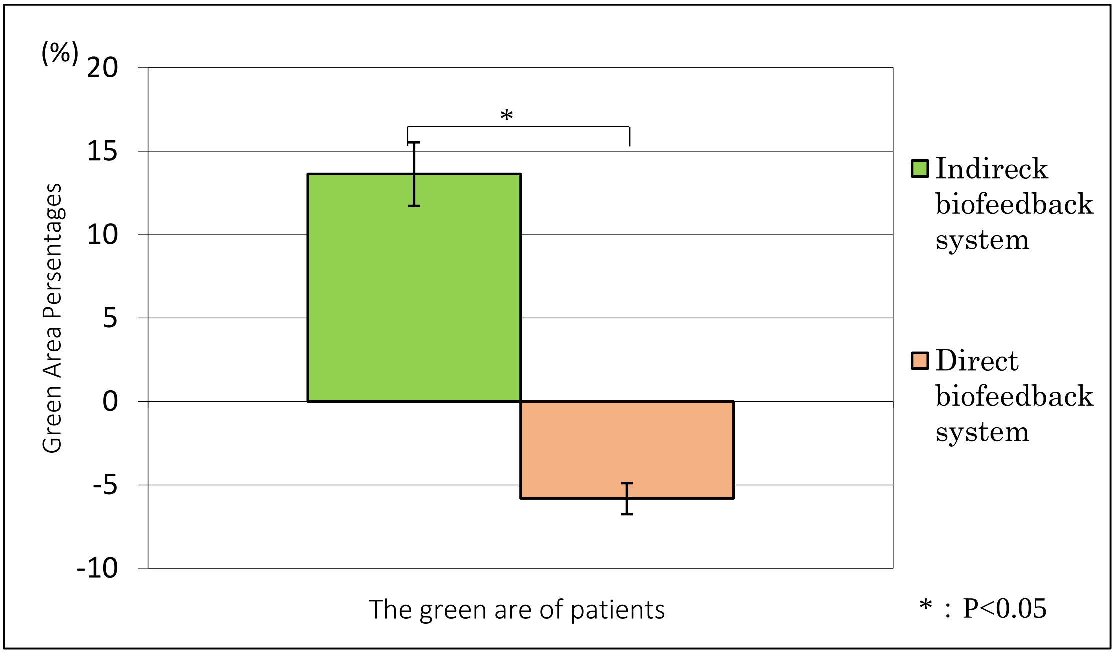

Figure 23. T-test results of the experiment about representation

(i.e. Increase of the good balance of ANS).

Some possible reasons for this result are:

3) 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 response in the subjects through straight expressions.

3) The direct feedback causes the participants to have stress with certain amount of tense or irritated and thereby reduce their level of ANS balance.

4) Indirect Biofeedback

1) The subjects can easily grasp their inner state through expressions easy to

understand.

2) The circular image and easily understandable expressions do not cause negative reactions which may occur in Direct Biofeedback to the participants.

Thus, we conclude that users can control themselves more easily using the proposed indirect biofeedback than the direct biofeedback common to existing biofeedback systems.

4.3 Discussion

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

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

4.4 Conclusions

In this research, we developed an indirect biofeedback system. This system externalizes and objectifies the user's physiological state for the purpose of allowing the user 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, we designed the system so that the circle represents the user him/herself.

We evaluated the measured data as well as the questionnaire results carried out after the experiments. The results indicate that study participants could properly control their inner states after the loads of stress, since they are healthy.

Moreover, we conducted the additional two experiments on the Placebo effect and on representation of biological information. In the experiment on the Placebo effect, when a participant has the fake information, we couldn't confirm any Placebo effect, however, when the participant has the real information, we could confirm the Placebo effect.

In the comparative experiment on representation of biological information, we could confirm that the indirect biofeedback is much better than the direct one.

Chapter 5

Multiple and Recursive Indirect-Biofeedback for Enabling Patient-Motivated Remedy

In this chapter, we propose a model of mutual acceptance between a patient, their family members, and medical staff, by sharing information through indirect biofeedback. As Japan develops into a super-aging society, effective and high-quality care for aged persons is becoming a serious problem. We focus on a psychological aspect of this problem, or deepening the mutual understanding and mutual acceptance between an aged patient, their family members, and medical staff, by sharing of indirect patient biofeedback information. In this research, we developed a multiple and recursive indirect biofeedback (MRIBF) system that is aimed for enabling patient-mediated remedy and improving the patients' quality of sleep. MRIBF brings patients the following effects; 1) patient-motivated remedy effect for pharmacotherapy and 2) improvement of their own natural healing ability. To clarify its usefulness of sharing indirect-biofeedback information, we have conducted an experiment with five elderly persons and two healthy ones as subjects as well as family members and medical staffs in a senior care home. We attempted to verify whether or not patients, their family members, and medical staffs could deepen their mutual understanding and mutual acceptance by sharing the indirect biofeedback information. Also, we evaluated whether or not the patients could improve their own conditions through the proposed indirect biofeedback.

5.1 Information Sharing through Indirect Biofeedback

We propose an indirect biofeedback mechanism that helps with patient awareness of their sleep quality and condition, through use of a device with visual features that vary according to the sleep data of the patient. We also propose a mechanism through which the patient, their family members, and medical staff can share the indirect biofeedback information.

In our previous work, we verified a possibility for a user to self-identify their mental state and to self-control it through indirect biofeedback. Based on affirmative results, here, we introduce a model of information sharing and verify a possibility of patient-motivated remedy as well as a possibility of self-identification and self-control of their mental state by their self, but also with sharing the information among their family members and medical staff through indirect biofeedback.

When the patient's indirect personal information can be shared, the expected situation will be beyond mere mutual awareness, instead moving to mutual acceptance.

What we emphasize as an aim of introducing indirect biofeedback is to seek a possibility for patient-motivated remedy through sharing indirect biofeedback information but not to provide information useful for disease treatment with a doctor nor to provide a useful care tool with care workers.

5.1.1 Concept

Figure 24 shows our proposed model for sharing of information through indirect biofeedback.

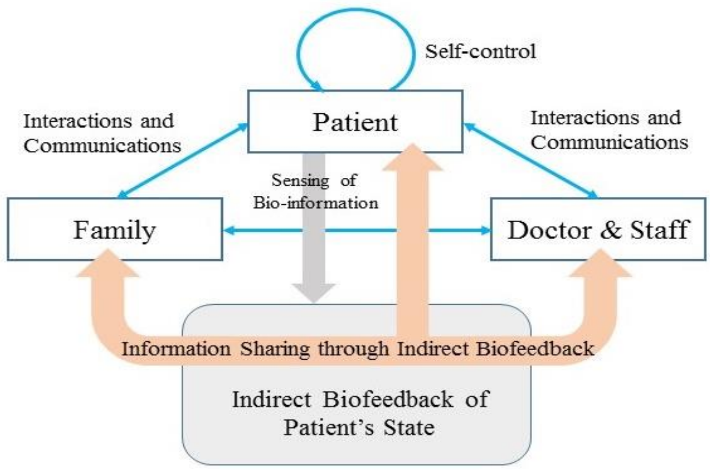

Figure 24. Model for information sharing through indirect biofeedback.

Sharing information about the patient's sleep state and quality influences the attitudes of others, and their interactions or communications with the patient. Medical staff can change their care plan for the patient, and the patient can be more relaxed and sleep more effectively.

5.1.2 Mutual Awareness by Sharing Information

Information sharing between people is useful for mutual awareness in general, as shown in Figure 25.

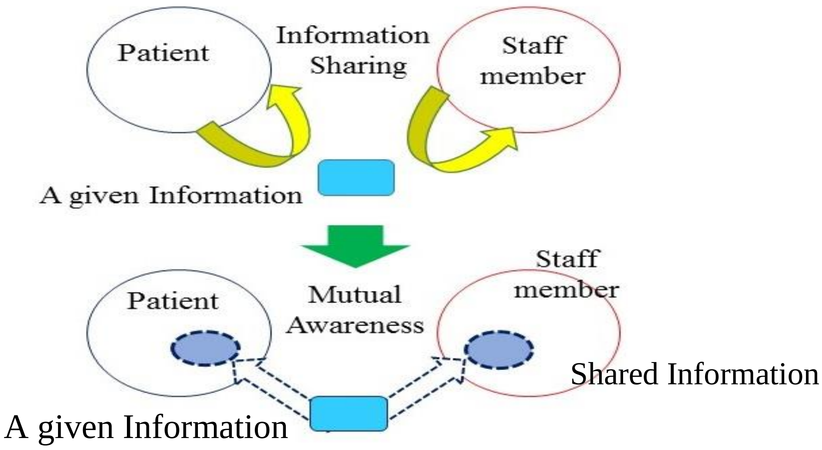

Figure 25. Mutual awareness through sharing of information.

In Figure 25, the light blue square represents the given information and dashed circles do the given information shared by a patient and a staff member through mutual awareness. If a friend visits the patient for example, a staff member knows this, and the patient is aware that the staff member knows this. Mutual awareness thus means that both know that they share certain information with each other.

The case which we focus on, however, is non-standard and additional considerations must be made. Medical staff are considered to be in strong position and a patient in a weak one, in the sense that the patient depends on medical care given by the staff. On the other hand, the patient pays for the medical care and services given by the staff, and information that should be shared with others, such as medical staff and family members, is the patient’s personal information.

Thus, information sharing between a patient and medical staff should be carefully designed considering the points mentioned above; however, awareness of the benefits of being understood and accepted by others through information sharing, may be of benefit to a patient.

5.1.3 From Mutual Awareness to Mutual Acceptance

Information sharing between a patient and medical staff should be carefully designed, particularly in that the patient information is highly personal and would not usually be seen by others. Generally, the patient does not want others to know highly personal information about themselves. Additionally, direct numerical feedback leads to negative feelings for the user, through a lack of understanding of unfamiliar data which display drastic numerical changes.

Indirect representation - or indirect biofeedback - therefore is useful. Information represented as indirect biofeedback and shared with others is still personal patient data, but provides enough distance from the patient that they can accept sharing of the personal information with others.

Figure 26 shows an image of the mutual acceptance that we are aiming to create between a patient and others. In Figure 26, dashed circles represents a patient's personal information, and Figure 26 shows that two big circles representing a patient and a staff member get closer by sharing the patient's personal information. It means that the patient feels a sort of familiarity to a staff member who gets to know the information, and the staff member also feels a sort of familiarity to the patient by knowing it vice versa.

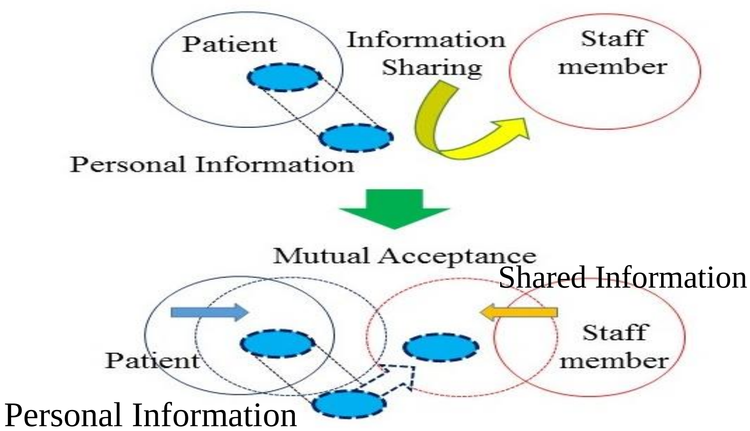

Figure 26. Mutual acceptance through sharing of information.

When the patient's indirect personal information can be shared, the expected situation should be beyond mere mutual awareness, instead moving to mutual acceptance.

5.1.4 Indirect Biofeedback for Sharing Information

Based on the above-mentioned necessity of indirect biofeedback against direct biofeedback, we can summarize the requirements for indirect biofeedback as follows: A representation of indirect biofeedback should exist as a familiar thing in our daily life, and could make some change depending on a person's biotic information and their inner state. In addition, it is quite important for people to easily and intuitively understand the meaning of the change. In considering senior patients this time, moreover, it should be natural even if it is displayed near their bed sides, and whether or not they can be aware of and/or interested in it. As for the negative feeling induced by indirect representation, we can control to weaken its effect by devising mapping of sleep score into some change of indirect representation. We consider it a merit of indirect biofeedback compared to direct biofeedback by numeric indication.

In this paper, we employ virtual plants and their changes as a representation of indirect biofeedback; this is shown in Figure 27. Some environmental studies support our intuition of employing virtual plants: As the objective results, plants elicit increase of Alpha waves in human brains, decrease of heart rate, increase of disease resistance and refreshment in both human's body and mind. As the subjective results, plants are effective in making people relaxed and relieved, and in increasing their motivation. Even fake plants can help people to be comfortable.

We consider that such representation will enable us to not only externalize and objectify a patient's physiological information, but will also allow the patient to aware of their inner state.

Indirect biofeedback by the proposed virtual plants can bring the following three effects.

1. The indirect biofeedback information can be used by the patient to gain awareness of sleep state and quality and to control their own self. In addition, since the patient's family members, doctors, and medical staff can also easily learn about the patient's sleep state and quality, the patient will be able to feel more understood. The indirect information is designed to be displayed in a way that anybody can understand and feel.
2. The indirect information through the proposed system in this research is not only fed back to the patient but also shared with the family members, doctors, and medical staff. Thus sharing some information about the patient's sleep state and quality influences other people's attitude towards the patient as well as the interactions and communications with the patient.
3. Medical staff can change their care plan for the patient and the patient can be more relaxed and sleep more effectively.

Figure 27. Plant-typed-avatars.

5.2 Related Works

Biofeedback has been used by psychologists to help treat a variety of issues, including post-traumatic stress disorder, attention deficit hyperactivity disorder, headache, and hypertension [35][36].

Nishino and his team found that we spend a significant part of our lives sleeping, which is essential to our physical and psychological well-being. However, sleep can easily be impaired by psychological and physical well-being [37][38]. Professor Shimamoto and his team found that a decline in the quality and total duration of sleep decreases physical activity levels, and increases daytime sleepiness; they also found that it increases the risk of lifestyle-related disease and depression [39].

In recent years, Japan has developed a super aging society, and an increase in the care required for elderly people is inevitable. Takadama and his team focused on this problem, and proposed a concierge-based care support system to provide a comfortable and healthy life for the elderly. The system estimates a user's daily sleep stage, and stores its personal data as big data. By doing so, care workers and doctors can design personal care plans for a specific user more effectively. The system for exploring life style improvement technology has the following characteristics [40][41][42],

1) Estimation of the sleep stage without connecting any devices to the user's body, and
2) Design of home care which supports elderly people who live in their house, a facility or a hospital.

On the other hand, these systems are not originally supposed to be used by ordinary users on a daily basis.

5.3 Information Sharing System through the Multiple and Recursive Indirect-Biofeedback

We have devised a multiple and recursive indirect biofeedback (MRIBF) system to enable patient-mediated remedy and improve the patients' quality of sleep, so that MRIBF could bring patients the following effects;

1) Patient-motivated remedy effect for pharmacotherapy

2) Improvement of patients' own natural healing ability such as maintenance of normal function and soundness in sleep

MRIBF is designed to support patients in tackling to improve their own condition through the Mindfulness-Based Cognitive Therapy (MBCT) and support members' speaking to them. MBCT provides a method to discipline a person to observe their selves apart from their selves, and works to promote patients' self-motivated attitude.

Figure 28 shows the configuration of information sharing system through MRIBF that has two unique features as follows:

1. Multiple indirect feedback to utilize multiple biological information as feedback resources, such as heartbeat and sleep
2. Recursive indirect feedback to utilize temporal changes of biological information as feedback resources

In Figure 28, thick solid lines represent indirect biofeedback, thick dashed lines do some support for a patient to tackle improvement of their condition, and dashed lines do recording information to a data base and getting information from the data base. By supporting patients to become aware of their condition and to motivate them, their quality of sleep and balance of their autonomic nervous system could be improved.

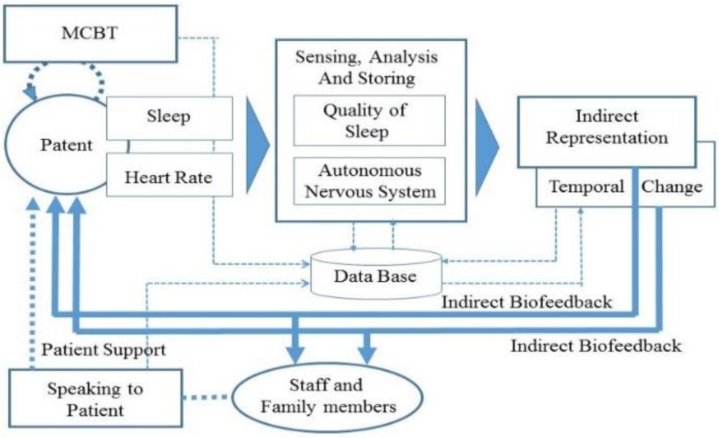

Figure 28. The configuration of information sharing system through the multiple and recursive indirect-biofeedback.

To obtain a patient's sleep data, we use the mattress sensor developed by TANITA, and an iPad as a display device for the patient. Sleep data are sent to a server using through a Wi-Fi router, and stored in a database to be analyzed. The analyzed results are transformed and visualized as a virtual plant which is provided as feedback to the patient, and also shared with medical staff and their family members.

5.3.1 Quality of Sleep

Sleep disorders increase the risk of lifestyle-related diseases and depression, and this decline has been observed in the Japanese populace with changes in lifestyle. Moreover, the quality and duration of sleep vary greatly with age, and previous studies have shown that sleep disorders commonly occur in the elderly.

The sleep state and/or sleep quality are determined by numerous factors. If the aim of this research is to exactly determine a patient's sleep state and/or sleep quality, it is indispensable for us to investigate how and what a factor affects sleep state and/or quality. However, the aim of this research is to seek a possibility for patient-motivated remedy through sharing indirect biofeedback information. For that purpose, we focused on how effective indirect representation can reflect some change of a patient's biotic information, and how effective such representation influences on information sharing. In other words, we determined the evaluation criteria on a patient's sleep state and/or quality depending on how effective indirect representation achieves information sharing. Thus, on this occasion we employed the sleep score calculated by some algorithm developed by TANITA, based on the length of deep sleep, the ratio of deep sleep, the number of nocturnal awaking and some sleep indicators, obtained through a mattress sensor.

Patient sleep states and quality of sleep are evaluated based on the data above; we also use these data as objective indicators, to judge the effect of indirect biofeedback and information sharing.

Additionally, we record a patient's daily events, such as taking a walk or bath, receiving a visitor, singing songs, or playing a game, as well as data on their sleep state. This accumulated data allows our system to show daily, weekly, monthly and/or yearly changes in a patient's sleep state, in the form of morphing virtual plant images. This also allows correlation analysis between these events and patient quality of sleep, and can be used to indicate a causal relationship between a specific event and their sleep.

5.3.2 Representation as Indirect Biofeedback

Based on the quality of sleep data acquired by the mattress sensor, the proposed system calculates the daily average sleep score, and compares changes daily. A patient's quality of sleep can be found by observing the changes and their variation from the daily average of all sleep factors.

As discussed, with our virtual plant model we do not employ direct feedback, but instead use indirect biofeedback. Our representation mimics the growth of plants, and is dependent on the difference between the pre-experiment average sleep score and the daily sleep score. We made computer graphics of a virtual plant by using the Linden-Mayer system that is a typical tool to generate plant-typed computer graphics. We generated around 50 graphics changing the parameters of both the number and size of flower and leaf respectively, and selected 20 graphics so as to correspond to the changes of patient's sleep score, as shown in Figure 29 [43][44].

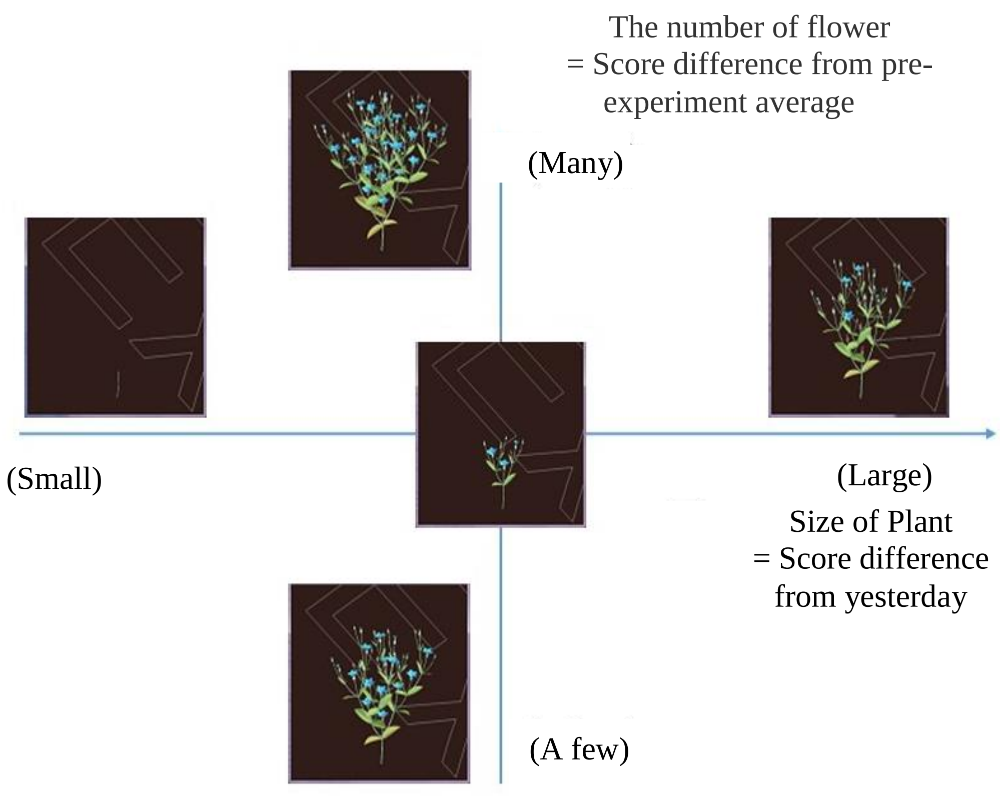

Figure 29. Mapping of sleep score into a virtual plant.

We developed the proposed system with simplicity in mind. We map the patient's sleep score to the corresponding flower. As our goal is to encourage voluntary self-therapy, we do not employ a direct mapping of sleep score to growth level. Instead, we first compute the average sleep score based on the score derived from the pre-experiment. This average sleep score serves as the basis of the mapping. When the patient's current sleep score matches their own basis, the growth level 10 flower is shown. For each 2.5 points of the patient's current sleep score that deviates their own basis, a different growth level flower is shown. This way, we are able to display a wide range of flowers for each patient, and are able to provide larger flowers when the patient improves regardless of their sleep score in the pre-experiment.

One issue we experienced when designing the algorithm is that some patients had extreme sleep score averages in the pre-experiment. When the score averages are close to the minimum or maximum, the basis does not allow room for growth. To solve this problem, we clamp the basis between 15 and 60. This way, even an average sleep score close to 0 will still display different flowers at different growth levels.

growth level = G

current sleep score [0 ~ 100] = S

basis [15 ~ 60] = B

$$G = 10 + \text{Floor}((S - B) / 2.5)$$

G is then clamped between 0 and 20.

Figure 30 shows the change in the sleep score for one patient, for 42 days. Figure 31 shows the virtual plant images corresponding to the sleep scores of the circled points in Figure 30.

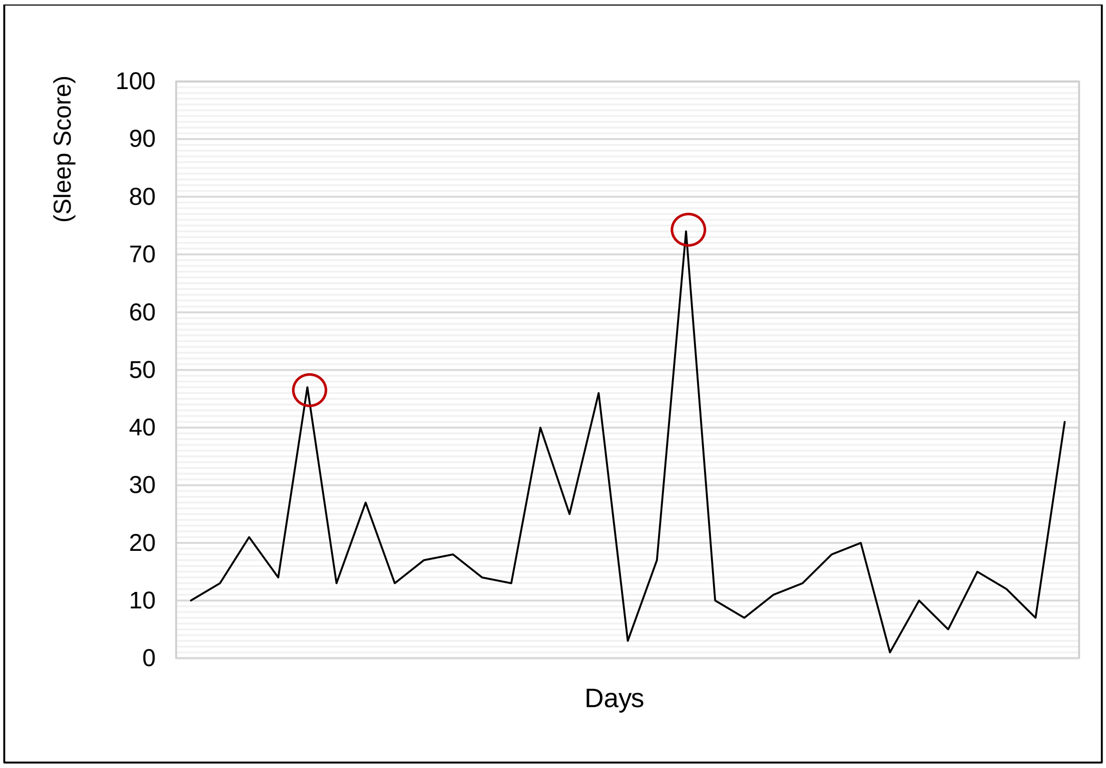

Figure 30. Change in sleep score for patient 5.

Figure 31. Virtual plant images corresponding to sleep score for the patient 5, as circled in Figure 30.

5.3.3 Information Sharing Design

Because sleep patterns can be obtained by evaluating all factors which influences sleep, the type of plant displayed should change depending on sleep patterns. Sleep patterns change daily according to a patient's state of sleep, and the types of plant are communicated to the patient, medical staff, and family members in advance; this allows them to recognize the patient's sleep state by looking at the types of virtual plants. We consider this helps staff and family members to talk to the patient more effectively. Knowledge of this information also allows the patient to change their own inner state and actions.

Figure 32 shows an example system display, and Figure 33 shows an example display which illustrates the relationship between sleep and events.

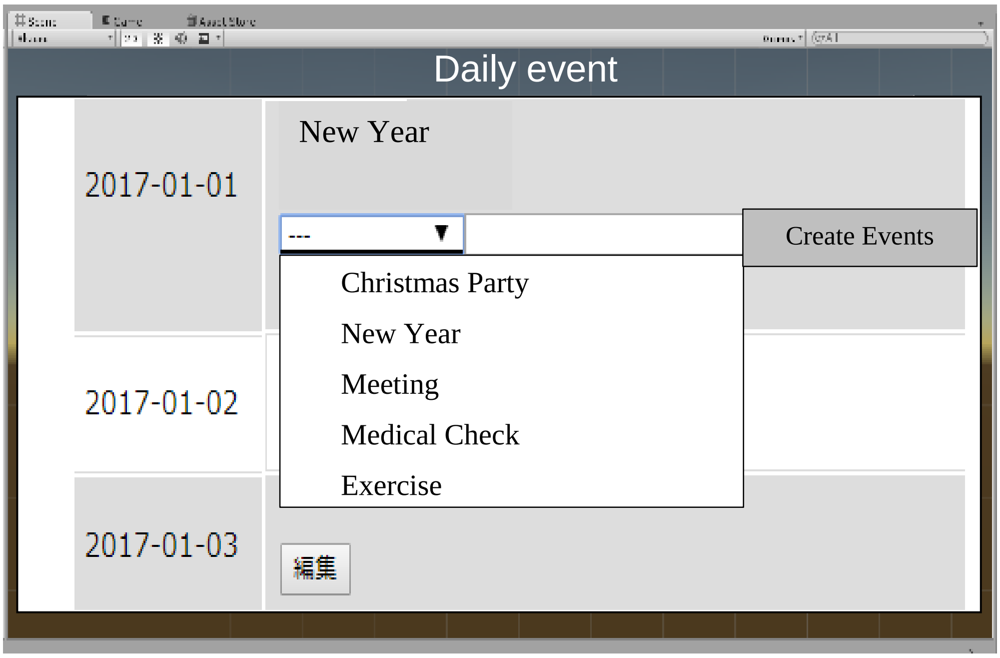

Figure 32. Example of system display.

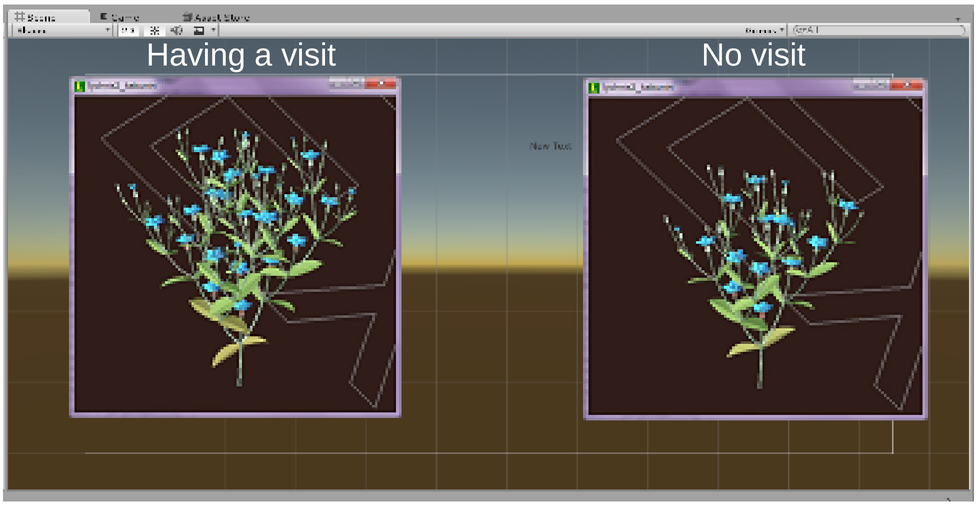

Figure 33. Display of the relationship between sleep (the plant) and an event.

In addition to the virtual plant display, direct numerical data is provided to hospital staff as shown in the Figure 34.

Days	Heart rate (low/high)	Sleep (Score)	LF/HF
5 / 16	56 / 91	40	0.4
5 / 15	58 / 99	60	0.2
5 / 14	54 / 92	55	0.6
5 / 13	56 / 93	52	0.1
5 / 12	54 / 93	53	0.2

Figure 34. Display of the patient's numerical data for the support members.

5.3.4 Patients' Self-Motivated Control of Their Condition

The proposed MRIBF supports patients to promote their self-motivated control of their condition with the following two ways;

1. Mindfulness-Based Cognitive Therapy (MBCT)
2. Support members' speaking to patients

MBCT is a psychotherapy approach originally created as a relapse-prevention treatment for depression. The goal of MBCT is to interrupt a user's self-reflective process and guide him/her to focus not on responding incoming stimuli but on accepting and observing him/herself without any judgment instead. Mindfulness and mindfulness meditation make much of becoming aware of thoughts and feelings caused by incoming stimuli and accepting them, not of being obsessed or reacting to them. This process is known as "Decentering" and aids in disengaging from self-criticism, rumination, and dysphonic mood that can arise when reacting to negative thinking patterns.

Support members' speaking to patients, on the other hand, also supports patients to be aware of and understand their sleep state, while support members such as family or medical staff can do the same as and accept patients much more and communicate them more effectively.

5.4 Experiments and Results

5.4.1 Experiment

In order to investigate whether indirect biofeedback can elicit patients' awareness of and interest in their own sleep state and quality and whether sharing such information can deepen mutual understanding and acceptance between patients, their family members and medical staff, we conducted experiments over seven weeks, including the pre-experimental phase. We designed a series of experiments with five patients resident in a senior care home, comprising two males and three females between 67 and 90 years of age. The patient sleep scores were obtained from a mattress sensor, and visualized on their own virtual plant. The patient and their support members saw the patient's virtual plant every day, and using this tried to talk to them more effectively; the virtual plant system can work as a good trigger for communications.

In this research, we are pursuing a possibility to realize a personal care system that can fit a specific patient and/or an individual. Since data on patients' sleep that we handle in this research are quite personal and rich in individuality, we position our research as a qualitative study to focus on individual and specific users compared to a quantitative study to focus on quantitative understanding. In that sense, we think it important to investigate the significance of this research even using data of a small number of patients [45].

5.4.2 Experimental Results

The patients and their support members were asked to complete questionnaires before and after the experiment.

Table.4 shows the average patient's sleep score during the experiment. Patients 1-5 refer to the patients in the senior care home, while 6 and 7 are healthy patients. As indicated in Table 4, the average sleep score of the patients is lower than those of the healthy patients. From the sleep evaluation of the algorithm of TANITA company, the average of sleep score of the healthy people is 50 score.

Table 4. Average of sleep score of patients.

Participant number	Sleep Score (Average)	Max. of Sleep Score	Min. of Sleep Score
1	12	25	1
2	7	23	1
3	17	54	11
4	6	17	1
5	19	74	1
6	43	66	10
7	41	90	10

5.4.2.1 Subjective Evaluation

In this experiment, we attempted patients' self-motivated control of their condition with the following two ways; Mindfulness-Based Cognitive Therapy (MBCT) and support members' speaking to patients. The participant was asked whether they tried MBCT and/or they experienced support members' speaking to them. After that, we then evaluated the patients' understanding and awareness of the virtual plant and its changes, and the degree of acceptance that they felt through use of the system. Figure 35 shows the results. The score range in evaluation is from one to five, and higher score means better evaluation.

By analyzing the questionnaire answers provided by study participants, we evaluated their degree of enjoyment, fun and/or interest to the virtual plant system; the results are shown in Figure 36. Patients 1 and 4 have dementia and had no interest in seeing the virtual plant.

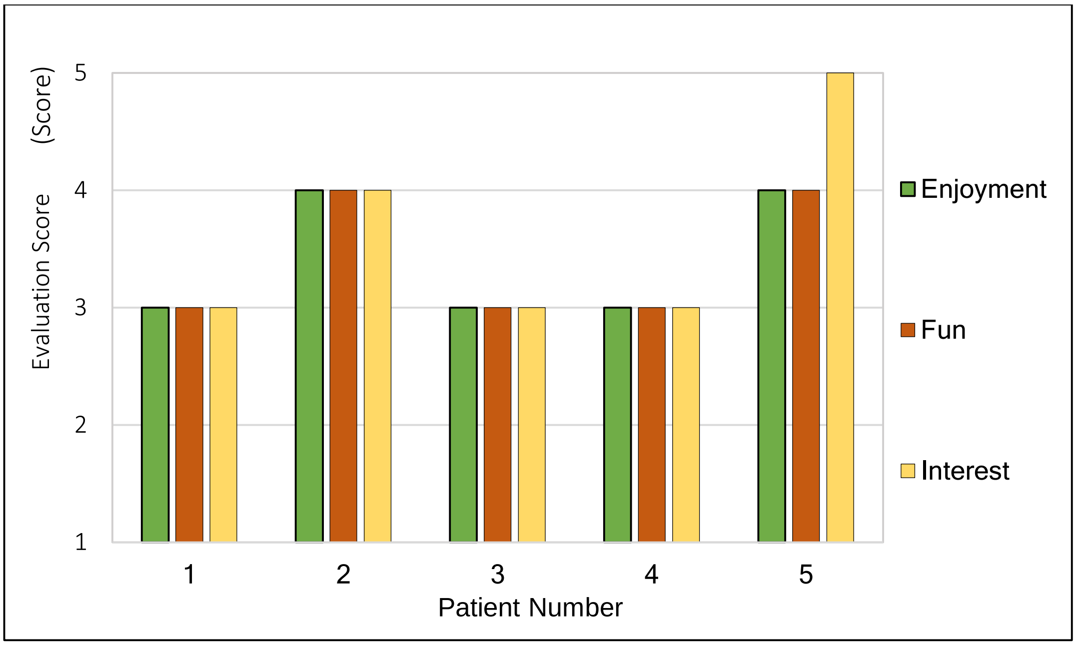

Figure 35. Degree of enjoyment, fun and/or interest in viewing the virtual plant.

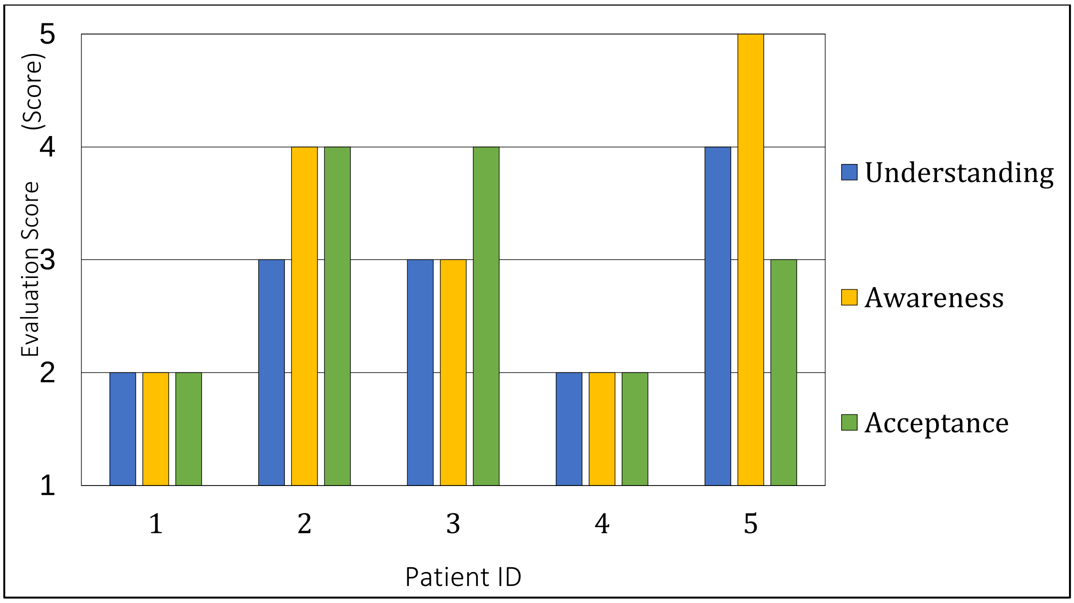

Figure 36. Degree of understanding, awareness and acceptance.

Figure 35 shows every patient's evaluation on enjoyment, fun and/or interest in viewing the virtual plant, where fun means how much they could be fun that the virtual plant and its change reflected their sleep state, interest means whether or not and how much they could be interested in their own sleep state. As shown in Figure 36, some patients could understand that the virtual plant and its changes reflected their sleep state, and through use of the system could have some awareness and accept the virtual; patients 1 and 4, however, who suffer from dementia, had no interest in the virtual plant.

We also evaluated how much the patient and staff members could share information about the patient's sleep state through use of the virtual plants; Figure 37 shows the results. The score range in evaluation is from one to five, and higher score means better evaluation.

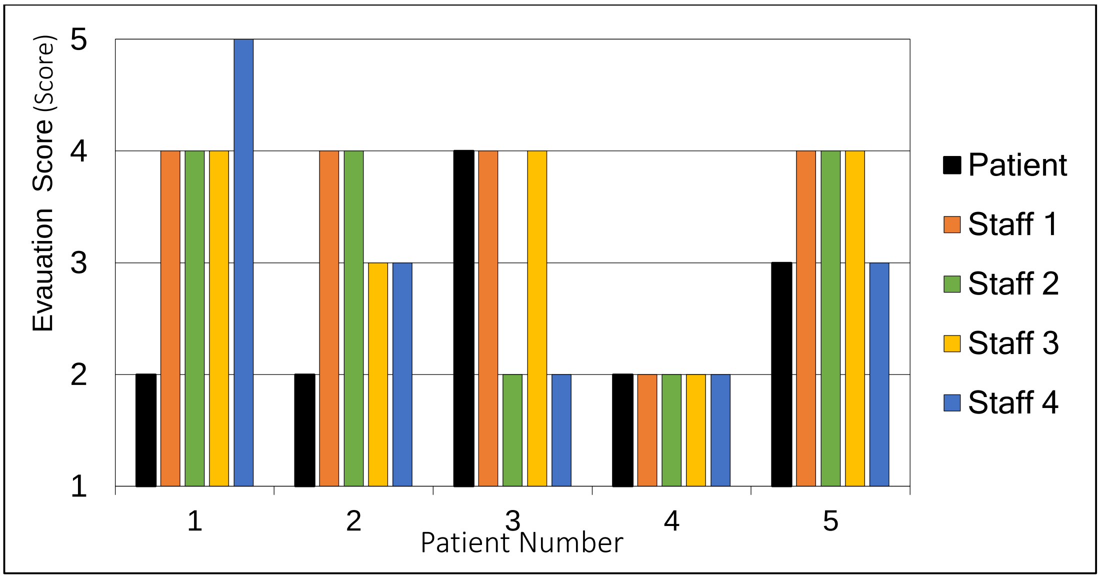

Figure 37. Degree of recognition of sleep state through virtual plants.

Figure 37 shows every patient's evaluation on how much they feel their sleep state could be shared by staff members through the virtual plant, and every staff's evaluation on how much they could share every patient's sleep state through the virtual plant. As shown in Figure 37, there are differences in recognition of information sharing on patients' sleep state between the patients themselves and their support members.

The above results confirmed that recognition of the patient sleep state by their support members is more accurate than the patient's. Patients could be aware of, and gain an understanding of, their own sleep state, while support members such as family or medical staff could be aware of, and understand, the patients' sleep state; they could also be more accepting of the patients, and could talk to them more effectively.

Some patients were not interested in the virtual plant because they were suffering from dementia, and some support members did not know how to use an iPad.

Results of the patients' questionnaire evaluation show that some patients enjoyed using the proposed indirect biofeedback representation. Results of the support members' evaluation show that some members recognized that there was difference in recognition of sleep state, between the patient and the support member.

5.4.2.2 Objective Evaluation

Since there is a possibility to improve patients' sleep state and quality as a possible side effect of information sharing, we analyzed patients' sleep scores, fluctuation of their heart rates while sleeping, and relationships with events which they experienced.

The increase of averages of patients sleep score before and after the experiment terms is shown in Figure 38. We evaluated the averages of patients sleep score before and after the experiment terms (the first and second) using the nonparametric Wilcoxon, which can identify a significant difference in a small amount of data.

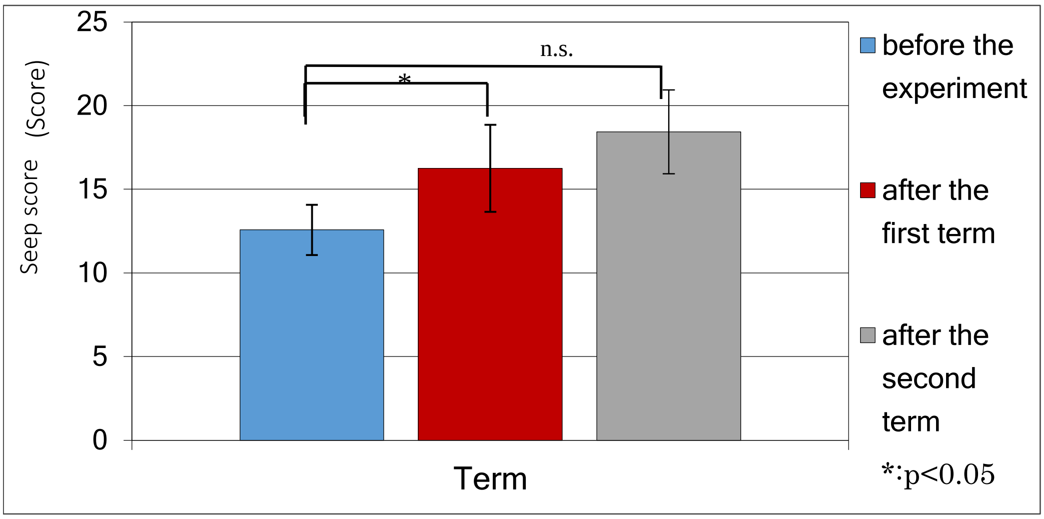

Figure 38. The increase of average of patients' sleep score

Figure 38 shows that there is no significance between before and after the first experiment term (*p*=0.15), but there is significance between before and after the second experiment term (*p*=0.03).

The daily fluctuation of patients' heart rate, that is, the difference between maximum and minimum heart rate in sleeping is one of the important indication for health, and a large fluctuation sometimes increases a possibility of some disease such as apoplectic stroke and Brady arrhythmia. As one of objective evaluation of introducing indirect biofeedback, thus, we analyzed the change of fluctuation of patients' heart rate in sleeping along with experiment terms, such as the term before the experiment, the first experiment term and the second term. Figure 38 shows the fluctuation of patients' heart rate averaged over the respective terms.

According to Figures 38, we could summarize in a comprehensive manner that the patients' sleep score was improved along with the process of this experiment was improved along with the improvement of sleep score. We could judge, thus, that indirect biofeedback with the virtual plant is useful for improving patients' sleep condition to some extent.

5.4.3 Mutual Relation between Sleep State and Event

We also attempted to evaluate the mutual relationship between a patent's sleep state, and their personal/social events. Although we could not get sufficient data on their personal/social events so far, as indicated in Table 5, we identified that patients' sleep scores were related to events such as a Christmas party or New Year's Day. Analysis based on sufficient data is one of further studies right now.

Table 5. Relationship between patients' sleep scores and events.

Participant Number	Date	Sleep Score	Event
1	2017/1/12-2017/1/17	1 (Minimum)	Influenza
3	2016/12/23	54 (Maximum)	Medical check and moving
4	2016/12/21	17 (Maximum)	Christmas party
5	2017/01/01	47 (Maximum)	New Year Day
7	2016/05/24	90 (Maximum)	Her birthday

5.5 Discussion

We designed a series of experiments with five senior and two healthy persons as subjects, and their family members and medical staff also participated in the experiment.

The aims of this experiment were to investigate whether sharing of this information can deepen mutual understanding and mutual acceptance between patients, their family members and medical staff, and to verify a possibility of improving a patient's sleep as a possible side effect of information sharing. The pre-experiment questionnaire showed that there was a difference in recognition of patients' sleep between patients and support members.

The experimental results showed that according to subjective evaluation, shown in Figure 35 and 36, we could confirm a few effect in understanding, awareness and acceptance of indirect biofeedback, but that according to objective evaluation, shown in Figure 38, we could confirm an effect to some extent in improving patients' sleep state in spite of their not-so-high self-motivation for sleep. Also, it is fact that some patients could enjoy and were interested in the proposed indirect biofeedback. Moreover, some patients had questions for improving their own sleep state and asked positively to the support members how to do it.

The results confirmed that recognition of the patient sleep state by their support members is more accurate than the patient's. Patients could be aware of, and gain an understanding of their own sleep state, while support members such as family or medical staff could be aware of, and understand, the patient's sleep state; they came to accept the patients, and could talk to them more effectively.

We also found that patient sleep score averages were lower than those of a healthy person. From the sleep evaluation of the algorithm of TANITA company, the average of sleep score of the healthy people is 50 score and the average of sleep score of the healthy people is 43 score in this research. In this research, however, the average of the sleep score of the elderly people was 12 score. The numbers of average of the nocturnal awakening between the healthy people and the elderly people are almost the same.

On the other hand, the elderly people got sleep more than the healthy people. In the experiment, the elderly patients slept over 12 hours every day. In addition, they got taking some naps some time during a day. We also found that they have sedentary lifestyles. However, the physical strength of the elderly people is lower than the healthy people in general. Thus, it is more difficult for the elderly people to get the deep sleep more than the healthy people. We considered that the elderly people got sleep longer than the healthy people. Therefore, sleeping too long might cause a light sleep for the elderly patients.

In this research, we adopted the sleep evaluation algorithm developed by TANITA. However, the algorithm does not take into account of a user's age. As one of further studies, thus, we should develop an algorithm suitable for the elderly people.

From the objective experimental evaluation, we concluded that the patients could recognized subconsciously and improved their own conditions through the proposed indirect biofeedback.

In this research, we employed the virtual plant as the feedback representation. In the future work, we have to adapt more representation ways as the feedback representation such as animals, plants and so on.

5.6 Conclusions

We have proposed an indirect biofeedback mechanism that helps patient awareness of their sleep quality and condition, by monitoring a device which displays a virtual plant. The structure of the plant varies according to the sleep data of the patient. We have also proposed a mechanism through which the patient, family members, and medical staff, can share indirect biofeedback information.

An experiment was conducted in a senior care home using five elderly people and two healthy people as subjects, with family members and medical staff participating in the experiment. The experiment attempted to clarify the usefulness of indirect biofeedback in the improvement of a patient's sleep. We also aimed to confirm that patients, their family members, and medical staff could deepen their mutual understanding and mutual acceptance by sharing the indirect biofeedback information. This effect was partially verified using subjective and objective evaluation.

In the future work, we will develop a system in which we can evaluate patients' conditions depending on their age, gender and disease so that patients and their support members can deepen mutual acceptance and understanding.

Chapter 6

Conclusion

In recent years, Japan has developed a super aging and mental disease society, and an increase in the care required for those people is inevitable. However, their situation is often not improved by consultation with specialists in psychiatry or psychosomatic medicine. A treatment with a specialist might not be very effective due to patient-motivated if it is a passive experience for the patient; if the patient is asked to approach the symptoms of their problems in a voluntary and proactive way however, the treatment is more likely to succeed. To elicit proactive behavior, the patient must be made aware of their current own state so that they can then act appropriately to maintain control.

Chapter 3 presented a new model for a user with mental health problems, and showed that the model can work for participants by gaining biological information, and by using the heart rate sensor. This chapter also showed several literary and experimental evidences that: taking a user-specific approach is better. Also experiments conducted suggested the indirect biofeedback can work for patients to control their own self and improve them.

Chapter 4 focused on the Placebo effect and on representation of biological information of indirect biofeedback.

In the experiment on the Placebo effect, when a participant has the fake information, we couldn’t confirm any Placebo effect, however, when the participant has the real information, we could confirm the Placebo effect.

In the comparative experiment on representation of bio feedback, we could confirm that the proposed biofeedback is much better than the conventional one.

Chapter 5 focused on an indirect biofeedback model that helps with patient awareness of their sleep quality and condition, through use of a device with visual features that vary according to the sleep data of the patient. We conducted an experiment in a senior care home, with family members and medical staff participating. We confirmed that patients, their family members, and medical staff could deepen their mutual understanding and mutual acceptance by sharing the indirect biofeedback information.

To sum up, the proposed model is: (1) helping for patients to control their own self and improve them, (2) having the Placebo effect and it is much better than the conventional one, (3) working for that the patients, their family members, and medical staff could deepen their mutual understanding and mutual acceptance by sharing the information through the proposed system.

We introduced indirect biofeedback and verified a possibility for a user to self-identify their state through indirect biofeedback.

We focused on seeking a possibility of a patient-motivated remedy as well as a possibility of self-identification.

1) Patient-motivated remedy effect for pharmacotherapy and

2) Improvement of their own natural healing ability.

We developed indirect biofeedback system that is aimed for enabling patient-mediated remedy, improving and sharing the patients' quality of autonomic nervous system and the sleep.

1) Patient-motivated remedy effect alternative to pharmacotherapy

The results indicated that the objective evaluation doesn't suggest significant but the subjective evaluation suggests significance.

2) Improvement of their own natural healing ability.

The results indicated that the subjective evaluation doesn't suggest significant but the objective evaluation suggests significance.

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The Effect of Transcription using Electronic Terminals on Mental Stability

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