A Multimedia System for Breath Regulation and Relaxation

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***Abstract*—In the hectic life today, detrimental stress has caused numerous illness. To adjust mental states, breath regulation plays a core role in multiple relaxation techniques. In this paper, we introduce a multimedia system supporting breath regulation and relaxation. Features of this system include non-contact respiration detection, bio-signal monitoring, and breath interaction. In addition to illustrating this system, we also propose a novel form of breath interaction. Through this form of breath interaction, the system effectively influenced user breath such that their breathing features turned into patterns that appeared when people were relaxed. An experiment was conducted to compare the effects of three forms of regulation, the free breathing mode, the pure guiding mode, and the local-mapping mode. Experiment results show that multimedia-assisted breath interaction successfully deepened and slowed down user breath, compared with free breathing mode. Besides objective breathing feature changes, subjective feedback also showed that participants were satisfied and became relaxed after using this system.**

Keywords—breathing; relaxation; biofeedback; interaction; multimedia

I. Introduction

Recently, mental stress is becoming one of the major factors causing illness. Health problems caused by stress include hypertension, cardiovascular diseases, increased likelihood of infections and depression [1-3]. To release stress multiple relaxation techniques have been developed over hundreds of years, including yoga, meditation, qi-kung, tai-chi, etc. in eastern culture society. Also in modern psychophysiology, relaxation techniques like autogenic training, diaphragmatic breathing, mindfulness, etc. are also developed [4].

Among those relaxation techniques breath regulation usually plays an essential role. Researchers demonstrated that breath regulation is beneficial for reducing blood pressure [5, 6] and focusing the mind for optimal performance [6].

Over the past decades, computing technologies have been utilized to support breath regulation in multiple applications. For instance, Moraveji proposed peripheral paced respiration, which integrated breath pacing application in the operating system, to slow down user breath during information work [7]. Yu proposed a multimedia biofeedback system for abdominal breath learning [8]. Park et al. designed multiple modes of breath induction to facilitate relaxation and other mental function promotion [9].

Most of these studies tend to influence user breath through providing respiratory guidance for users to follow, and turned their breath slow and deep eventually. However, human breath actually involves randomness between each cycle of inhalation and exhalation. Even in calm status, there exit correlation plus random variation between each breath. Breath features like breath period, breathing depth, and the inhalation/exhalation ratio varies spontaneously. In fact, a range of studies has shown that healthy breathing is characterized by complex variability consisting of considerable structured variability and some random variability [10-13]. Forced breath pacing though mechanically changes user breath, the subjective feeling of relaxation may not be promoted [14]. Therefore, pure guiding style of breath regulation may not be suitable when applied for relaxation.

Fig. 1. The relaxation system appearance

In the breath interaction module of our relaxation system, we propose a target-based breath regulation. Unlike traditional pure breath guiding, in which the guiding multimedia is unrelated to user breath and the user is required to breathe following the guide during the entire process of the breath regulation, the visual or aural feedback reflects user breath in the target-based breath regulation. The user is asked to achieve some feedback target through his or her breathing. For instance, if the visual feedback of user breath is a flower, which opens and closes to reflect inhaling and exhaling. The instruction given to the user may be “Let the flower open to the maximum and close to the minimum through your breathing”. After giving the instruction to the user, we can influence users’ breathing pattern differently through manage the underlying signal mapping mechanism. The mechanism mapping the breath signal to the visual/aural multimedia feedback can be designed to slow down and deepen user breaths as we expected. The difference between this target-based breath regulation and common pure breath pacing is that user breath is less constrained. Target achievement timing is loosely stipulated. Tension and discomfort caused by forced breath pacing reduce while the influence on breath can still be achieved because of the attempt to accomplish the given target.

Except proposing novel form of breath regulation, we integrate newly developed noncontact breath detection technique, special reflection mechanism, and bio-signal monitoring to implement a relaxation system. Following, we first illustrate the construction of the system in Section II. Then we detailed the proposed breath interaction mechanism and a preliminary experiment conducted in Section III. In Section IV, a formal experiment is introduced. The experiment procedure designed to investigate the effects of three forms of breath regulation - pure guiding mode, target-based mode, and free breathing mode, which means no multimedia feedback is involved, is demonstrated. The experiment results are also reported and illustrated. In Section V, the analysis and comparisons of physiology changes are demonstrated. Subjective reports when experiencing these three modes are also discussed. Finally, conclusions and acknowledgements are represented in Section VI and Section VII.

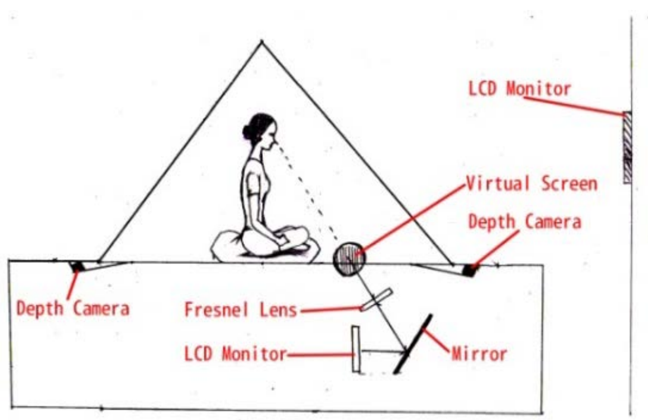

Fig. 2. The platform design diagram

II. System Design

A. System Structure

The reason we have the opportunity to implement this multimedia system is because of a collaborative project with a professional music company. The system will be settled at a realistic music store for long term commercial exhibition after this study. Therefore, sometimes the reason of the appearance selection is partially due to the artistic sensation, not entirely for the technical reasons. To deliver the isolated and stable visual sensation, the appearance of this system is specially designed in the shape of a pyramid. Copper tubes are used to construct the pyramid shape frame (Fig. 1). Construction of the system is illustrated in Fig. 2. A user is required to sit at a specified position under the pyramid so that his or her respiration can be detected correctly. Two depth cameras are placed in the front and in the back of the user to detect respiration [15], in the meantime, a blood volume pulse (BVP) sensor and a skin conductance response (SCR) sensor are integrated in a sphere (Fig. 3). The sphere is put aside the seat and meant to be hold by the user when using this system.

There are two monitors in this system. One is embedded in the wall in front of the user, showing immediate detected bio-signals including breaths, heart rate, and SCR (Fig. 4). The other one is under the user's sitting ground displaying a metaphor (i.e. a lotus in our design). Displayed metaphor image is reflected by a mirror and projected through a Fresnel lens so that only people sitting at the specified position under the pyramid can have a clear view of it [16] (Fig. 2). Because the background of the metaphor image is removed and the special optical effect of the Fresnel lens, this projected metaphor looks floating in the air in front of the user.

B. Sensors

1) Respiration Sensor

In the past, the respiratory inductive plethysmography (RIP) sensor is usually the choice of the respiration sensor, and it is widely used in respiration related researches. Although the bound feeling while using RIP makes the user uncomfortable, traditional noncontact respiration detection techniques are too expensive and related settings are complicated. For instance, optoelectronic plethysmography requires the user being attached with multiple light-reflecting markers.

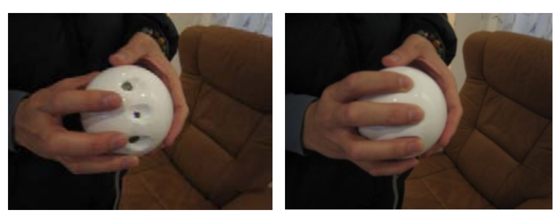

Fig. 3. The remade sphere shape sensor of heart rate and skin conductance

Until recently, a novel respiration detection method using depth camera is proposed [15]. The emitter mounted in the depth camera emits infrared (IR) light beams and the depth sensor reads the IR beams reflected back to the sensor. The reflected beams are converted into depth information measuring the distance between an object and the sensor. Since we put two depth cameras in front and in back of the user. We can obtain the distance from the front side of the user to the front depth camera and the distance at the back side. Then, given the distance between two depth cameras, we can obtain the thickness of the user torso. Therefore, the respiratory signal (respiratory rate and depth) can be measured through the thickness changes as a result of breathing. This depth information based detecting method is not only cheap but also simple to operate. The only device needed are depth cameras and no other miscellaneous gadget is required. Therefore, we choose this technique as our respiration detection method.

Another advantage of using depth cameras as the respiration sensor is that we can observe the fluctuation at chest and at belly separately. With this information, we can provide user more concrete visual feedback when practicing diaphragmatic breathing (Fig. 4). Diaphragmatic breathing, also known as abdominal breathing, is a well-known breathing technique which activates parasympathetic nervous system (PNS) and induces relaxation [18]. It will be recommended to the users when using this relaxation system in our experiment.

2) Heart Rate and Skin Conductance Sensors

The bio-sensor adopted is the peripheral device of WildDivine, which includes a photoplethysmograph (PPG) sensor and two electrodes so that user's BVP and SCR can be detected [17]. In order to provide comfortable and naturalistic sensor interface, we specially embedded the bio-sensor into a sphere ball with pits for easy contact (Fig. 3).

3) Biofeedback Medium

There are two forms of visual feedback in this system. The first one is the bio-signal monitoring shown on the screen in front of the user (Fig. 4). Signals shown in the order: left up, left down, right up, and right down, are respectively chest breath, belly breath, heartbeat, and SCR. There is a rectangle mask composed of blue and green regions in the middle window. This mask uses blue region to cover the chest part and green region to cover the belly part. A user can adjust the position of this mask and the covering range of the blue and green regions by mouse clicks. This enables identifying the proportion of the abdominal breath. Besides, the SCR curve at the right down window also indicates the relaxing extent of the user.

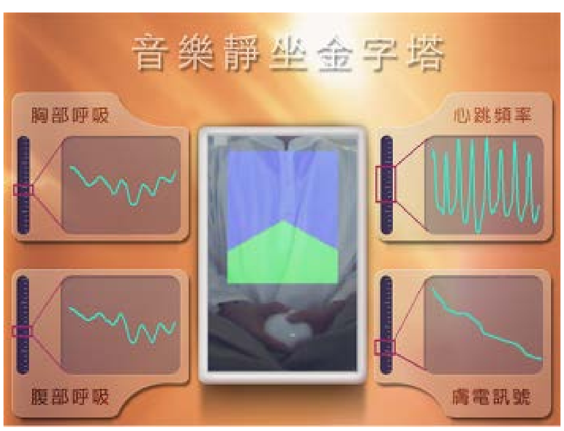

Fig. 4. Bio-signal monitoring

The second form of visual feedback is a metaphor (it is a lotus in our application) projected by the reflection mechanism beneath the sitting ground. The user sitting at the specific position so that he or she can have a special visual effect that the projected metaphor seems floating in the air. The projected metaphor is replaceable, and we choose a lotus as the metaphor of breath in our application because that a lotus is widely used in eastern culture to symbolize a pure, peaceful and clear mental state. Later in the experiment, the lotus is designed to open and close to imply inhalation and exhalation of the user respectively.

III. Breath Interaction

A. *The Mapping Mechanism*

Traditionally, to influence user breath, users are required to breathe following visual or aural guidance, which is unrelated to their breath. However, pure guiding style of breath regulation though mechanically slow down and deepen user breath, it also induces tension due to unnatural paced breathing.

Therefore, we propose the concept of target-based breath regulation. The target-based breath regulation reflects user breath with the visual or aural multimedia. Users are required to achieve some feedback target through their breathing. Hence, the underlying mapping mechanism which maps breath signal to the feedback multimedia content can affect the result of breathing pattern.

To verity that managing the underlying mapping mechanism can effectively affect the breathing pattern of the user a preliminary experiment is conducted. In this preliminary experiment we use a variable circle to symbolize user breath. The circle expands when the user breathes in and shrinks when breathing out. Two mapping mechanism are designed. The first one, named local-mapping mode, maps the extremes of the circle variation to the local extremes of the breath signal. The second one, named global-mapping mode, maps the extremes of the circle variation to the global extremes of the breath signal. Details are described below.

We first generate n circle images with the radiuses ranging from 1 to n. Then we index these circle images from 1 to n orderly so that the bigger the index is the bigger the circle is.

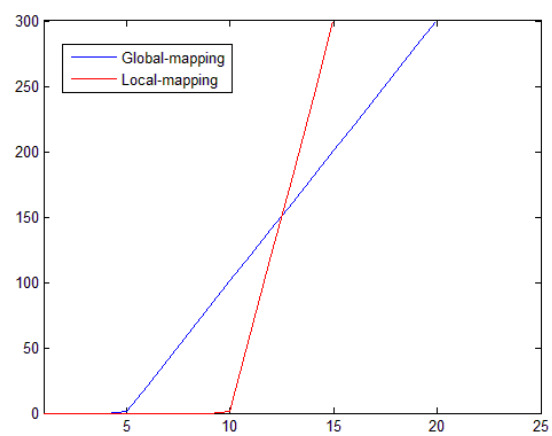

Fig. 5. An example of mapping of the breathing depth and the corresponding image index

Assume the breath signal is f(t) and the corresponding index of the circle image displayed is g(t). Then we let

$$g(t) = \frac{f(t) - \min(f(t))}{\max(f(t)) - \min(f(t))} \times n$$

where $max(f(t))$ is the local maximum and $min(f(t))$ is the local minimum in local-mapping mode, and they are global extremes in the global-mapping mode. An example of mapping illustration using *n*=300 and breathing depth signal ranging from 5mm to 20 mm is shown in Fig. 5.

In the local-mapping mode, the extremes are obtained in the period from immediate sampling time *t* to 15 seconds backward *t*-15. The reason 15 seconds are specified is that we hope to find the extremes in at least one complete breath cycle, and normally people breathe with the frequency higher than 4 times per minute, which means the breath period should be lower than 15 seconds. In the global-mapping mode, the extremes are found in the period from t=0 to immediate time t.

B. *Preliminary Experiment*

We recruit 12 labmates (5 females) as experiment participants. Each participant was required to proceed 3 trials of abdominal breathing practices. Each trial lasts 3 minutes and total 9 minutes for a participant. For all participants, the first trial is free breathing without multimedia. For 6 of the participants the second trial is the local-mapping mode and the third trial is the global-mapping mode. For the other 6 participants the order of the second and the third trial is reversed. Experiment results show that breathing patterns are significantly different in these three modes (Fig. 6, Fig. 7).

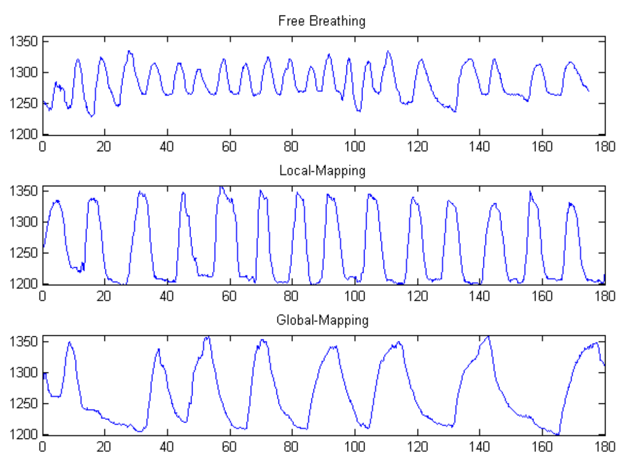

Fig. 6. Three breathing patterns in the preliminary experiment: Free breathing mode, Local-Mapping mode, and Global-Mapping mode

A one-way repeated measure analysis of variance (ANOVA) was conducted to evaluate the average breathing depth and frequency among three modes. The results indicated a significant difference in breathing depth (N=12, F (2, 10) = 10.29, p=0.004). Follow up pairwise paired t-test comparisons also showed significant difference in breathing depth (p<0.05), but not in breathing frequency.

There was significant increase in breathing depth when multimedia feedback was used, and the increase in global-mapping mode is even higher than that in the local-mapping mode. However, the result of ANOVA conducted to compare breathing frequency showed no significant difference. Follow up pairwise paired t-test comparisons showed that the breathing frequency in global-mapping mode was significant lower than those in the other two modes. But there was no significant difference between the free breathing mode and the local-mapping mode (Fig. 7).

According to the research of McCaul et al. in 1979, slowing respiration rate reduced physiological arousal and self-reported anxiety [19]. Although the global-mapping mode performed better in deepening and slowing down user breath, subjects reported that achieving the given target, which was to maximize and minimize the lotus through their breathing, was harder in the global-mapping mode. Some of the participants even feel uncomfortable tension instead of relaxation. To compromise on the effect of slow and deepen user breath and the subjective feeling of tension due to over required effort. We choose the local-mapping mode as our design of the underlying mapping mechanism of the breath regulation. It can effectively deep and slow user breath while the multimedia feedback target provided for the user can be achieved without causing uncomfortable tension instead. In our formal experiment, we compare it with the traditional pure guiding mode and the free breathing mode.

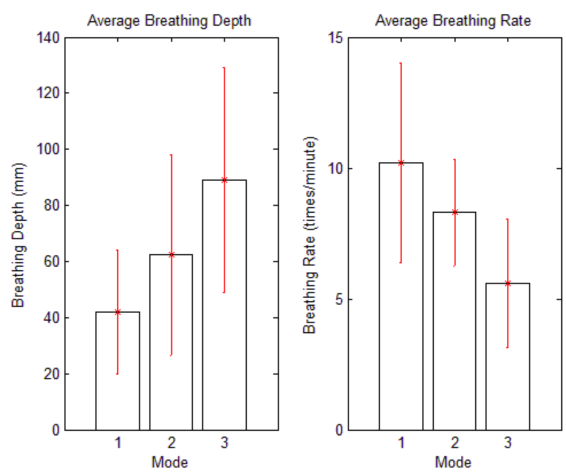

Fig. 7. Comparison of average breathing depth and frequency in three modes. The number 1 to 3 in x-axis represent free breathing mode, local-mapping mode, and global-mapping mode respectively

IV. EXPERIMENT

Among several relaxation techniques, deep breathing or diaphragmatic breathing (DB) is an easy and intuitive evidence-based method for stress management [18]. DB addresses the autonomic nervous system (ANS) imbalance that arises after exposure to a stressor and activation of the sympathetic 'fight-or-flight' response. As DB activates the parasympathetic ANS branch, action of the sympathetic branch becomes inhibited which leads to a calmer, more relaxed state.

Generally, the chest part fluctuates more obviously than the belly part when breathing normally. When practicing DB, the primary motion should be changed to the abdominal part. The aim of the experiment is to investigate the effects of slowing and deepening user's abdominal breath in three different forms of breath regulation. We also compare the induced tension of the user when using the proposed target-based breath regulation and the common pure guiding style of breath regulation. Following, we describe three modes of breath regulation in the experiment, the experiment procedure, and the analysis of the experiment results.

A. Three Modes of Breath Regulation

In Mode-I, the free breathing mode, the user was required to close eyes and practice DB comfortably. No multimedia assistance was adopted.

In Mode-II, the pure guiding mode, a lotus used as the metaphor for breathing guided user's respiration. At first, the system detected the user's initial respiration frequency, then the lotus started to open and close at the same frequency (e.g. 14 times per minute). After the frequency synchronization, the user was told to follow the visual guide and practice DB. If the user paced their breathing to the guidance well, the guiding frequency decreased eventually (e.g. 13 times per minute).

In Mode-III, the local-mapping mode, the lotus reflected user breathing. It opened and closed corresponding to the inhalation and exhalation. The underlying mapping mechanism has been detailed in the last section. The users were told that the lotus variation reflected their breathing, and they were instructed to breathe to make the lotus open to the maximum and close to the minimum.

B. Participants

We recruited subjects in our laboratory without considering rigorous demography. Total 17 subjects participated in this experiment, including 12 males and 5 females with ages ranging from 21 to 38. Three of them had ever learned abdominal breathing before the experiment while others were not familiar with it.

C. Experiment Procedure

Every subject was first taught how to correctly proceed DB. Then they ran through these three modes of trials in a random order, five minutes for each trial. Between two trials, there was a two minute rest for users to answer some feedback questions. Total time cost was about 20 minutes. At the beginning of each trial the user was instructed to sit properly and hold the bio-signal sensor fitly. When bio-signals including breathing, heart rate, and skin conductance were correctly shown on the screen (Fig.4), the trial began.

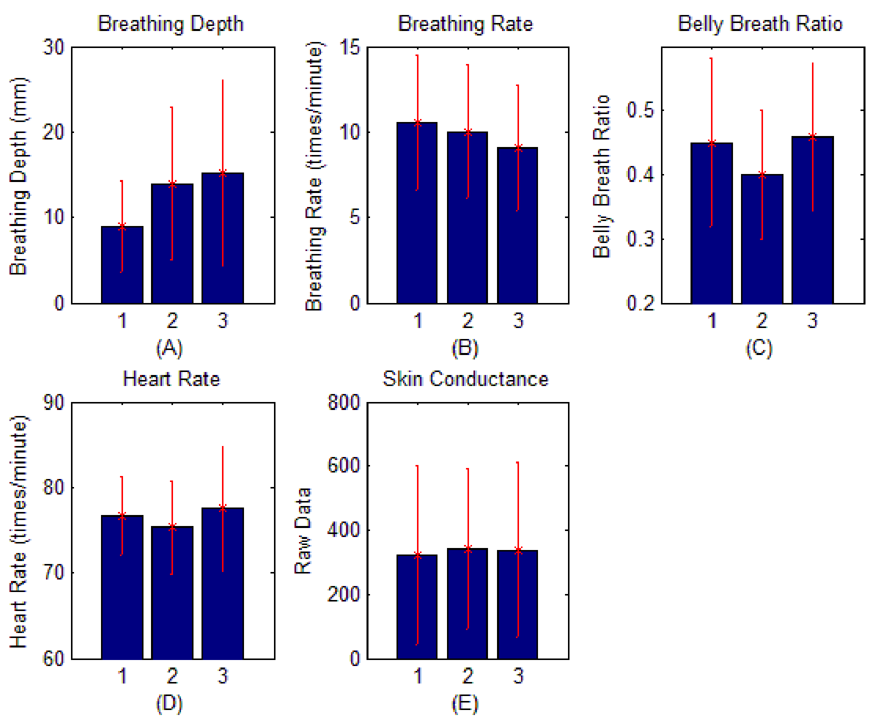

Fig. 8. Bio-signal features of three modes. (A) Breathing Depth (B) Breathing Rate (C) Belly Breath Proportion (D) Heart Rate (E) Skin Conductance Response

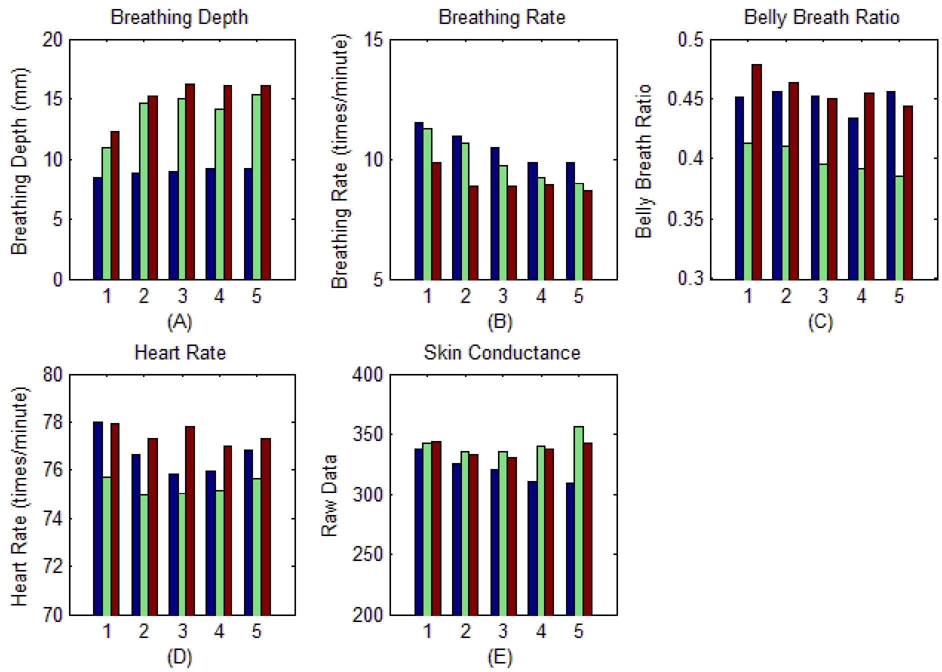

Fig. 9. Bio-signal features during five minutes experience process. (A) Breathing Depth (B) Breathing Rate (C) Belly Breath Proportion (D) Heart Rate (E) Skin Conductance Response. The unit of x-axis is minute and three bars at each minute indicate the results of Mode-I, Mode-II and Mode-III from left to right. (Blue: Mode-I, Green: Mode-II, and Red: Mode-III)

After entire three modes of trials, a five minutes interview was conducted to further realize the user experience of using this system.

D. Experiment Results

Recorded bio-signals include breath, BVP, and SCR. They were analyzed and transformed into five bio-signal features including breathing depth, breathing frequency, belly breath proportion, heart rate, and SCR. The averaged bio-features in three modes are shown in Fig. 8. We ran a one way ANOVA to investigate the difference of these three modes in each bio-signal feature, but there was no overall significant difference found (Breathing Depth: F=2.48, p=0.095, Breathing Frequency: F=1.78, p=0.18, Belly Breath Proportion: F=1.35, p=0.27, Heart Rate: F=0.59, p=0.56, SCR: F=0.05, p=0.95).

To further investigate the effects of the two types of multimedia-assisted breath regulation, we conducted paired t-tests to compare the bio-signal features in Mode-II and Mode-III to those in Mode-I respectively.

The results show that the breathing depth in Mode-II and Mode-III is higher than that in Mode-I (Mode-I vs. Mode-II: p=0.03, Mode-I vs. Mode-III: p=0.009), however, there is no significant difference between Mode-II and Mode-III (p=0.353).

In respect of breathing frequency, Mode-III is significantly slower than Mode-I (p=0.001), and other comparisons of Mode-II vs. Mode-I and Mode-II vs. Mode-III show no significant difference (Mode-II vs. Mode-I: p=0.195, Mode-II vs. Mode-III: p=0.107).

These results indicate that multimedia-assisted breath regulation effectively deepen user breath, and that Mode-III, the local-mapping mode, can also slow down user breath significantly.

In respect of the belly breath proportion, which means the proportion of belly fluctuation among entire breath fluctuation involving chest and belly fluctuation, Mode-III and Mode-I are not significant different (p=0.47), but Mode-II is significantly lower than Mode-I (p=0.035). It means users breathe with fewer belly part and more chest part in the pure guiding mode. The reason for this result will be discussed later. Other comparisons in heart rate and SCR show few differences.

To realize the variation of each bio-signal feature in time, we also calculate averages per minute for each feature (Fig. 9). This figure shows that the average breathing depth remains relatively stable for Mode-I during entire five minutes process, and a raising trend is shown in Mode-II and Mode-III (see Figure 6(A)). This shows multimedia-assisted breath regulation deepen user breath eventually.

In respect of breathing frequency, the decreasing trends are shown in three modes, and the breathing frequency in Mode-III is relatively lower than those in the other two modes. This indicates that there is a trend users slow down their breath rate naturally during practicing DB, and that the local-mapping mode may slow down user breath more rapidly and significantly.

When discussing about belly breath proportion, compared with other features, this feature shows fewer variation during the entire process. Fig. 9(C) shows that proportions of Mode-I and Mode-III are similar, and Mode-II is with the especially lower proportion from beginning the end. Finally, in respects of other bio-features - heart rate and SCR, there is few difference in three modes is observed.

V. Discussion

A. Bio-signal Feature Observation

The experiment result indicated that multimedia guidance or feedback indeed facilitated deepening abdominal breathing when practicing DB. The visual guidance (Mode-II) or visual feedback (Mode-III) of respiration reminded users of staying in the process of breath regulation so that their breathing depth continuously increased during the entire process of the trials (Fig.9 (A)(B)). The overall effect increased the amount of oxygen exchange and slowed down the breathing rate, which was beneficial for relaxation [19].

Among three modes of trials, the effect of slowing and deepening breathing of Mode-III is better than that of Mode-II. Some users reported that following the breath guidance in Mode-II caused mental tension because of worrying about falling behind the guidance. In contrast, the lotus reflected user respiration in Mode-III. Although users were given a target that to maximize and minimize the lotus through their breathing, they can accomplish the target at their own paces without rushing. The tension caused in Mode-II may also be the reason that the belly breath ratio of Mode-II is specially lower. According to user feedback, people reflected that they tended to breathe with more chest part forgetting to proceed DB when they focused on following the guidance. To sum up, the local-mapping mode of breath regulation, proposed based on the concept of target-based method, effectively slow and deepen user breath when practicing DB, in the meantime, eliminate the drawback of causing mental tension as in traditional pure guiding style method.

The experiment results in perspective of breathing depth and frequency fulfilled our expectation, but there was some unexpected features observed. For instance, the averaged SCR decreased at first in three modes but increased in the end of the trials in Mode-II and Mode-III (Fig.9 (C)). In Mode-II the phenomenon may be easier to explain. The guiding frequency of the pure guiding mode decreased as long as the user can still catch up with the guidance. Therefore, in the end of the trial the frequency had become so slow that to breathe following the guidance become uncomfortable. This even induced the raise in SCR.

However, the reason for the phenomenon in Mode-III is not clear. The explanation may be similar. In the local-mapping mode, the mechanism mapping the respiratory signal to the opening state of the lotus maps the local extremes of the respiratory signal to the most and the least opening state of the lotus. Once the user increased their breathing depth, they had to remain or rise their breathing depth so that they can achieve the next target. Therefore, in the end of the trials, they may also suffer from uncomfortableness due to the attempt of achieving too deep breathing. This should be noticed and be further improved in the next design of mapping mechanism.

B. User Feedback

After experiencing three modes of trials, some participants reported that they can concentrate on breath regulation better when eyes were closed in the free breathing mode (Mode-I), and others thought it more interesting to have a visual feedback. They reported that the visual feedback was advantageous for reducing wandering minds and calming down.

In the pure guiding mode (Mode-II), some participants thought it difficult to follow the guidance. Others can follow the guiding rhythm and become comparably more concentrative. The reason why the guiding rhythm is hard to follow may be that we simply activate the opening and closing of the lotus by a sinusoidal wave with different frequencies. So the length of the inhaling and exhaling periods are equal, which is usually not the case our voluntary respiration is. This reminds us that a customized ratio of inhalation and exhalation should be considered in a pure guiding style of breath regulation in the future.

In the local-mapping mode (Mode-III), most of people tested the accuracy of the lotus response at first. Sometimes participants thought the reflection inaccurate. We found the reason for that was the inappropriate locating of the respiration detection mask. Looking at a loosely controlled lotus certainly bothered users. However, for most cases of correct breath detection, participants favor this mode because of the connection between their breathing and the motion of the lotus. It made them feel more relaxed and immersive in the process of breath regulation. Those feedback suggest that the interaction form through real time visualization of respiration may be beneficial and suitable when applied in the relaxation application.

There are also user feedbacks about other components in this relaxation system. Most of users thought that the bio-signal feedback on the wall (Fig. 4), was assistive for identifying whether they breathe primarily with the abdominal part. Besides, the reflected image of the lotus also interested multiple users. They like the design of visual feedback and the immersive visual effect created by that.

VI. Conclusion

In this paper, we integrate the non-contact breath detection technique, the bio-signal sensors and the specially designed reflection mechanism to construct a multimedia system for breath regulation and relaxation. A novel form of breath regulation named target-based breath regulation is proposed. This concept is between the pure guiding style and the pure reflecting style of breath regulation. Through managing the underlying mapping mechanism we can variously affect the breathing pattern of the user. A preliminary experiment was conducted to prove the concept.

Finally, two forms of multimedia-assisted breath regulation were adopted in the formal experiment to investigate the effects of the pure guiding mode and the local-mapping mode on breathing depth and frequency and the subjective experiences. Quantified analysis of bio-signal features was conducted and the results were discussed. Experiment results show that the local-mapping mode is actually beneficial for slowing and deepening user breathing, in the meantime, reduces the drawback of inducing mental tension, which is usually the case in the common pure guiding style of breath regulation. At the end, some user feedbacks from interviews were discussed and essential factors worth noticing for constructing a breath-based application for relaxation in the future were suggested.

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