i-m-Breath: The Effect of Multimedia Biofeedback on Learning Abdominal Breath

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Abstract. Breathing is a natural and important exercise for human beings, and the right breath method can make people healthier and even happier. *i-m-Breath* was developed to assist users in learning of abdominal breath, which used Respiration Girth Sensors (RGS) to measure user's breath pattern and provided visual feedback to assist in learning abdominal breath. In this paper, we tried to study the effect of biofeedback mechanism on learning of abdominal breath. We cooperated with College of Medicine in National Taiwan University to take the experiments to explore whether the biofeedback mechanism affect the learning of abdominal breath. The results of the experiments showed that *i-m-Breath* could help people in improving the breath habit from chest breath to abdominal breath, and in the future the system will be used the hospital. Finally, this study is important for providing a biofeedback mechanism to assist users in better understanding of his breath pattern and improving the breath habit.

Keywords: Abdominal Breath, Multimedia Biofeedback, Optoelectronic Plethysmography (OEP).

1 Introduction

Breathing is a natural behavior, which occurs without conscious control. Therefore, the breathing behaviors are very important for the maintenance of our physical health and the balance of various physiological functions. When the breathing depth decrease and can't provide enough oxygen and energy, it disables the body to eliminate its fatigue and makes us nervous and upset. Many studies show that breathing is a fundamental behavioral manifestation of the psychological and physiological state of human beings [2]. Blumenstein [7] also demonstrated that breath pattern is strongly associated with techniques for the regulation of mental states. Besides, many studies

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also show that appropriate breath habit can reduce the times of asthmatic attack [9], delay the deterioration of chronic obstruction of pulmonary diseases [10], and reduce the probability of post-operative pain and complications on patients [11]. Abdominal breath, commonly known as diaphragmatic breathing, is a recommended breath method. Abdominal breath is very beneficial for the body, because breath abdominally allows a good quantity of oxygen in to your lungs. Therefore, this study aimed to develop a system that can assist users in learning of abdominal breath.

In the part of breath detection, there are many techniques in detecting the breath pattern and analyzing the breath information, such as Optoelectronic Plethysmography (OEP) [13], Ultra Wideband (UWB) [14], Spirometer, Gas Analyzer, Respiration Girth Sensor (RGS), and ECG-derived respiration technique [15]. Traditional training of breath learning demands one-by-one instruction and lacks of standardized evaluation. In this paper, we describe the breath-aware garment and biofeedback mechanisms of *i-m-Breath*, and use the training of abdominal breath as an example application to evaluate the effectiveness of it. The main purpose of this study is to determine if the use of biofeedback mechanisms would improve inappropriate breath habit of the users, and toward to recommend breathe habit – abdominal breath. In view of the preceding research purpose, two major sets of research questions to be addressed in this study are as follows: (a) whether *i-m-Breath* can assist users in learning abdominal breath, and (b) whether *i-m-Breath* can improve the breath habit and increase the total volume of breath. The goal of this study is to develop and verify an effective biofeedback mechanism to assist people to breathe correctly, and toward to the ideal of preventive medicine. In this paper, we have organized the rest of this paper in the following way: the first section of the article is a review of the literature, addressing both breath detection methods and the application in breath learning. This is followed by the introduction of different measurement of breath pattern. The third section describes the methodology and procedures for the collection of breathing data on multimedia biofeedback. The results for the various analyses are presented following each of these descriptive sections. Finally, conclusions are presented and suggestions are made for further research.

2 Related Work

A traditional method of breathing rehabilitation and breath learning needs professional respiratory therapist for learning assistance. The treatment requires lots of manpower and lack of quantitative evaluation of the progress during the period of breath learning. However, with the development of the information technology and human-computer interaction in recent years, some studies used multimedia and biofeedback mechanisms to assist users in the field of rehabilitation, self-healing, and health-care. Wild Divine Company [16] developed a well known self-healing system which used interactive animations and sounds to help users to control the breath and get better conditions both in mind and body. Morris's research [12] aimed to help people tune in to early signs of stress and modulate reactivity that could potentially damage their relationships and long-term health, and developed mobile therapies which provided just-in-time coaching. Thought Technology Ltd. [3] developed a biofeedback system which detected user's vital signal and visualized to the form of interactive multimedia. Besides, Venkat [8] used accelerometer which was put on user's abdomen to detect the movement of abdomen, and displayed the breath information. Kaushik [4] proved that biofeedback assisted abdominal breath and systematic relaxation was very useful in migraine and had significantly better long-term prophylactic effect. Pastor [5] obtained demonstrated that biofeedback combined with this breath pattern produced a significant reduction in psycho physiological activation and improved learning through biofeedback techniques. However, none of related research in our survey has a complete study to prove the effect of the proposed biofeedback mechanisms, and whether the user has actually improved breath habits. In this study, a complete research on integrating breath-aware garment and multimedia feedback for improving breath habit was proposed. In this paper, we will describe the measurement of breath signal, the breath-aware garment and the calibration mechanisms of sensing signal, the biofeedback mechanisms, the experimental design, and the experimental results.

3 System Framework

i-m-Breath includes a breath-aware garment to detect user's breath pattern, an wireless transition module by bluetooth, and a desktop system to analysis the breath signal and provide visual feedback. In this section, the method of breath detection and biofeedback mechanisms of *i-m-Breath* will be introduced.

3.1 Breath Detection

There are many techniques in detecting the breath signal. This study used the technique of Respiration Girth Sensors (RGS) [21] and OEP [13] to detect participants' breath pattern. The method of RGS is used in *i-m-Breath*, and it has the advantage that it is portable and easy to use. The method of OEP is used as the evaluation tool in this study. OEP has the advantage that it can measure respiratory information accurately, and can measure breath volume in chest and abdomen separately. The following will introduce the detection method and the calibration procedure separately.

In the part of RGS, *i-m-Breath* uses Procomp Infinity [21] and two respiration girth sensors (RGS) to detect user's chest and abdominal elongation while breath. The sample rate is 25 samples per second. Before breath detection, the RGS sensor would be calibrated to translate the detection unit from raw data of ProComp2 to unit of length (cm). In each RGS, a mapping table was established to record the relationship between the value of the raw data and the unit of length. The default length of RGS is about 6 cm in unforced condition, and the pre-tensor of RGS is about 12 cm. Therefore, a ruler is used to calibrate the RGS from 12 cm to 25 cm. The system records the raw data with increment of RGS in 0.5 cm which pulls by hand (see Fig. 1a). Finally, the mapping table will have 27 paired mapping values to translate the raw data to the unit of length. Fig. 1b shows the mapping table of one RGS. The RGS is a sensitive *girth sensor* using a latex rubber band, and it could have the problem of fatigue. For this reason, the RGS could calibrate periodically. In this study, the RGS was calibrated every day during the experiment.

After calibrating the measurement unit of RGS, users should wear the breath-aware garment and adjust the wearing tightness and breathe parameters. In order to keep users not to wear the RGS too tight or too loose, the minimal breath elongation should in the period of 12~13 cm. In the calibration procedure, users are asked to exhale

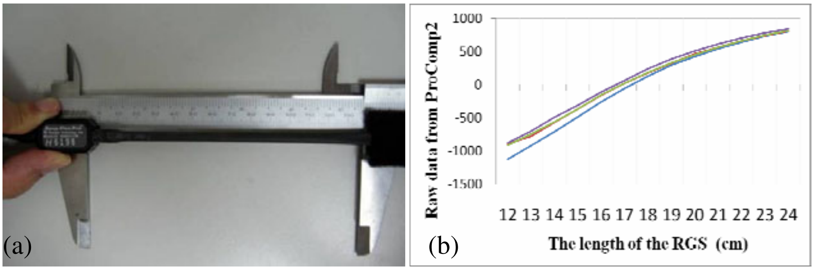

Fig. 1. Calibration of the RGS from raw data to the unit of length. (a) Using a ruler to calibrate the RGS every 0.5 cm; (b) The mapping table of the RGS four times.

extremely to get the minimal breath elongation. If the length is less than 12 cm, users should tighten the RGS, and if the length is greater than 13 cm, users should loosen the RGS. The procedure of wearing tightness would repeat until the minimal breath elongation is between 12~13 cm.

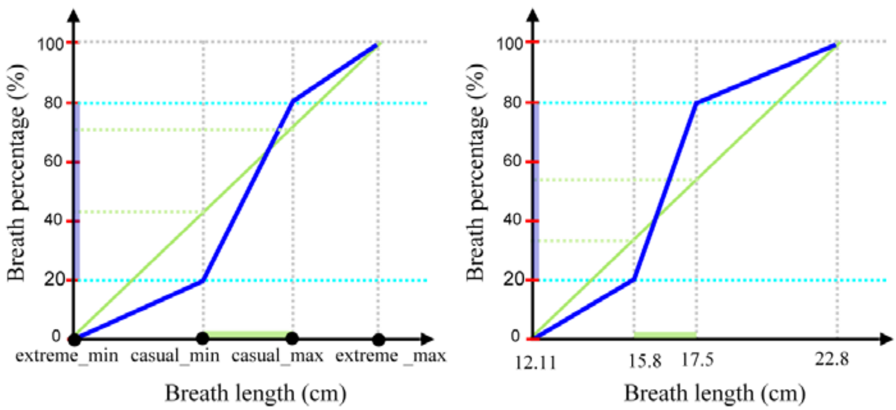

Fig. 2. Calibration of the breath length and the dynamic range. Green line indicates the result after linear interpolation. Blue line indicates the result after the calibration of dynamic range. (a) The diagram of the calibration; (b) An actual calibration result and the dynamic range by a participant.

Besides, because the dynamic range of user's breath elongation is small in general condition, and even he could not use abdominal breath, it could ineffective in the mechanism of biofeedback. Therefore, this system adopts a procedure to calibrate the dynamic range of user's breathe. In this calibration procedure, users are asked to calibrate the length of RGS in the condition of maximal breath extremely, minimal breath casually, and maximal breath casually separately. We set the range of breath from minimal breath extremely to maximal breath extremely. The dynamic range of casual breath (minimal breath casually ~ and maximal breath casually) is 60% (20%~80) of the length of deep breath, and others has 40% (0~20% and 80~100%). An experiment was adopted and the results showed that the calibration procedure of dynamic rage could enhance the effect 2.2 times than the method of linear interpolation. After the procedure, users could interact with the system more easy and effective. Fig. 2 shows the calibration chart of breath length and dynamic range.

Another technique of breath detection used in this study is OEP [13] (see Fig. 3). In the experiment, in order to detect user's breathing pattern accurately, OEP was selected as the evaluation tool. OEP System can measure the volume of user's chest wall and its variation during breathing, using reflective and non invasive markers attached to the thoraco-abdominal skin by biadhesive hypoallergenic tape. The three-dimensional positions of the markers are obtained thanks to infrared light video cameras with flashing LED's. OEP System measures the different compartments of the chest wall, provides the continuous monitoring of all ventilatory parameters. In our experiment, OEP System was used to measure participants' breath pattern, including chest volume, abdominal volume.

Fig. 3. Breath detection by using OEP equipment. (a) A participant is testing the breath pattern; (b) Detecting the breath pattern and visualized in real-time.

3.2 Biofeedback

While user already wear the breath-aware garment and calibrate the wearing tightness of abdominal RGS and chest RGS, he can start to use the biofeedback system to learn abdominal breath. This study adopted two phases of breath learning, including a real-time reflection mechanism to help user in learning abdominal breath, and a real-time guidance mechanism to assist user in following the regularity of suitable breath pattern. Besides, a ratio chart was representative of the chest/abdomen ratio with user's breath pattern while breath. The following would introduce the mechanisms of *i-m-Breath*. In the mechanism of real-time reflection, an animation of a virtual frog was representative of the abdominal breath situation with user's inhalation and exhalation. The animation of virtual frog was designed by a 3D model, and in order to decrease the computation of the system, we rendered 100 static pictures with a sequential movement of the frog. The resolution in each picture was 1024 pixels in width and 768 pixels in depth, and the sampling rate of the system was 15 frames per second. When inhaling, the virtual frog would plump its belly; when exhaling, the virtual frog would shrink its belly (see Fig. 4).

Respiratory pacing is an easily learned self-control strategy and potentially may be a useful therapeutic tool [6]. In the mechanism of real-time guidance, a breathing curve was representative of the guidance line and a light spot would fly on the path of

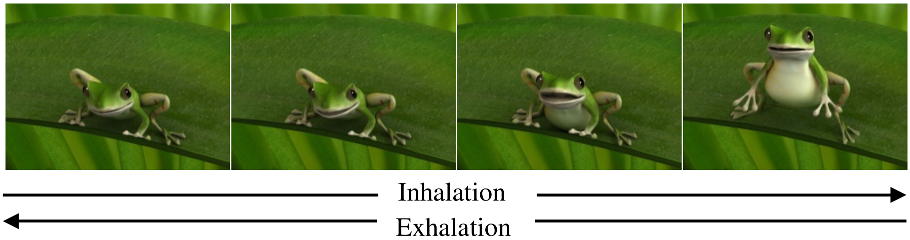

Fig. 4. The reflection mechanism to learn abdominal breath: An animation of a virtual frog to represent user's breathe condition on abdomen

the curve, which could guide user to breathe with its rhythm. The light spot was the guidance of specified breathing frequency. The light spot will move with a dotted curve which shows the guidance of the breath pattern. Besides, a virtual lady bug was representative of user's status of abdominal breath. While user inhaling, the virtual lady bug would fly higher, and while user exhaling, the virtual lady bug would fly lower. The rhythm of breathing curve can be changed by users, doctors or respiratory therapists to set a appropriate guidance of breath frequency (see Fig. 5). Moreover, *i-m-Breath* provided an evaluation mechanism. While user's breath followed with the curve of breathing guidance well, and the flower would bloom. On the contrary, while user did not follow with the guidance of breath curve and the flower would wither.

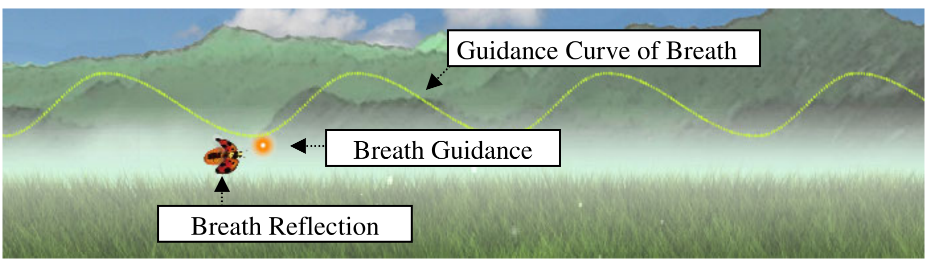

Fig. 5. The guidance mechanism to train the regularity of breath: The yellow curve shows the path of the breath pattern; the movement of light spot shows the guidance of breath depth; the movement of lady bug reflects user's abdominal breath depth

Therefore, *i-m-Breath* also provided a diagraph both in the above two phases to show the chest/abdomen chart to assist users in understanding of his breath method. The diagraph could display the relationship between user's chest breathing and abdominal breath. The X-axis indicated the breath depth of user's abdominal breath, and Y-axis indicated the breath depth of user's chest breathing. The location of the yellow ball was composed by chest breath depth in X-axis and abdominal breath depth in Y-axis in the same time (see Fig. 6). If user uses abdominal breath more than chest breath, the yellow ball would locate at lower right of the chart (Fig. 6a). On the contrast, if user uses chest breath more than abdominal breath, ane the yellow ball will locate at higher left of the chart (Fig. 6b). However, diagraph could also show the information of breath depth. If user uses shallow breath , ane the yellow ball will locate at lower right of the chart (Fig. 6c). If user uses deep breath , ane the yellow ball will locate at higher right of the chart (Fig. 6d). The breath ratio chart shows in the lower left corner of the screen both in frog animation and flower animation.

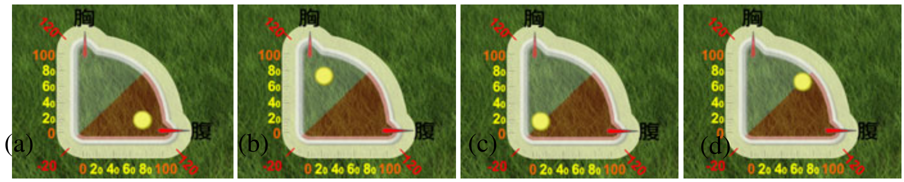

Fig. 6. The diagraph of the relationship between chest breath and abdominal breath. (a) shows that user used abdominal breath; (b) shows that user used chest breath; (c) shows that user used shallow breath; (d) shows that user used deep breath.

4 Experimental Methods

4.1 Participants and Location

The participants volunteered to participate in this experiment, and the average age of them is 24 (SD=3.71). All participants did not have the experience of learning abdominal breath. There were five participants in experiment group, and five participants in control group. During the experiment, we ensured that all participants did not get sick during experiment. Besides, the gender of all participants was male because they were asked to undress on upper body to adhesive twenty reflective balls on body while using OEP test. The experiment was held in two places, including a department of respiratory measurement at National Taiwan University hospital and a laboratory in the faculty building at National Taiwan University. The participants in experimental group were asked to learn the abdominal breath by using *i-m-Breath* at laboratory for one month, and the participants in control group were asked to learn the abdominal breath himself.

4.2 Experimental Procedure

In this experiment, all participants were asked to learn the method of abdominal breath for one month. In order to analysis the breath pattern accurately, participants were asked to measure the breath pattern by using OEP equipment in day one, day two, and day thirty-one in the National Taiwan University Hospital. In day one of the experiment, participants' original breath pattern was recorded. In day two, a senior respiratory therapist taught all participants the skill of abdominal breath, and then tested the breath pattern by using OEP equipment, too. In day three to day thirty-one, all participants were divided into two groups, experimental group and control group. Five participants in experimental group were asked to use *i-m-Breath* to practice abdominal breath for 20 minutes once every two days, and another days they were asked to practice abdominal breath themselves. Besides, five participants in control group were asked to learn abdominal breath every day, and twenty minutes in each time. Fig. 7 shows the experimental procedure in this study.

We reminded the participants in control group to practice abdominal breath every week and give them a teaching manual of abdominal breath to ensure that they had practiced abdominal breath on time. Finally, all participants were asked to test the breath pattern by using OEP equipment in day thirty-one. While testing, all participants were asked not to breathe deliberately. None of the participants were blind as to the nature of the experiment. They were not told, however, what types of results were expected.

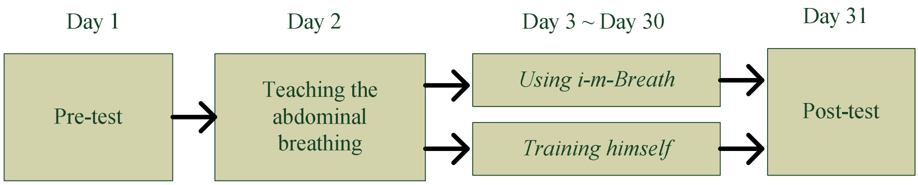

Fig. 7. Experimental procedure

4.3 Experimental Results

We analyzed participants' average volume of breath in chest and abdomen by using OEP equipment, and also analyzed their breath pattern (total volume of breath and chest-abdominal breath ratio) both in experimental group and control group. All participants were measured the breath pattern in day 1 (pre-test), day 2 (after teaching by respiratory therapist), and day 31 (post-test). They were asked to breathe naturally and not to breathe deliberately. Each measurement time was ten minutes by using OEP equipment.

In the comparison of abdominal breath, the average volume of abdominal breath was 45 ml per minute in experimental group, and 54 ml per minute in control group in the first day. The result showed that there were no significant different in abdominal breath between experimental group and control group in the beginning of the experiment (See Fig. 8a). In the second day, after teaching of abdominal breath by respiratory therapist, the average volume of abdominal breath was 60 ml per minute in the experimental group, and 63 ml per minute in the control group. The result showed that learning of abdominal breath by respiratory therapist had significant effects increasing the volume of abdominal breath both on the experimental group ($p < .005$) and the control group ($p < .05$). After one month, the average volume of abdominal breath was 80.5 ml per minute in the experimental group, and 54.2 ml per minute in the control group. The result showed that there was significant increase on the experimental group after one-month experiment ($p < .005$), but there was no significant effect on the control group. In the comparison of chest breath, the average volume of chest breathing was 38.3 ml per minute in the experimental group, and 30.6 ml per minute in the control group in the first day. The result showed that there were no significant different on abdominal breath between the experimental group and the control group in the beginning of the experiment (see Fig. 8b). In the second day, after teaching of abdominal breath by professional respiratory therapist, the average volume of abdominal breath was 24.8 ml per minute in experimental group, and 20.5 ml per minute in the control group. The result showed that learning of abdominal breath by respiratory therapist did not have significant effect both in the experimental group and the control group. After one month, the average volume of abdominal breath was 8.9 ml per minute in the experimental group, and 31 ml per minute in the control group. The result showed that there was significant decrease on the experimental group after one-month experiment ($p < .005$), but there was no significant effect on the control group.

In the comparison of total volume of breath, the average total volume of breath was 83 ml per minute in the experimental group, and 84 ml per minute in the control group in the first day. The result showed that there was no significant different

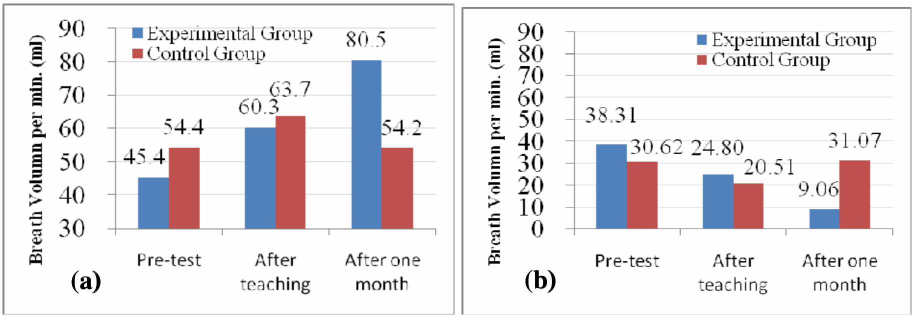

Fig. 8. The comparison of breath vloumn between pre-test (day 1), after teaching, and after one month. (a) the comparison of abdominal breath volume per min; (b) the comparison of chest breath volume per min

between the experimental group and the control group in the beginning of the experiment (See Fig. 9a). In the second day, after the teaching of abdominal breath by respiratory therapist, the average volume of abdominal breath was 85 ml per minute in the experimental group, and 84 ml per minute in the control group. The result showed that learning of abdominal breath by respiratory therapist did not have significant effect on change the total volume of breath both in the experimental group and the control group. After one month, the average volume of abdominal breath was 89 ml per minute in the experimental group, and 85 ml per minute in the control group. Overall, the result showed that the total volume of breath increases in the experimental group and the control group, but there were no significant effects.

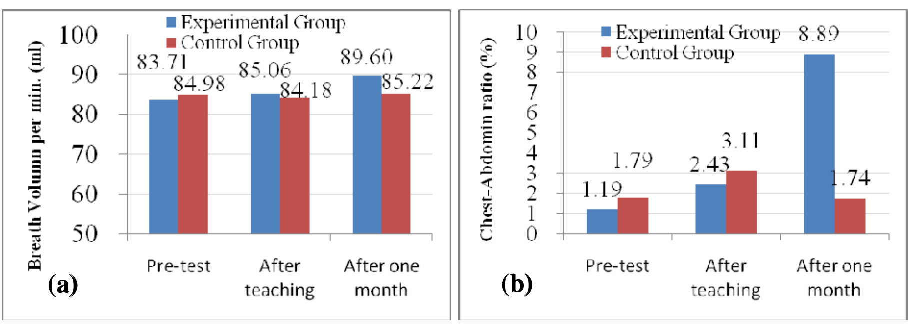

Fig. 9. The comparison of overall Breath pattern between pre-test, after teaching, and after one month. (a) the comparison of total breath volume per minute; (b) the comparison of chest-abdominal breath

The ratio of chest-abdominal breath is defined as volume of abdominal breath divided by volume of chest breath. The more the value means the more the abdominal breath be used. In the comparison of chest-abdominal breath ratio, the average chest-abdominal breath ratio was 1.19 in experimental group, and 1.79 in control group in the first day. The result showed that there was no significant difference between the experimental group and the control group in the beginning of the experiment. In the second day, after the teaching of abdominal breath by respiratory therapist, the average ratio of chest-abdominal breath was 2.43 in the experimental group, and 3.11 in the control group. After one month, the average ratio of chest-abdominal breath was 8.89 in the experimental group, and 1.74 in the control group (see Fig. 9b). The result showed that the chest-abdominal breath ratio had significantly increased in the experimental group after the one-month experiment ($p<0.005$), but there was no significant effect on the control group.

In conclusion, the results of the abdominal breath volume, total volume of breath, and the ratio of abdomen-chest breath in this study showed that *i-m-Breath* had significant effect on the learning of abdominal breath. According to the observation of the experiment, participants could not control the frog easily in the beginning. However, they could control the frog easily after several days. Besides, the mechanism of breathing guidance is a complex problem, because there are many factors that could affect user's breath pattern, such as user's body type, exercise condition, emotion condition, etc. If the system provides improper guidance of breath pattern, users might get dizzy and uncomfortable. Therefore, we asked participants to set the time of breathing guidance, including the inhaling time and exhaling time.

6 Conclusions and Future Work

In this paper, we proposed *i-m-Breath* system with multimedia biofeedback and we have cooperated with College of Medicine in National Taiwan University to take the experiments to explore whether the biofeedback mechanism affect the learning of abdominal breath. The results of the experiments showed that *i-m-Breath* could help people in improving the breath habit from chest breath to abdominal breath. We had the following conclusions: (a) in our experiments, it showed the obvious and immediate effect to improve abdominal breath during learning with the advise of respiratory therapist around, (b) our biofeedback mechanism could increase users' interest and fun for helping the long-term breath learning and improve the breath habit effectively, and it is our main contribution which will be used the hospital. In our research, the participants were all healthy young man, and this study does not prove that the biofeedback mechanism has effect on other specific-groups, too. Besides, our study did not test the effect of biofeedback on the regularity of breath pattern. These problems will be improved in the future. Currently, we have developed a portable biofeedback system to assist users in breath learning anywhere they want. For the future research, we will develop a high accuracy of breath detection method and investigate the relationship between activity and breathing more precisely. In addition, we will integrate *i-m-Breath* system, activity recognition system, and multimedia biofeedback to develop a health care system in daily life.

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