Gamified Wearable Breathing Monitoring System For Lowering Hypertension

Na An, Stuart Adam Eisenstadt, Woojin Paik

Abstract: Hypertension is known as the “Silent Killer.” Worldwide, over 7 million people die each year from hypertension complications. Hypertension can damage a person’s arteries, heart, brain, and kidneys. Stress is one of the significant causes of hypertension by repeatedly incurring blood pressure elevations and by stimulating the nervous system to produce large amounts of vasoconstricting hormones that increase blood pressure. To avoid applying various medications to treat both stress and hypertension, there has been growing interest in alternative and holistic methods. For example, a wearable breathing game system was developed for people to frequently conduct deep breathing exercises for the purpose of relaxation. The rationale behind this system is that slow and regular breathing increases the bar reflex sensitivity, which can reduce autonomic imbalances. An experimental study showed that an eight-week breathing exercise regimen elicited significant reductions in both stress and blood pressure level. However, it is difficult for regular people to continue performing these breathing exercises for an extended duration without sufficient motivation. The goal of the wearable breathing monitoring system in conjunction with a simple visual game proposed here was to ease such difficulty by providing encouragement and motivation.

Index Terms: assistive technology, deep breathing, cybercare, hypertension, medical information system, meditation, wearable computer

1. INTRODUCTION

HYPERTENSION occurs when the force of blood against artery walls becomes sufficiently high to lead to a variety of health problems [1]. These problems include heart failure, coronary heart disease, kidney disease, stroke, and even eye problem. Worldwide, about 1.13 billion people have a high blood pressure problem. In 2015, one in five women and one in four men had hypertension; two-thirds of such people lived in developing countries. In addition, less than one in five people have their high blood pressure under control [2]. In addition to various medications and general lifestyle changes, there are other alternative treatments for lowering high blood pressure that are effective if practiced continuously. These alternatives can be cheaper and have fewer side effects than medicine-based approaches, but they require the subject to be motivated to work successfully. One research goal is to determine how gamification techniques can help motivate people to learn and continuously use alternative methods to reduce high blood pressure. Fitness/health-related wearable devices such as Jawbone’s Up Move, Fitbit, Garmin’s Vivoactive, Misfit Shine, Basis Peak, and Apple Watch are currently in widespread use. Omron’s HeartGuide is the first wearable blood pressure monitor [3]. However, it is difficult for the user of such a device to lower their blood pressure in the case that the device detects an anomaly, as there is no quick way to reduce blood pressure. By contrast, wearable glucose monitors, such as Dexcom CGM, can alert the subject to inject insulin or start exercising to lower their blood sugar level [4]. This research’s primary objective is to test the effectiveness of a gamified wearable breathing monitoring system in lowering high blood pressure through a self-guided deep breathing game. The secondary objective is to determine whether the game-based approach promotes the continued practice of deep breathing in the long term.

2. RELATED WORKS

2.1 Deep Breathing and High Blood Pressure

One of the best approaches for reducing hypertension-related morbidity and mortality involves the early detection of elevated blood pressure and controlling it [5]. This strategy is consistent with the proposed use of deep breathing to lower blood pressure as a potential early-stage treatment for mild and moderate instances of HBP. Deep breathing, also known as diaphragmatic breathing, abdominal breathing, or belly breathing, is performed by contracting the muscle of the diaphragm that is located between the stomach and the chest cavity in order to allow air to enter the lungs at a very high volume and expand the abdomen [6]. A variety of breathing techniques, including deep breathing/abdominal breathing, have been used as means of self-regulation, and these allow an individual to control systems that are typically autonomous, such as heart rate [7]. Breathing is also often used in the treatment of psychophysiological disorders, e.g., panic, anxiety, and stress, as well as the conditioned hyperventilation from stress [8]. A large-scale study was conducted in Japan to elucidate how deep breathing affects blood pressure and pulse rate [9]. The test group in this study, which was the deep breathing group, included 4,377 normotensives (ones without HBP), 11,217 treated hypertensives, and 3,066 untreated hypertensives. The control group consisted of 1,096 normotensives, 1,220 treated hypertensives, and 587 untreated hypertensives. In the test group, blood pressure was taken before each subject took six deep breaths within 30 seconds and after the sixth breath, while in the control group, it was taken before and after a 30 second rest without deep breathing. The study found that systolic and diastolic blood pressure as well as pulse rate were reduced significantly compared to the baseline measurements after deep breathing exercise or a 30-second rest (p<0.001) in both groups. Furthermore, systolic blood pressure was lowered more in the deep breathing group in comparison to the 30 second rest group. The study concluded that deep breathing could lead to decreases in both blood pressure and pulse rate. The primary purpose of device-guided deep breathing is to help people learn how to correctly perform deep breathing exercises, as it is not easy for people to simply follow audial instructions on breathing in a certain way. One training system aiming to
achieve this goal monitored breathing in real-time to assist patients suffering from chronic obstructive pulmonary disease while also providing biofeedback [10]. Another such portable respiratory breathing rate system used biofeedback and breathing pacing to treat hyperventilation by converting signals obtained from sensing breathing into audible tones for inhalation and exhalation. The sounds served as signals to guide the users to follow a specific type of breathing pattern to reduce their hyperventilation [11]. Another device aimed to help the user control their respiratory activity by generating signals related to the respiration characteristics of the user [12].

One of the device-guided deep breathing studies to treat hypertension was conducted under the assumption that slow and even breathing patterns as well as regular exercises can help lower blood pressure [13]. To test this hypothesis, the researchers used the Breathing with Interactive Music (BIM) technique to induce a slow and even breathing rate. BIM was used as a part of a randomized, double-blind test with 65 subjects to verify its effectiveness as a non-drug treatment in lowering blood pressure and respiratory modulation. The BIM treatment group was compared to a Walkman group, who listened to pre-recorded quiet electronic music for ten minutes a day for eight weeks, and the BIM group showed significant drops in systolic, diastolic, and mean arterial pressure. Thus, the conclusion was that breathing modulation could be used as a low-risk and complementary therapy for hypertension, and that regular and slow breathing could be useful in lowering HBP in general.

2.2 Gamification

Gamification is the use of game thinking to engage and educate users in a non-game context to help them solve problems. The rationale was based on a psychological idea suggesting that individuals will be more engaged and learn better when their needs for competition, achievement, status, and closure are met [14]. The increased use of games and similar strategies within healthcare was explained as part of a movement toward giving users a sense of control, as well as motivating and engaging them [15]. There have also been studies about how the rewards and incentives within such gamification affect motivation. One such study considered how different game elements can address various motivational mechanisms [16]. Another study identified the specific ways in which gamification changed users’ health behaviors by analyzing data of 132 health and fitness apps available in the Apple App Store that are specifically related to physical activity and dieting. Each app was checked to determine whether it included proper game elements, health gamification components, and health behavior constructs. Most apps had gamification features, but many lacked health behavior components, which are required to make health-related behavior changes [17]. One game was designed for diabetes management using gamification and involved in-game social components to motivate the patients to develop good habits of regular self-measurement of their blood glucose levels [18]. However, there were no empirical results regarding the application of gamification in healthcare in most of these studies due to the difficulties associated with obtaining ethical clearances as well as the prohibitively high cost of conducting trials.

3 SYSTEM DESIGN AND IMPLEMENTATION

Fig. 1 shows the gamified wearable breathing monitoring system described in our study including hardware components, such as the Micro Controller Unit (MCU) and sensor, as well as software to operate the system.

3.1 Hardware Design and Implementation

The system included a custom-made breathing belt attached to the MCU, which was an Arduino UNO. The device was designed to measure the deep breathing rate of a user by analyzing the inhalations and exhalations detected by the belt and then passing the data to the software, which was running on a PC, ultimately enabling the user to visualize, adjust, and control his/her breathing.

![Gamified Wearable Breathing Monitoring System Components](image-url)

As shown in Fig. 2, the breathing belt consisted of a long elastic cloth belt (4cm wide by 110cm) and a stretch sensor, which is a carbon-black impregnated rubber (diameter of 2mm and a length of approximately 13cm). In a ‘relaxed’ sta
te, the resistance value of carbon-black impregnated rubber is measured between 140 and 160 ohms per centimeter; the resistance of the 13cm strip was 3,600 ohms. The particles of carbon within the rubber are forced further apart, and the resistance is increased when it is stretched. The cord can be stretched to about 50% - 70% longer than its resting length, but it will fracture if stretched further. Once the stretching force has been released, the rubber will immediately begin shrinking back, but it takes about two to three minutes to revert to its original length.

![Fig. 2. Stretch Sensor on Breathing Belt](image)

The rubber was found to be weak and susceptible to tearing and breaking, which resulted in inaccurate measurements. The alligator clips were also problematic, as they cut into the rubber. Fig. 3 shows an improved setup that was developed to lessen the strain on the stretch sensor. In the improved setup, the sensor is placed just above the wearer’s navel to capture the most significant movements during his/her deep breathing. A piece of 10cm long elastic cloth was sewn onto a larger elastic cloth belt using the conductive fabric sewn on each end. The rubber stretch sensor was then attached to the conductive fabric. Finally, the alligator clip leads were attached to the conductive fabric on each side.

![Fig. 3. Schematic Diagram of the MCU and the stretch sensor](image)

3.2 Software Design and Implementation

The MCU received voltage based on the variable resistances of the stretch sensor then translating them to digital values between 0 and 1023. The values were then transmitted to the PC over a serial connection in real time as input to the breathing game. The game was programmed in the Processing language, which is a visual programming language that is easy to learn, includes a Graphical User Interface (GUI) library and a set of controllers that make it easy to change and adjust values while the program is running.

![Fig. 4. Screen Shot of the game](image)

The game is about the journey of a dandelion seed. It begins with a dandelion seed breaking away from a dandelion head and subsequently floating through the air. The goal is to guide the floating seed to land on an island through deep breathing. Upon landing on the island, the seed will germinate and make a new dandelion. Fig. 5 shows the end state of the game. The player guides the seed by controlling the wind through deep breathing: There are updrafts when the player inhales, and inhaling will lead to vertical movement of the seed from the bottom to the top. When the player exhales, there will be a gust of wind going from the left to the right, so exhaling will lead to horizontal movement of the seed from left to right. If there is no wind (no breathing), the seed will stop moving horizontally and gradually drop to the bottom. The game will end and the player will lose if the seed reaches the water. The background color of the user interface was blue. Visual elements such as clouds, waters, and flowers were also placed in the scene to help players relax. There was also background music, specifically ‘Prelude 1 in C Major BMV 846’ by Johann Sebastian Bach. The repetitive nature of the music was a subtle cue to help the players regulate their breathing rates. The game was intentionally programmed to help players learn the most efficient deep breathing method. In this method, the player has to expand their belly and inhale as much as possible, then hold the breath for about five seconds to make the most vigorous updrafts. Similarly, the player has to shrink their belly and exhale as much possible then hold their breath for about five seconds to produce the strongest gusts of wind going from left to right.

![Fig. 6. Screen Shot of the game](image)

Fig. 6 shows the voltage value measured by the stretch sensor during deep breathing in regular intervals. The voltage value was used to detect whether the player was exhaling or inhaling based on the fact that the voltage will go up or down in sync with the resistance when the current is constant. The X-axis shows the sampling time period. The sampling rate is ten voltage readings per second. The value goes up when the player exhales and goes down when he/she inhales. If the measured value is greater than 160, the dandelion seed will float up, and if the measured value is less than 160, it will float to the right.
and had an age range from 19 to 26 years old. These subjects were divided randomly into intervention and control groups.

| TABLE 1  |
| DESCRIPTIVE STATISTICS ABOUT 14 SUBJECTS |
|          | min | max | M   | SD   |
| age      | 19.0 | 26.0 | 22.14 | 2.35 |
| height (cm) | 168.0 | 188.0 | 175.21 | 5.89 |
| weight (kg) | 67.0 | 115.0 | 85.21 | 12.04 |
| BMI      | 22.6 | 36.3 | 27.75 | 3.58 |
| systolic (mmhg) | 126.0 | 156.0 | 142.36 | 8.45 |
| diastolic (mmhg) | 76.0 | 94.0 | 85.43 | 5.33 |

Body Mass Index (BMI) was calculated using the heights and weights of the subjects. The BMI value which was less than 18.5 is underweight, between 18.5 and 24.9 is normal, between 25 and 29.9 is overweight, and greater than or equal to 30 is defined as obese. There were two smokers in each group. Five subjects in the intervention group drank regularly while all seven subjects in the control group drank regularly. There were no statistically significant differences between the intervention and control groups regarding all variables. Table 1 shows the descriptive statistics regarding the 14 subjects. The subjects in the intervention group used the system to perform deep breathing exercises, while the control group subjects were simply told to breathe deeply during the experiments.

The experiment was conducted for seven days from Monday to Sunday. The subjects came to the laboratory once a day to participate in the trial. They were told not to smoke or drink any caffeinated drinks 30 minutes before the experiment. There were five steps in the experiment: First, all subjects were asked to sit and relax for five minutes. After this rest, each subject’s blood pressure was measured. The subjects in the intervention group were directed to wear the breathing belt and then play the breathing game for ten minutes. Afterward, each subject’s blood pressure was measured again. Table 2 shows the intervention group’s measurements. Instead of playing the breathing game, the control group subjects were asked to breathe deeply for ten minutes. Table 3 shows the control group’s measurements.

5 RESULTS

For the data collected on each day of the week, a paired-samples t-test was conducted to compare the systolic and diastolic blood pressure values before and after playing the breathing game for the intervention group. The same paired-samples t-test was conducted to compare the systolic and diastolic blood pressure values before and after deep breathing exercises for the control group.

For the intervention group, there were significant differences in the systolic blood pressure values before playing the breathing game, and after playing the game on Thursday, Saturday, and Sunday. There were no significant differences on the other days, as shown in Table 4.

For the control group, there were significant differences in the systolic blood pressure values before deep breathing exercise, and after the exercise on Monday, Tuesday, and Wednesday. There were no significant differences on the other days, as shown in Table 5.

There was a significant difference in the diastolic blood pressure values before playing the breathing game (M=81.6, SD=6.66) and after playing the game (M=74.3, SD=7.18) conditions; t(6)=3.86, p=0.008 on Saturday in the intervention group. However, there were no significant differences on the other days in either the intervention group or the control group.

In summary, playing the breathing game reduced systolic blood pressure after a few days of practice. However, the game did not reduce diastolic blood pressure most of the time.

The ordinary deep breathing exercise reduced systolic blood pressure in the first three days, but this trend did not continue. There was no reduction in diastolic blood pressure as a result of the deep breathing exercise.

A series of discussions with several experiment participants revealed that it was initially somewhat challenging to play the game. This explains why the systolic blood pressure was reduced on the fourth, sixth, and seventh days after no reductions were observed.
One of the reasons for developing such a gamified wearable breathing monitoring system was to motivate people to begin regularly practicing deep breathing exercises. The problem of loss of interest in the deep breathing exercise is reflected in the control group's experiment result, as there was a statistically significant reduction in systolic blood pressure during the first three days but none thereafter.

6 CONCLUSION

A Gamified Wearable Breathing Monitoring System was developed to test the effectiveness of continued practice of deep breathing in lowering high blood pressure.

It is difficult to quickly lower one's blood pressure even if hypertension is detected. Thus, there must be a shift from reactive to preventive care [19]. The proposed is such a system.

There are three primary findings: 1) The deep breathing exercise is useful for lowering systolic blood pressure but not for lowering diastolic blood pressure; 2) The deep breathing exercise loses its effectiveness in lowering systolic blood pressure as it is repeated; and 3) The gamified wearable breathing monitoring system did not initially lower systolic blood pressure due to the users' unfamiliarity with the system, but it did lower the values after a few days of practice.

One of the practical goals of this paper was to develop a blood pressure-lowering deep breathing game that is easy to learn and use. The outcome of this research is definitely a positive step toward achieving this goal.
### TABLE 3

**Systolic and diastolic numbers before and after deep breathing exercise (control group)**

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### TABLE 4

**Systolic blood pressure changes before and after the breathing game (intervention group)**

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### TABLE 5

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**REFERENCES**


