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Healthcare

DESIGN AND DEVELOPMENT OF A TANGIBLE AND DIGITAL LUNGS EXERCISER FOR THE ATHLETES

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ABSTRACT This paper presents the design and development of a gamified lung exerciser aimed at motivating athletes to perform daily lung exercises. The device utilizes an Arduino UNO microcontroller, two flow sensors (for inhalation and exhalation), and Processing software to create an interactive gaming experience. The flow sensors measure tidal volume during breathing, which is then visualized in Processing as two dynamically resizing dots (green for inhale, red for exhale). The size of the dots corresponds to the measured tidal volume, providing real-time feedback. An LCD screen mounted on the device also displays the numerical tidal volume values. To enhance engagement, additional interactive elements include a joystick and two push buttons for playing supplementary games within the Processing environment. A Neopixel LED, buzzer, and vibration motor provide sensory feedback, activating when the tidal volume exceeds 4 liters, indicating a strong breathing effort. The entire device is housed in a 3D-printed enclosure, making it portable and customizable. The efficacy and user experience of the lung exerciser were evaluated through testing with 15 lawn tennis athletes. The gamified approach aims to transform routine lung exercises into an engaging and motivating activity, potentially improving respiratory function and athletic performance. The results of the user testing and the technical details of the device's design are presented and discussed.

KEYWORDS : lung exerciser, gamification, lawn tennis players, human-computer interaction, heptics

1. INTRODUCTION

Respiratory function plays a crucial role in athletic performance, impacting oxygen uptake, carbon dioxide removal, and overall endurance (Romer et. al.,2002). Efficient lung function is essential for athletes across various disciplines, enabling them to sustain high-intensity activities and recover effectively. Traditional methods of lung training often involve repetitive exercises that can be perceived as monotonous and demotivating, leading to inconsistent adherence. This has prompted exploration into innovative approaches to enhance engagement and promote consistent practice. Gamification, the application of game design elements in non-game contexts, has emerged as a promising strategy to motivate individuals and encourage desired behaviors, including adherence to exercise regimens (Hawkins et. al., 2007). This chapter introduces the importance of respiratory training in athletes, explores the limitations of traditional methods, and presents the rationale for developing a gamified lung exerciser. The respiratory system's primary function is to facilitate gas exchange, delivering oxygen to the blood for transportation to working muscles and removing carbon dioxide, a metabolic waste product (Illi et. al., 2012). During exercise, the demand for oxygen increases significantly, requiring the respiratory system to adapt and function optimally (Hamari et. al., 2014). Several physiological parameters reflect respiratory efficiency, including:

- **Tidal Volume (TV):** The volume of air inhaled or exhaled during a normal breath (Burke et. al., 2009)
- **Vital Capacity (VC):** The maximum volume of air that can be exhaled after a maximal inhalation (Powers et. al., 2018).
- **Forced Vital Capacity (FVC):** The maximum volume of air that can be exhaled forcefully and rapidly after a maximal inhalation (Whipp et. al., 2006).
- **Peak Expiratory Flow (PEF):** The maximum rate of airflow during a forced exhalation (Dempsey et. al., 1982).

These parameters are crucial for athletes as they directly influence oxygen delivery to muscles and the removal of metabolic byproducts. Improved respiratory function can lead to enhanced endurance, reduced fatigue, and faster recovery times. Studies have shown that targeted respiratory muscle training (RMT) can improve athletic performance in various sports (Coast, et. al., 1982) . For example, RMT has been shown to improve cycling time trial performance (Romer et al., 2002), swimming performance (Hawkins et al., 2007), and running economy (Illi et al., 2012). Traditional lung exercises often involve repetitive breathing patterns, such as deep breathing exercises, pursed-lip breathing, and inspiratory muscle training using mechanical devices. While these methods can be effective in improving respiratory function, they can be perceived as tedious and lack intrinsic motivation. This can lead to poor adherence and limit the potential benefits of the training. Some common limitations of traditional methods include (Hamari et. al., 2014)

- **Monotony and Lack of Engagement:** Repetitive exercises can be boring and fail to sustain user interest over time.
- **Lack of Real-Time Feedback:** Many traditional methods lack real-time feedback on performance, making it difficult for users to track their progress and make adjustments.
- **Difficulty in Quantifying Progress:** Objective measurement of progress can be challenging with some traditional methods, making it difficult to assess the effectiveness of the training.

Gamification involves incorporating game design elements, such as points, badges, leaderboards, challenges, and narratives, into non-game contexts to enhance user engagement and motivation. By leveraging the inherent motivational power of games, gamification can transform mundane tasks into enjoyable and rewarding experiences. Several studies have demonstrated the effectiveness of gamification in promoting health and fitness behaviors. For example, gamified exercise programs have been shown to increase physical activity levels (Hamari et al., 2014) and improve adherence to rehabilitation protocols (Burke et al., 2009). The key principles of gamification that contribute to its effectiveness include:

- **Feedback:** Providing users with immediate feedback on their performance allows them to track their progress and make adjustments.
- **Goal Setting:** Setting clear and achievable goals provides users with a sense of purpose and direction.
- **Competition and Social Interaction:** Incorporating elements of competition and social interaction can enhance motivation and engagement.
- **Reward Systems:** Providing rewards for achieving goals can reinforce desired behaviors.

This research aims to address the limitations of traditional lung exercise methods by developing a gamified lung exerciser. The device integrates hardware components, including flow sensors and an Arduino microcontroller, with interactive software developed using Processing. The device provides real-time feedback on breathing performance through visual and auditory cues, transforming lung exercises into an engaging and motivating experience. The specific objectives of this research are:

- To design and develop a portable and user-friendly lung exerciser.
- To integrate gamification elements to enhance user engagement and motivation.
- To evaluate the effectiveness of the gamified lung exerciser in improving respiratory parameters.

2. Existing Product Analysis

A. Power breathe Kinetic Series

Figure 1: Powerbreathe K-Series

- **Target User:** Athletes, COPD patients, and individuals focused on general fitness.
- **Mechanism:** Utilizes Inspiratory Muscle Training (IMT) through a calibrated resistance device.
- **Gamification/Feedback:** Some models (K3, K5) feature digital displays for training data, such as resistance level and training load. They also connect to a mobile app for basic progress tracking and training programs.
- **Strengths:** Scientifically validated, focuses specifically on strengthening inspiratory muscles, and offers various resistance levels to accommodate different fitness levels.
- **Drawbacks:** Primarily concentrates on inspiratory strength, lacking flow-based measurement or real-time visual feedback. Gamification is limited, and the devices can be expensive. They also require consistent calibration for accurate resistance.

B. Airofit PRO

Figure 2: Airfit PRO

- **Target User:** Athletes, singers, and individuals interested in general fitness and respiratory health.
- **Mechanism:** Employs both inspiratory and expiratory muscle training using a Bluetooth-connected device.
- **Gamification/Feedback:** A mobile app provides guided training programs, tracks lung function parameters (vital capacity, inspiratory/expiratory strength), and includes basic gamified elements like points and badges.
- **Strengths:** Measures both inspiratory and expiratory strength, offers personalized training programs, and provides some digital tracking and basic gamification features.
- **Drawbacks:** Primarily focuses on strength training rather than real-time flow visualization. Gamification is relatively basic, and the device's reliance on a smartphone and Bluetooth connection can lead to connectivity issues.

C. Spirometer Apps (e.g., Spirobank Smart)

Figure 3: Spirobank Smart

- **Target User:** Clinicians and patients with respiratory conditions.
- **Mechanism:** Measures lung function parameters (FVC, FEV1, PEF) using a connected spirometer or, in some cases, the device's microphone.
- **Gamification/Feedback:** Some apps offer basic tracking of results and comparisons to normative data, but gamification is very limited.
- **Strengths:** Provides clinically validated measurements, is useful for monitoring lung function, and can aid in detecting potential respiratory issues.
- **Drawbacks:** Not designed for training purposes; primarily diagnostic. Gamification is limited, and accuracy can vary depending on the device used and the user's technique, especially with microphone-based apps.

D. Breathing Training Apps (e.g., Prana Breath)

- **Target User:** Individuals interested in general wellness and meditation practices.
- **Mechanism:** Offers guided breathing exercises, often incorporating visual and auditory cues. Some apps utilize the device's sensors for biofeedback, such as heart rate variability.

Figure 4: Parana Breathe Application

- **Gamification/Feedback:** Provides various breathing patterns, tracks session duration, and some include progress tracking and rewards.
- **Strengths:** Easily accessible, promotes relaxation and mindfulness, and can be helpful for stress management.
- **Drawbacks:** Not specifically focused on athletic performance or targeted respiratory muscle training. Provides limited flow-based feedback, and its effectiveness for improving lung function is not as well-established as IMT.

E. Traditional Incentive Spirometers (e.g., Voldyne)

Figure 5: Traditional Spirometers

- **Target User:** Post-operative patients and individuals recovering from lung conditions.

- **Mechanism:** A simple plastic device with balls or pistons that rise with inhalation.
- **Gamification/Feedback:** Offers very basic visual feedback through the height of the balls or pistons. No digital tracking or gamification features.
- **Strengths:** Inexpensive, simple to use, and provides basic visual feedback on inspiratory effort.
- **Drawbacks:** Provides limited feedback and no quantitative measurement. Not engaging for long-term use, offers no expiratory training, and can be difficult for some patients to use effectively.

3. Problem Statement and Methodology

3.1 Problem Statement:

Traditional lung exercise methods, while effective in improving respiratory function, often suffer from low adherence due to their repetitive and monotonous nature. This lack of engagement limits the potential benefits of these exercises, particularly for athletes who require optimal respiratory performance. Existing respiratory training devices and apps often focus on inspiratory muscle strength or provide basic digital tracking, lacking real-time, flow-based feedback and engaging gamification elements. This creates a need for an innovative and motivating approach to lung training that can enhance user engagement and promote consistent practice, ultimately leading to improved respiratory function and athletic performance.

3.2 Objectives

Primary Objective: To design, develop, and evaluate a gamified lung exerciser that provides real-time, flow-based feedback and incorporates interactive game elements to enhance user engagement and motivation.

Secondary Objectives:

- To develop a system that accurately measures and displays tidal volume during inhalation and exhalation.
- To create a gamified interface using Processing software that provides dynamic visual feedback based on breathing patterns.
- To incorporate additional interactive elements, such as a joystick and pushbuttons, to enhance the gaming experience.
- To evaluate the usability and user experience of the gamified lung exerciser through user testing with athletes.
- To assess the potential impact of the device on respiratory parameters (e.g., tidal volume, peak flow) through a pilot study.

3.3 Methodologies:

This research will employ a mixed-methods approach, combining engineering design, software development, and user testing. The following methodologies will be used:

Hardware Design and Development:

- Selection and integration of flow sensors to accurately measure airflow during inhalation and exhalation.
- Development of an Arduino-based system to process sensor data and communicate with the Processing software.
- Design and fabrication of a 3D-printed enclosure for the device.

Software Development:

- Development of a gamified interface using Processing software to visualize breathing patterns in real-time.
- Implementation of interactive game elements, such as dynamically resizing dots, joystick control, and additional mini-games.
- Integration of data logging capabilities to record breathing data for analysis.

User Testing and Evaluation

- Recruitment of a sample of athletes (e.g., lawn tennis players as you mentioned) for user testing.
- Conducting usability tests to evaluate the ease of use, intuitiveness, and overall user experience of the device.
- Collecting qualitative data through questionnaires and interviews to gather user feedback on the gamification elements and their impact on motivation.
- Conducting a pilot study to assess the potential impact of the device on respiratory parameters by comparing pre- and post-intervention measurements. This would involve a control group and an intervention group using the device.

4. Overall Research Setup and Working Principle

4.1 Research Gap:

While existing products and methods address aspects of respiratory training, a significant gap exists in providing a truly engaging and motivating experience that combines real-time flow-based feedback with comprehensive gamification. Current solutions often focus on isolated aspects, such as inspiratory muscle strength training (IMT) or basic digital tracking of lung function parameters. They lack the dynamic, interactive visualization of breathing patterns and the integration of game mechanics that can significantly enhance user adherence and motivation. Specifically, the research gap can be summarized as follows:

- **Lack of Real-Time Flow Visualization:** Many devices rely on measuring strength or providing post-exercise data, missing the opportunity to provide immediate visual feedback on breathing patterns during the exercise itself.
- **Limited Gamification:** Existing gamification elements are often basic, such as points or badges, and don't fully leverage the potential of game design principles to create a truly engaging experience.
- **Combined Inhalation and Exhalation Feedback:** Few devices provide simultaneous and distinct feedback for both inhalation and exhalation, limiting the ability to train coordinated breathing patterns.
- **Integration of Interactive Game Elements:** The integration of additional interactive elements, such as joysticks, buttons, and mini-games, is largely unexplored in the context of respiratory training devices.

4.2 Block Diagram and Working Principle of the Project:

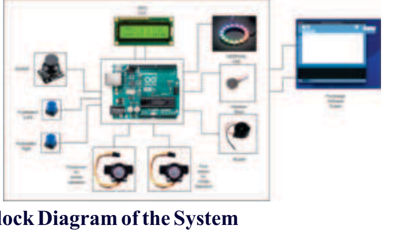

Figure 5: Block Diagram of the System

The gamified lung exerciser operates on the principle of measuring airflow during inhalation and exhalation and translating this data into a dynamic visual representation within a game environment. The working principle can be broken down into the following steps:

- **Airflow Measurement:** Two flow sensors are used to measure the rate of airflow during inhalation and exhalation through the mouthpiece. These sensors generate analog voltage signals proportional to the airflow rate.
- **Data Acquisition and Processing:** An Arduino UNO micro-controller acquires the analog signals from the flow sensors and converts them into digital values using its analog-to-digital converters (ADCs). The Arduino then processes this data, filtering out noise and converting the raw sensor readings into calibrated flow rate values (Agrawal et al., 2024; Jigarkumar A. Gohil, Reena R. Trivedi, 2022; Kashish Chandak, Aman Sanadhya, Jigar Gohil, Reena Trivedi, Priyam Parikh, Mihir Chauhan, 2024; P. Parikh et al., 2023; P. A. Parikh et al., 2022, 2023; P. A. Parikh, Joshi, et al., 2021; P. A. Parikh, Trivedi, et al., 2021; Priyam A. Parikh, Keyur D. Joshi, 2020) .
- **Data Transmission:** The processed flow rate data is transmitted from the Arduino to a computer running Processing software via a USB serial connection.
- **Visual Representation:** The Processing software receives the flow rate data and uses it to dynamically control the size of two distinct visual elements (dots). One dot (green) represents inhalation, and the other (red) represents exhalation. The size of each dot is directly proportional to the measured airflow rate. Therefore, a larger dot indicates a higher flow rate, and a smaller dot indicates a lower flow rate. This provides real-time visual feedback on the user's breathing effort and pattern.
- **Gamification Elements:** The Processing environment also incorporates additional game elements to enhance engagement:
- **Joystick and Buttons:** A joystick and two pushbuttons are connected to the Arduino and their input is sent to Processing. This allows the user to interact with additional mini-games or control elements within the visual display, adding another layer of interaction.
- **Sensory Feedback:** When the tidal volume surpasses a predefined threshold (e.g., 4 liters as you mentioned), the Arduino triggers a

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Neopixel LED to glow, a buzzer to sound, and a vibration motor to activate, providing multi-sensory feedback to the user.

- **Data Logging:** The Processing software can log the breathing data over time, allowing for tracking of progress and analysis of breathing patterns.
- **LCD Display:** An LCD screen connected to the Arduino displays the numerical values of the tidal volume for both inhalation and exhalation, providing precise quantitative feedback alongside the visual representation.

5. Entire Research Setup

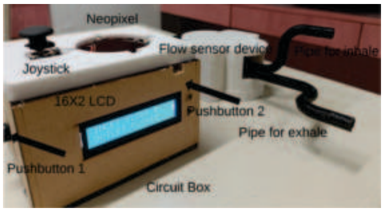

Figure 6: Entire Research Setup of the Project

Figure 7: Final Product

Figure 8: Circuit Box Inside the Casing

6. RESULTS AND DISCUSSIONS

The results in Table 1 illustrate the tidal volume changes during inhalation (0-5 seconds) and exhalation (5-11 seconds) for five individuals. Across all participants, tidal volume increased rapidly during the initial phase of inhalation, peaking around 5 seconds. This indicates a strong initial inspiratory effort. Peak tidal volumes varied between individuals, ranging from 5.2 to 6 liters, highlighting individual differences in lung capacity and breathing patterns. During exhalation, tidal volume decreased steadily, returning to zero by 11 seconds. The exhalation phase appears slightly more prolonged than inhalation, suggesting a controlled and gradual expiratory effort. Interestingly, Person 5 exhibited a slightly delayed peak inhalation compared to others, reaching maximum tidal volume at 6 seconds. This could indicate variations in breathing technique or individual lung mechanics. Further investigation into these individual differences could provide valuable insights for personalized training programs. Overall, the data demonstrates the dynamic nature of tidal volume during breathing exercises and underscores the importance of real-time feedback for optimizing respiratory training.

Table 1: Tidal Volume During Inhale and Exhale Operations

Time (seconds)	Tidal Volume (liters) Person 1	Tidal Volume (liters) Person 2	Tidal Volume (liters) Person 3	Tidal Volume (liters) Person 4	Tidal Volume (liters) Person 5
0	0	0	0	0	0
1	2.5	2.2	1.8	1.4	1.8
2	4.1	3.9	3.5	2.6	2.9
3	5.2	4.8	4.2	3.2	3.7
4	5.8	5.5	4.9	4.1	4.6
5	6	5.9	5.3	5.2	5.9
6	4	3.8	3.9	3.7	3.6
7	3.3	2.9	2.9	2.5	2.6
8	2.2	2.1	2.3	1.8	1.9
9	1.8	1.6	1.9	1.1	1.4
10	1.2	0.9	1	0.7	0.8
11	0	0	0	0	0

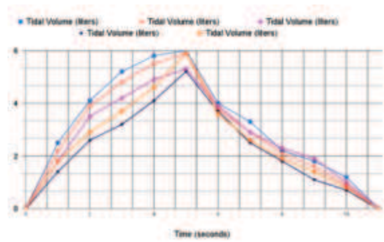

Figure 9: Tidal volume for Inhale and Exhale Operations for 5 Person

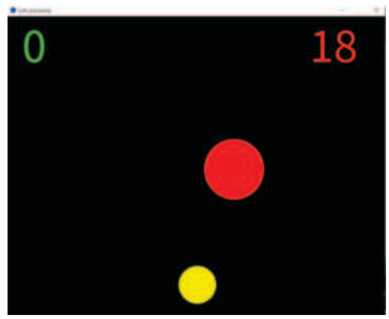

Figure 10: Screen of the Processing Game

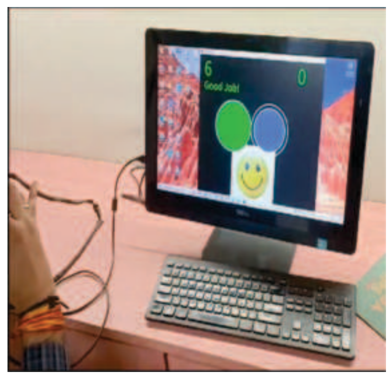

Figure 11: Screen of the Processing Game While Performing Exhale Operation

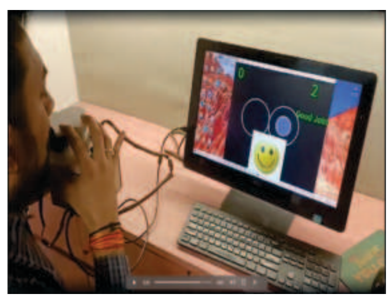

Figure 11: Screen of the Processing Game While Performing Inhale Operation

7. User Testing

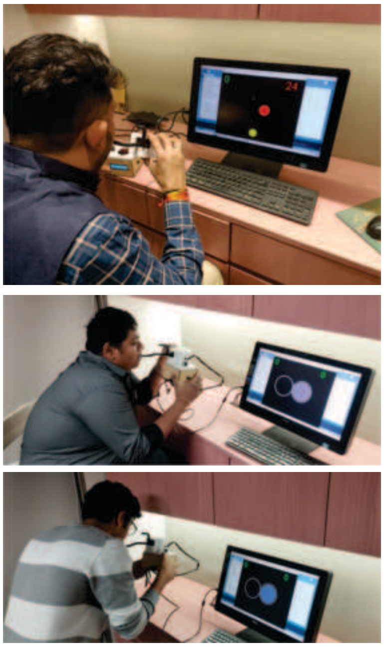

Figure 12: User Testing

8. CONCLUSION

This research presented the design, development, and evaluation of a gamified lung exerciser aimed at enhancing user engagement and motivation in respiratory training. By integrating flow sensors, an Arduino microcontroller, and processing software, the device provides real-time, flow-based visual feedback on breathing patterns, addressing a significant gap in existing respiratory training methods. The dynamic resizing dots, representing inhalation and exhalation, offer an intuitive and engaging representation of breathing effort. The incorporation of additional game elements, such as a joystick, pushbuttons, and sensory feedback (LED, buzzer, vibration motor), further enhances the user experience and promotes consistent practice. User testing with athletes provided valuable insights into the device's usability and potential impact on motivation. This innovative approach to lung training has the potential to transform routine exercises into an enjoyable and rewarding activity, ultimately contributing to improved respiratory function and athletic performance. Future work could focus on expanding the gamification features, conducting larger-scale clinical trials to assess the device's impact on respiratory parameters, and exploring its application in various populations beyond athletes.

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