Games with biofeedback for pulmonary rehabilitation

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Introduction

In this paper we explore computer and sensor based technologies for breathing exercises in pulmonary rehabilitation. We describe games with biofeedback developed for the purpose of the PulmoRehab project and discuss our experience.

Breathing exercises are part of pulmonary rehabilitation programs [Hill 2006, Sharma 2011, Rodrigues 2020]. Breathing exercises increase quality of life for people with asthma [Santino 2020] as well functional exercise capacity for people with COPD [Holland 2012, Yufan Lu 2020]. Breathing exercises can improve pulmonary function, respiratory muscle strength, exercise capacity, dyspnea, health-related quality of life [Holland 2012].

Two main directions in computer assisted pulmonary rehabilitation are: virtual reality solutions promoting aerobic exercises [Colombo 2020], breathing exercises with computer feedback promoting proper breathing patterns [Bingham 2010, Garcia-Hernandez 2022]. In this paper we focus on training proper breathing patterns. The typical setup here is that the patient follows the instruction from the application and performs inhalation and exhalation. The breathing pattern is measured with the sensor (the patient is equipped with e.g. pressure sensor, microphone) and the base of the measured signal, the application provides feedback about correctness of the exercise. The patient may adjust breathing patterns according to the feedback. Examples of the training are: slow breathing with given frequency, long exhalation. Feedback is provided for example as a bar/balloon with the size proportional to the pressure/volume (blow up virtual balloon) or position of agent on the screen (the goal is to keep agent in given boundaries/tunel).

Beside pulmonary rehabilitation, breathing exercises with computer feedback may find application in treatment of psychological disorders [Sonne 2016] and wellness [Patibanda 2017]. Interesting study of various breath based mechanics for game control going beyond the typical approach is presented in [Tennent 2011].

There are following advantages in incorporation of breathing exercises with computer feedback into pulmonary rehabilitation programs, especially in the tele-rehabilitation model: information about the correctness of the exercise/remote patient supervision and possibility of adjustment of the exercise parameters; information about compliance with therapeutic recommendation; making exercise more attractive, especially for younger; providing biofeedback for patient, which is important especially for those with lower body consciousness.

The most common approaches are:

- Spirometry games: These games utilize smartphone sensors or external devices to measure lung function and encourage users to achieve specific breathing targets.
- Breathing Relaxation Apps: Focused on reducing stress and improving lung function through deep breathing techniques, these apps often include guided exercises set to calming visuals or narratives

There are several issues for consideration during development of computer feedback system for breathing exercises:

- Source of signal for breathing monitoring:
    - chest belt/warables (e.g. bioimpedance, tensometry, accelerometer) or hand hold devices (e.g. tube with pressure sensor); there are evidences that users prefer solutions where they can focus on physical objects (like tube) [Patibanda 2017], more over chest based solutions have higher inertia which results in lower user experience;
    - dedicated devices (flow meter, pressure sensor) or general devices (microphone); although microphone are more available they provide few information (flow/no flow) and that impact possibility of game control;
- Game control and game mechanics:
    - signals derived from breathing have much higher inertia in comparison with standard controller (keyboard, mouse), they are less controllable by the player and contain higher level of noise; game mechanics and dynamics have to be adjusted to these factors; mistakes of the players should be gradually incorporated into state of the game (e.g. high initial level of live and recovering with time in follow the path like games);
    - rapid change in the game state make that player involuntarily stop breathing; the information for the player should not be provided in form of the rapid/game changing events (collisions etc);
- Size of the mouthpiece should match the type of game. Large mouthpiece proper for spirometry/forced exhalation make difficult to control games where long breathing patterns are expected.
- Physiological issues:
    - calibration of sensor sensitivity due to wide physiological ranges;
    - hyperventilation.

Methods and Results

In the PulmoRehab project we focused on games promoting proper breathing patterns. Our solution is based on the airflow measurement (pressure). We developed computer feedback

widgets for mobile to support slow frequency breathing and long exhalation training (see FIG. 1 for description). On the basis of user feedback we developed games (for mobile and PC, see FIG. 2). The user has to control the agent moving through the tunnel. The shape of the tunnel models expected breathing pattern. We tested game control mechanics using airflow (pressure) and chest volume (bioimpedance).

The solution preserves signals recorded during exercise. It is possible to verify correctness of exercise (FIG. 3) and calculate indicators like airflow, volume and observe their dynamics (FIG. 4).

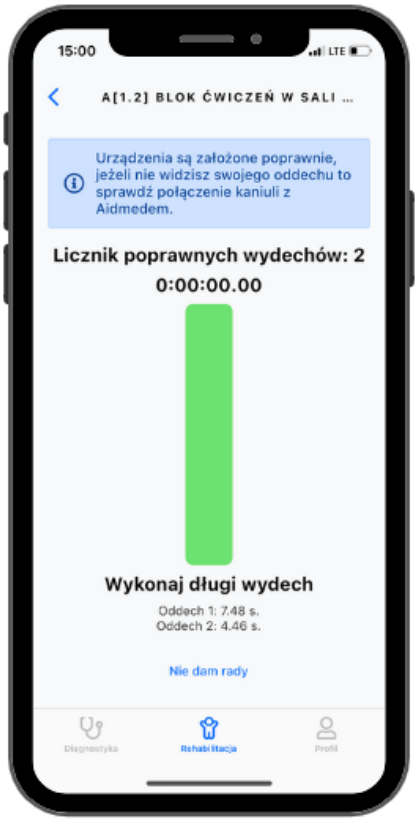

FIG 1) Slow exhalation training: the application asks the user to exhale as long as it is possible. The application measures duration of exhalation. There is a threshold for airflow to accept the exhalation. User is informed about airflow level with the vertical bar. The bar is green if airflow is over the threshold. It is possible to set a threshold and minimal duration of exhalation.
Low frequency breathing training: the application asks the user to perform exhalation or inhalation. There is a threshold for airflow to accept the activity. User is informed about airflow level and direction with the vertical bar. The bar is green if airflow is over the threshold and has proper direction. It is possible to set a threshold and minimal duration of activity and duration of the rest period between activities..

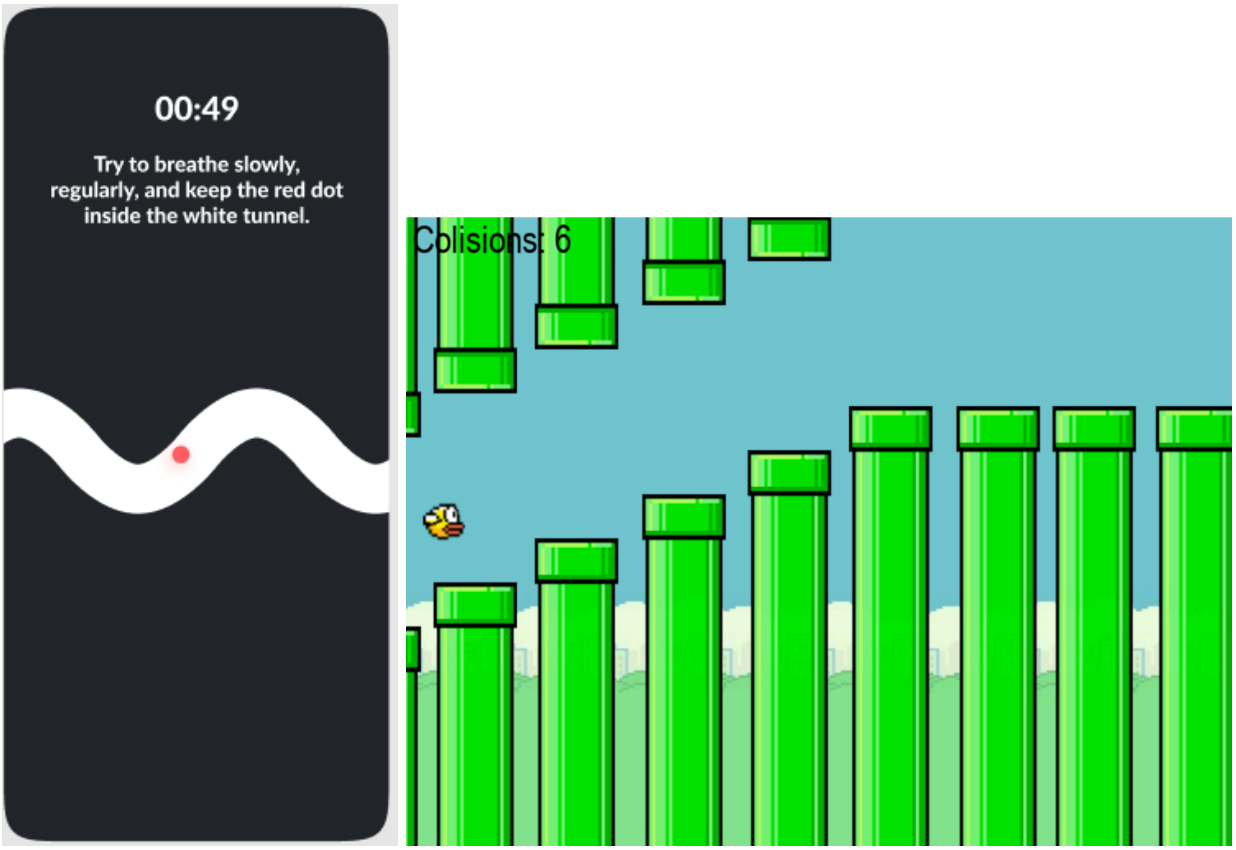

FIG 2) Mobile and PG games for training of breathing pattern. The user has to control the agent (red dot/bird) and follows the tunnel. The shape of the tunnel models expected breathing pattern. The user gets feedback about breathing out of the pattern (collisions).

In the games we use biofeedback (frequency and shape of breathing curve) in 3 games which have different physiological functions:

1) Control of breath frequency (for instance give slow frequency 8-10 RR) [FIG 2]
2) Control of breath to keep ball in the corridor (to learn how to adjust throat and mouth in air flow) [FIG 3]
3) Control of HR and SPO2 to keep patients in the most effective range of oxygen reactions and alarm them if HR is too high/too small and SPO2 too low.

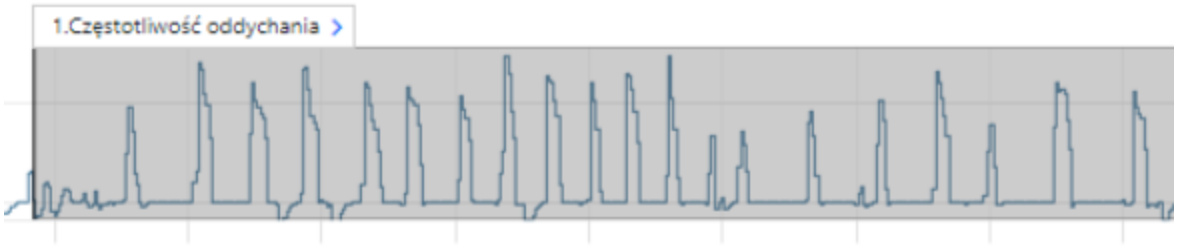

FIG. 3) Airflow registered during slow frequency breathing. It is possible to observe if the user breathes periodically with given frequency.

1) Benefits of Control of Breath Frequency (e.g., Slow Frequency 8-10 RR) are:

- Improved Respiratory Rate Regulation: By training users to slow down their breathing to a target rate of 8-10 breaths per minute, this game helps in promoting diaphragmatic breathing, which is more efficient for gas exchange.
- Stress Reduction: Slow breathing is known to activate the parasympathetic nervous system, reducing stress levels and lowering blood pressure, which is beneficial for overall cardiovascular health.
- Enhanced Pulmonary Rehabilitation: For patients with conditions like COPD or asthma, learning to control breath frequency can aid in managing symptoms and improving lung function over time.

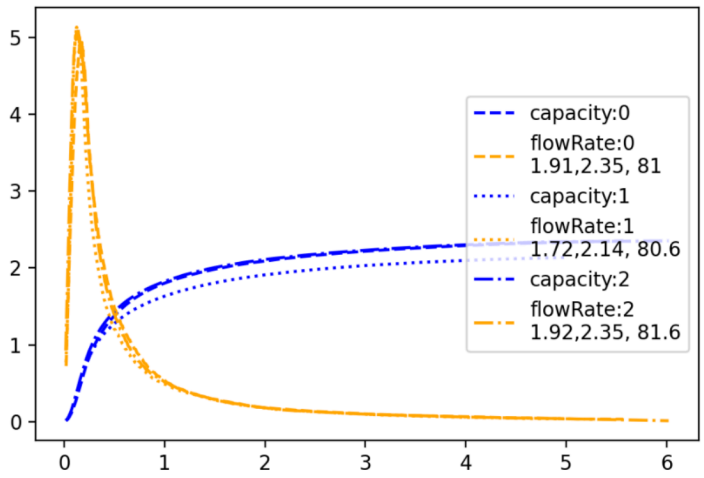

FIG 4) Flow rate and capacity during exhalation.

2) Benefits of Control of Breath to Keep Ball in the Corridor are:

- Fine-tuned Airflow Control: This game helps users learn how to adjust their throat and mouth to control airflow more precisely, improving techniques for effective coughing and breathing that are crucial for clearing airways in conditions like cystic fibrosis.
- Enhanced Breathing Efficiency: By mastering control over breathing mechanics, patients can improve their overall breathing efficiency, which is especially beneficial for individuals with restrictive lung diseases.
- Cognitive-Behavioral Engagement: Engaging patients in a task that requires focused attention on breathing mechanics can enhance mindfulness and the psychological aspects of breathing rehabilitation, making therapy more interactive and less monotonous.

3) Benefits of Control of HR and SPO2 to Keep Patients in the Most Effective Range of Oxygen Reactions are:

- Optimized Oxygen Saturation and Heart Rate: This game encourages patients to maintain their heart rate (HR) and oxygen saturation (SPO2) within a target range, optimizing oxygen delivery to tissues and improving exercise tolerance and stamina.
- Early Detection of Deterioration: By alarming users when HR or SPO2 falls outside of the safe range, the game facilitates early detection of potential exacerbations or complications, allowing for timely intervention.
- Self-Management of Chronic Conditions: For patients with chronic heart or lung conditions, learning to maintain HR and SPO2 within a specific range empowers them to manage their health proactively, reducing dependency on healthcare providers and possibly decreasing hospital admissions.

Discussion

During the pilot study we touch some issues:

- Accuracy and Effectiveness: The effectiveness of these games can vary, and their ability to accurately track and improve lung function should be validated through clinical research. In a project we measure subjective and objective progress of a full tele rehabilitation program, but we cannot say how much is based on our games, as the program is treated as intervention.
- User Engagement: Maintaining long-term engagement with these games can be challenging. Developers must continually update the content and features to keep users interested. We see that patients like oxygen range games, but lose attention quickly with breathing exercises and often have problems with how to do them. Thus, training by a physiotherapist in person is required.
- Accessibility: While smartphone-based, not all potential users may have access to the necessary technology or possess the tech-savvy to use these applications effectively. As we used Aidmed One sensors for biofeedback, we recommend a program where

patients have sensors for 2-4 weeks and later then can use only apps on their smartphones.

Conclusions

The concept of "pulmonary games" on smartphones refers to mobile applications designed to support lung health, including respiratory exercises, monitoring, and rehabilitation. These games are not just for entertainment; they serve a therapeutic purpose, often targeting individuals with chronic respiratory conditions such as asthma, chronic obstructive pulmonary disease (COPD) -as we were making them for, or those recovering from respiratory infections. By integrating gamification elements, these applications aim to motivate users to engage in regular, beneficial respiratory practices.
The therapeutic use of these games in medical treatment harnesses the power of technology to make rehabilitation exercises more engaging and effective. By focusing on key parameters like breathing frequency, airflow control, heart rate, and oxygen saturation, these games offer a personalized and interactive approach to managing respiratory and cardiovascular conditions. This not only enhances the efficacy of traditional therapies but also improves patient adherence and outcomes by making the rehabilitation process more enjoyable and engaging.

Acknowledgment

Work was supported by eeagrants “Pulmorehab”.

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