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OIKONOMOU, Andreas and DAY, David

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Using Serious Games to Motivate Children with Cystic Fibrosis to Engage with Mucus Clearance Physiotherapy

Andreas Oikonomou
School of Computing
University of Derby
Derby, UK
a.oikonomou@derby.ac.uk

David Day
Department of Computing
Sheffield Hallam University
Sheffield, UK
D.Day@shu.ac.uk

Abstract— Positive expiratory pressure (PEP) therapy is an effective method for removing mucus build-up in the lungs of sufferers of chronic lung diseases such as cystic fibrosis (CF). However, the compliance by young children and adolescents to undertake such physiotherapy can lead to confrontation and stressful situations within families, and can impact on the health of the individual. We have developed game software which is controlled through breathing into a PEP mask or mouthpiece using an air pressure sensor to interface with the PC. By combining games with mucus clearing devices, it could provide a powerful means of encouraging children, teenagers and adults to engage more frequently, and effectively, with vital mucus clearance physiotherapy. This paper presents promising initial results and describes further usability testing plans.

Cystic Fibrosis; games; serious; breathing; controller; respiratory; intervention; tube; pressure ;medical ;biomedical

I. INTRODUCTION

Cystic Fibrosis (CF) is one of the UK's most common life-threatening inherited diseases and affects over 9,000 people in the UK [1]. Cystic Fibrosis is caused by a single faulty gene that controls the movement of salt in the body [2]. In people who have Cystic Fibrosis, the internal organs become clogged with thick, sticky mucus resulting in infections and inflammation making it hard to breathe and digest food. There is currently no cure for CF and only half of those living with CF are likely to live past their late 30s [3].

The condition is managed through a combination of:

- Physiotherapy [4]
- Exercise [5]
- Medication [6]
- Diet [7]

Physiotherapy is necessary to remove mucus build up on the lungs; to reduce infection and prevent damage to the lungs. Physiotherapy takes place one to four times per day depending on the amount of secretion. Positive Expiratory Pressure (PEP) uses a mask to hold open the airways, whilst undertaking repetitive breathing exercises, this helps loosen secretions in

the lungs, allowing the patient to clear mucus more effectively from the airways [8].

II. METHODOLOGY

There are many challenges involved in the daily life of a parent of a child who has Cystic Fibrosis. This includes regularly having problems engaging their child to undertake their daily PEP physiotherapy.

Independent literature review commissioned and conducted by a physiotherapist at the Queen's Medical Centre, Nottingham University Hospitals confirmed that these anecdotal observations have an impact on compliance with therapy.

We have developed game software which is controlled through breathing into a PEP using an air pressure sensor to interface with the PC. Gaming technology is inexpensive; the devices upon which it is played are widely available; and especially appealing to young people. By combining games with mucus clearing devices, it could provide a powerful means of encouraging children, teenagers and adults to engage more frequently, and effectively, with vital mucus clearance physiotherapy.

This project and the community within which it will operate have a number of characteristics which make the research applicable to other areas beyond CF:

- a) PEP device therapy, is not isolated to CF and is suitable to clear mucus build up from the lungs in a number of conditions including Chronic Obstructive Pulmonary Disease (COPD), chronic bronchitis, bronchiectasis, and following surgery to remove bronchial secretions.
- b) The device can potentially be adapted for other mucus clearance breathing devices, including the Oscillating PEP (flutter and coronet) devices. Users are not therefore limited by physiotherapy device
- c) Unfortunately for those affected CF and COPD are chronic conditions which have no cure. A means through which daily therapy could become less mundane and be seen as a

recreational or challenging activity is very attractive to sufferers and their families

- d) Currently developed for interface with a PC through a USB drive, the air pressure sensor could be developed to interact with iPhones and android phones and potentially games consoles.
- e) CF sufferers cannot meet in person, because of the risk of infection. Online gaming with chat facilities is therefore an attractive community for those with CF, as this is the closest they can interact with their peers

III. HARDWARE DEVELOPMENT

PEP devices are available from medical suppliers and are supplied free of charge on the NHS to CF patients who are asked to undertake their physiotherapy via PEP. The PEP device, like the PC, is non-proprietary. The innovation we have developed is the connector and the games that can be controlled through air pressure.



Figure 1: Version 2 of our breath controller

The innovation comprises a prototype USB game controller that uses air pressure as input to control custom made games for Cystic Fibrosis patients. The controller converts air pressure exerted by a patient using a PEP device during physiotherapy exercises into a digital signal. The signal is then communicated to a computer via the USB port. The digitalized signal is then used to control a variety of games and game actions within each game. Figure 1 shows the current version (version 2) of the device. As it can be seen the device is quite small and portable. In contrast with our previous version this one is not only smaller but also USB bus powered making it more convenient.

In addition to our hardware controller players can use a standard keyboard and mouse for extra gameplay control. However, all physiotherapy related actions are solely controlled by the custom game controller. It is impossible for a player to progress in any of the games by using only the keyboard and mouse.

IV. SOFTWARE DEVELOPMENT

To date four games have been developed, based on existing physiotherapy guidelines for Cystic Fibrosis patients. The games cater to a wide variety of playing preferences and skill levels and are all designed for pre-teen children.

In addition to the above we have also developed a prototype software platform that can be expanded with future games easily whenever a new game becomes available. The platform tracks user progress in the form of scores and engagement with each of the games and provides additional motivation for players to keep playing through competitive ranking of team performance. Although each game is individual to each user their score counts towards their team. Scores are updated daily for each team and all users can access score information from the main menu of the game.

In addition to scores the system collects usage information on the amount of time spent on each game, the time and frequency of play, the time spent per game and the litres of air exhaled by each user. This has potential use for:

- Academic research
- User insight to inform further developments
- Monitoring patient prescribed physiotherapy to optimize treatment

A. *Cave Flight game*

Our first game puts the player in control of a dragon flying through a system of caves. The purpose of the game is to successfully navigate your dragon out of the caves without crashing on the various stalactites, stalagmites and other obstacles. In addition bonuses and power ups at challenging points along the way provide for extra fun adding risk and reward elements to the game.

The game becomes more and more difficult as the player progresses. This happens through more dense as well as bigger stalagmite/stalactite, a gradual increase in speed and more challenging position for the collectable items.

The user interface consists of a pressure meter positioned on the top left side of the screen. This is a real-time indicator of the pressure being applying to the sensor through breathing. The user must maintain the pressure at a certain level to be able to control their dragon avatar. This is represented by a red ball floating inside a transparent tube. On the top left side of the screen the player can also see their current game score. In the same area they can also see their "game streak" score. This score refers to the number of collectable items they have managed to collect without losing a life. If the player manages to accumulate more than 10 collectable items without losing a life they get additional points. This helps to motivate the player to focus more and plan their flight path as much in advance as possible. This is particularly so if they are getting closer to completing a game streak. On the top right side of the

screen there is an indication of how many lives the player has remaining as well as how many “breaths”. The “breaths” indicator refers to how many exhalations they need to complete before the game is over. This is something that is set by their physiotherapist and can be adjusted by their parents in the main menu screen of the game. The game finishes when they complete the amount of breaths set by their physiotherapist. Figure 2 shows a screenshot from the “Cave Flight” game.

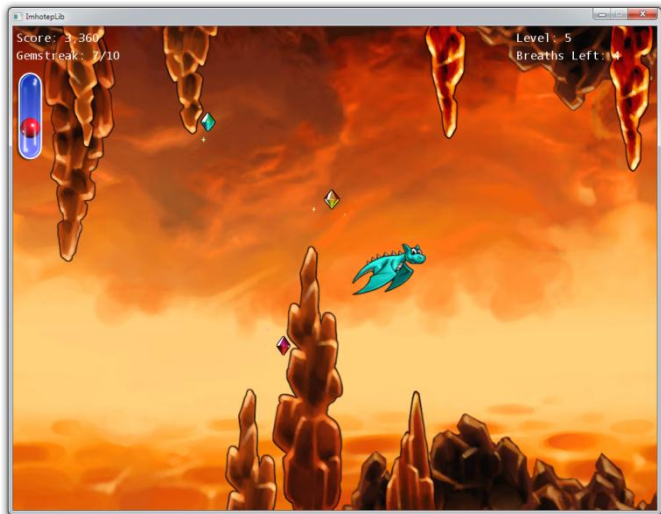


Figure 2: "Cave Flight" game screenshot

B. Flower Garden game

This game was inspired by the activities usually involved in gardening (such as seed sowing) due to the appeal of such activities to young children and because of the potential of having a colorful environment to play in which is also favored by children.

The game works as follows. The player is introduced into an empty garden. They are then given a selection of colored seeds that they can use to plant flowers of the same color in their garden. The game then splits the garden into random areas by putting a colorful border around them. The player has to plant the appropriately colored seed to the corresponding area of the garden. This is done by first clicking on the colored bag of seeds at the bottom of the screen to select it and then by moving their mouse over the area marked with the same color in the garden. To start sowing seeds they must blow into our hardware interface thus simulation the action of blowing the seeds in place. By repeating this action they must cover the whole garden with seeds. As soon as the seed touches the earth a beautiful flower grows out of it. This gives a visual indication to the player of where the flowers were planted and also works as a reward for their effort.

This alone however would become repetitive and boring quite quickly if there wasn't a challenge for the player to continuously keep them engaged. This is provided via the

concept of wind which affects the flight path of seeds as they are being blown towards the garden. The wind direction and strength change continuously and randomly. This is represented via an arrow at the bottom right of the screen. The player must continuously therefore monitor the direction and strength of the wind and adjust the flight path of the seeds accordingly as they blow with their mouse. In addition to this challenge the amount of seeds available is also limited so if the player is not careful and plants a lot of seeds outside their designated area they risk running out of seeds of a particular or even all colors before completing the level. Each level finishes when either more than 95% of the garden has been planted or when all seeds have been exhausted. Players win points for accuracy (planting the right color seed within its designated area) and speed (planting the whole garden as quickly as possible).

The top right side of the screen contains the same information as for the previous game. This is the number of lives and breaths remaining before the game is over. Figure 3 shows a screenshot of a game in progress.



Figure 3: "Flower" game screenshot

C. Pirates game

“Pirates” is the third game in our suite of games. This is an action adventure game with a pirates theme. The player controls a pirate boat equipped with cannons. The aim of the game is to look for and collect treasure hidden around the map. This is done via exploring the map with your boat. However, other pirates lurk around that the player has to avoid if they don't want to end up fighting with. To aid with treasure discovery and guide the player around the environment a small treasure chest icon is used at the bottom left of the screen. This icon flashes when the player is in close proximity to treasure. The faster the rate of flashing the closer the player is to the treasure. This allows the player to intelligently plot courses and search for the treasure. The controls work as follows. The player uses the keyboard (arrow keys) or mouse to direct the

V. RESULTS

boat towards the desired direction and then blows into our hardware interface to blow virtual wind in the sails of the boat. This is a highly satisfying action as children can easily understand and connect with the gameplay metaphor used.

If the player encounters other pirates in the travels and decide to fight them, or get caught up by them the game enters into fight mode. The screen changes showing the two boats from a side view as if one is pursuing the other. The player then gets control of a canon which they can fire. To successfully hit the enemy boat they have to adjust the angle of the canon to hit the moving opponent and fire at the right time. To adjust the canon angle players must use the keyboard up and down arrow keys whilst to fire they must blow into the hardware interface.

In addition to pirates the player has to look out and avoid water whirlpools that can trap their boat. If a player gets too close to a whirlpool their boat gets trapped and starts whirling requiring them to put extra navigational and blowing effort to get it untrapped.

The user interface consists of 5 items in this game. In addition to number of lives and breaths remaining the pressure meter is also shown at the top left of the user interface. On the top right side of the screen a mini map is shown where the player can see a representation of the area they have already explored. Finally the treasure tracking compass is shown at the bottom left of the interface. Figure 4 shows a screenshot from a "Pirate" game in progress.

The game moves to the next level when all treasure items have been collected from the map. The level of difficulty as well as the amount of treasure increases with every new level. Difficulty increases in three ways. Additional pirate ships, water whirlpools and land obstacles that the player has to navigate through. Reward increases through more treasure available to collect.



Figure 4: "Pirates" game screenshot

The prototype interface and suite of games were trialed for 2 weeks by a young patient and their parents. The purpose of the study was to determine the usability and engagement potential of the system. We were also interested in evaluating the possibility of running a future medical trial to establish whether the system offers any medical benefits as. Particularly how it compares with traditional physiotherapy approaches and if there are any counter indications.

A. Usability feedback

The patient and their family were given the prototype device, an installable version of the software and instructions of how to install and use both the device and the games. They were then asked to record their sessions and keep an online journal of their observations of the sessions. Table 1 shows an edited summary of the parents' comments following observation of their child using the system. The actual name of the child has been changed to protect their identity.

Table 1: User comments table

1	I think we need to add "unlimited" to the number of breaths options. It often finishes at frustrating times during game play (cave and flowers games) when Laura isn't ready to stop.
2	Cave flight idea just isn't working. Laura said "I can't keep breathing!" as she tried in vain to keep the game out of pause long enough to get any playability. I think we need to scrap the pause idea, and focus on blowing to keep the dragon in the air for up and down. - addendum, tried this again and she just through the controller down in a tantrum. She really likes the dragon characters, which frustrates her more.
3	Music for cave game should be swapped with the flowers one, and vice versa. It would seem more appropriate.
4	During a demo I have seen pirate fights in the pirate game, but can't find them now. Definitely need more pirates!
5	Flowers - Impossible to color in all sections in the game using the maximum 10 breathes. Even I couldn't do it! (See point 1)
6	A quick pause feature should exist on all games, for example, hit the space bar. This would allow to pause for coughing at the discretion of the parent
7	Pirates game needs more features. How about sharks that can chase you? Laura keeps saying "where is the whirl pool?". Whirlpool was a brilliant idea, but she is looking for other interesting things as she soon gets bored and asks to play flowers. How about sharks that can chase you?
8	Pirates game - how about something you need to chase? i.e. other pirates carrying treasure you can steal?
9	Flowers - she wants to pick her own colors for the coloring area. We have to keep restarting the game until "yeay ... pink". If this was an option before coloring started it would be better.
10	Flowers - ability to turn off the wind feature, sometimes she just wants to color in multiple sectioned screens, which don't appear in the lower

	levels. She isn't so bothered about the score, just wants to color them in, and the wind feature on the harder levels makes it too difficult to play.
11	Have the options settings tied with the profile. The number of sets and breathes should be set with the profile so they don't need to be amended every time the game starts.

As can be seen from the above preliminary results there are a number of areas where the games could be improved. Interestingly there were no comments regarding the hardware device which seemed to have worked as expected.

B. Parent suggested ideas

In addition to the usability feedback received in section A the team also sought parent suggested ideas for future games development. Below is a summary of the ideas received during the trial:

1. More painting and arty games like flowers would be good for Laura's age group.
2. A game which includes an air brush and some pictures to be coloured in, in colors of your choosing. Blowing causes the air brush to paint. No score system necessary.
3. A racing game. Blowing makes a car or boat race against others.
4. Something involving blowing bubbles around. Where you get to blow bubbles and a dog, cat or other pet chases them around.
5. Something involving blowing a kite into the air and keeping it there.
6. Little girls love fairies. How about blowing which makes fairies fly?
7. Something about blowing up balloons and then they fly away.

A common theme of matching real action (blowing) to virtual action is observed amongst the comments. In addition the parents felt that themes matching the interests of the age group should play a more central role in future games. Racing was also mentioned suggesting that competitive gameplay should be utilized more in the future, or at least exist as an option.

C. Time spent playing

Unfortunately the time records kept by the parent were incomplete therefore no significant conclusions can be drawn on the basis of those records. However the following observations were made that may be of interest. Firstly, the child played an average of 8 minutes per session without offering any resistance to executing the exercises as would have been typical when doing the traditional, non-games based exercises. Secondly, the parents felt that they needed to use the

system in conjunction with the existing physiotherapy routine alternating between it and the games. Especially towards the end of the trial. This was due to the fact that the games themselves, given their prototype nature and limitations became boring. Initially the child resisted strongly going back to the old routine and wanted to use the games again. By the end of the trial however both systems were being used interchanging.

In terms of preference the preferred game appeared to be flowers. The child did not care for score much but instead was captivated by the activities offered.

In the "Pirates" game she deliberately sleeked out the whirlpool suggesting that she was interested in variety and challenges in the game. The parents reported that she was "desperate to find the pirates!" future work. It was also observed that increasing the number of times the child had to breath to control the game resulted in her wanting to stop playing earlier than normal.

VI. CONCLUSIONS AND FUTURE WORK

We have developed a Serious Games system to motivate children with Cystic Fibrosis to engage with mucus clearance physiotherapy. Our system which consists of both a hardware and a software component was tested in a case study to evaluate its usability. The results were promising but limited in scale. Our aim is to update the system –particularly the software- and conduct a further usability trial involving 20-30 participants. These will not necessarily be Cystic Fibrosis patients but rather players representing the age group of our target audience. We hope the study will provide us with valuable feedback that we can then incorporate into a clinical trial that will not only target CF patients exclusively in terms of usability but will also examine the clinical benefits of the system.

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