Mobile, Exercise-agnostic, Sensor-based Serious Games for Physical Rehabilitation at Home

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Abstract
Serious games can improve the physical rehabilitation of patients with different conditions. By monitoring exercises and offering feedback, serious games promote the correct execution of exercises outside the clinic. Nevertheless, existing serious games are limited to specific exercises, which reduces their practical impact. This paper describes the design of three exercise-agnostic games, that can be used for a multitude of rehabilitation scenarios. The developed games are displayed on a smartphone and are controlled by a wearable device, containing inertial and electromyography sensors. Results from a preliminary evaluation with 10 users are discussed, together with plans for future work.

CCS Concepts
•**Software and its engineering** → **Interactive games;**
•**Human-centered computing** → *Mobile devices;*
•**Applied computing** → *Consumer health;*

Author Keywords
Serious games, Physical rehabilitation, EMG, IMU, Mobile health, Health

Introduction
Physical rehabilitation commonly takes place in clinics, where physiotherapists supervise the correct execution of

exercises [3]. Patients are also advised to continue exercising at home, for a speedier recovery. However, performing exercises at home can be challenging, because exercises must be carefully executed. At home, the physiotherapist cannot monitor exercises and offer feedback, thus there is the need for simple, portable, and easy-to-use technological solutions that extend physiotherapy programs to the home.

Serious games[1] have been used in a variety of rehabilitation settings, including: balance and mobility [5, 4, 9], limb functionality [6, 10], back and neck afflictions [11], respiratory rehabilitation [12], and posture training [2]. These serious games used different sensors for evaluating the execution of the physiotherapy exercises, including Microsoft Kinect [2, 11], the user's smartphone [4, 12], or inertial and optical sensors combined [9].

Some serious games have been evaluated in preliminary field trials showing good potential to increase exercise adherence and performance [8]. However, in general, serious games tend to be limited to well-defined scenarios. In particular, the literature lacks examples of serious games that can be used to train a variety of exercises, as is often the case in physiotherapy rehabilitation. Apart from demonstration purposes, it is hard to make an impact if serious games are tied to specific exercises. This was the main purpose of developing a mobile, exercise-agnostic platform for the *Physio@Home* project.

This paper proposes a solution based on a smartphone and a wearable device containing an electromyography (EMG) sensor, and an inertial measurement unit (IMU) sensor. The sensors track the execution of the movements, and the smartphone displays intuitive games that guide the user through the execution of the exercises (see screenshot of the Gates Game in Figure 1). The metrics collected during the games are stored and made available to the physiotherapist through a web portal, guaranteeing a second layer of quality assessment.

[1]Serious games consist of game systems for purposes other than solely entertainment [7], in this case, physical rehabilitation at home. Serious games are increasingly common and have been used to support different purposes in healthcare, including health education, physical activity, self-management, and physiotherapy [8].

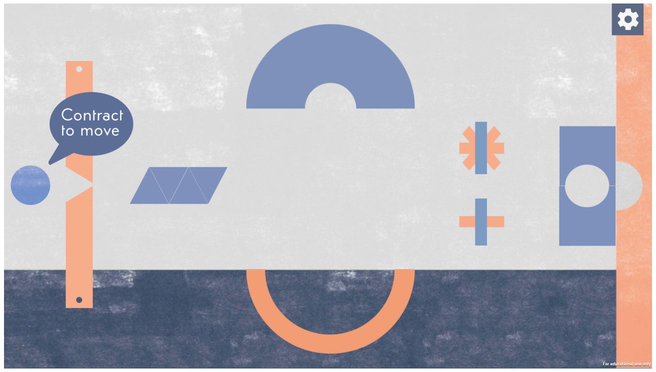

Figure 1: The goal of the 'Gates Game' is to open the gates and let the circle go through them. Contracting the muscle makes the gates open, while relaxing it enables the ball to move forward.

By being exercise-agnostic, the developed serious games can adapt to a multitude of exercises, which can improve the adoption of serious games for physical rehabilitation at home, beyond demonstration purposes.

Game Design

Context

The target audience for the developed serious games is very broad since it includes anyone who is undergoing physical rehabilitation sessions. This means that the game should be appropriate for children, teenagers, stroke patients, athletes with any kind of neuromuscular injury, or older people. In addition, each one of these individuals will be in a very particular exercise regimen, highly dependent of their goals.

The developed games needed as well to be abstract enough to support different exercises. Physiotherapists planned to use the *Physio@Home* project platform to prescribe more than one hundred different exercises, and developing a game for single one of them would be impossible in the available time. Thus, we decided to design games that adapt to multiple exercises.

Developed solution

The proposed solution is a game module that supports the execution of rehabilitation exercises, by presenting them in a more dynamic and entertaining "package". So far, games were designed to be controlled by an EMG sensor that is connected via Bluetooth to the smartphone running the game. Metrics extracted from the sensor's signal control the game. If the values that are being measured are above the threshold defined by the physiotherapist in the clinic, or, in other words, if the player is contracting the muscle appropriately, they will be able to move the object and advance in the game. With values bellow the threshold, the player will be relaxing the muscle and the object won't move. There are also moments in the game in which the player is expected to relax the muscle, and the game promotes that activity.

The developed games are modular and designed to integrate well with the work of physiotherapists. These professionals can easily define the number of series, number of repetitions, relaxation time, and contraction time, in their platform at the clinic, knowing that the games of the patient will adapt to the characteristics that they defined[2]. At the end of each game, therapists receive all the session data, to accompany their patient's progress and, if necessary, adapt their exercise prescription.

The game environment reflects itself the modular design. It is also for that reason that it is shaped with geometric and simple forms that challenge the user to move and interact with it, in order to unlock paths or complete puzzles. Such a minimal environment was designed to be used by a diverse range of players, for a wide array of exercises, and also due to the constraints of the mobile form factor.

Bridges Game

The goal of this game is to make the circle move to the right, until it reaches its final end point. The game has several rectangular platforms that are raised when the user contracts the required muscle (see bars of Figure 2 at the bottom of the screenshot). When the platform reaches the top, the circle element advances. After contracting the muscle to raise the platform, the user needs to rest for some seconds, while the circle advances to the right.

The player needs to respect the contraction and rest times, as otherwise the game does not proceed. If the user stops contracting the muscle, for example, the platform starts falling, to remember the user to contract. Similarly, if the user does not respect relaxation times, the circle stops advancing. This way, the system ensures that the exercises are performed correctly.

The number of platforms are defined by the therapist, when setting the number of series and repetitions.

[2] The platform for physiotherapists is called *physioplux* and was developed by Plux, Portugal.

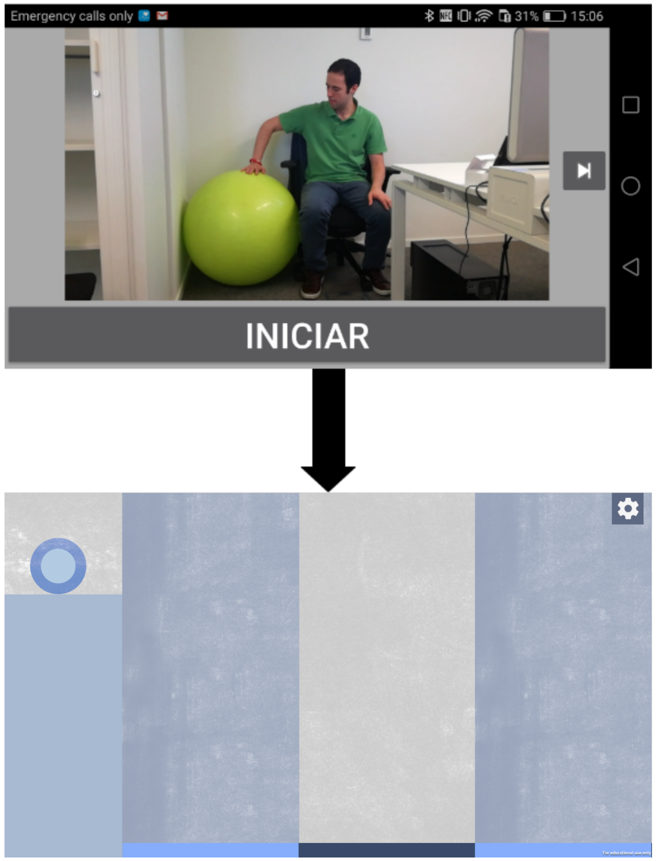

Figure 2: The top screenshot shows the video the player sees before starting an exercise session. On the bottom the 'Bridges Game' is displayed. The goal of this game is to raise the bridges, so that the circle can advance.

Figure 3: In the 'Labyrinth Game' the player contracts the correct muscles to make the circle advance through the maze.

Labyrinth Game
In this game the user guides a circle throughout a labyrinth path. Contraction advances the circle on the right direction to follow the labyrinth path. If the user relaxes the muscle before reaching a checkpoint, the circle will move backwards. The checkpoints are semi circles where the circle fits and stops its motion. The checkpoint will only release the circle once the user relaxes the muscle for a period of time. This guarantees that the player respects the contraction and relaxation times defined by the therapist.

The number of obstacles is also defined by the therapists in their platform, when setting the series and repetitions.

Gates Game
In this game the player needs to open gates in order to advance and reach the final destination. The execution of a contraction will open each gate. After the gate is opened the circle will automatically move to the next one.

In order to maintain the mandatory relaxation phase of the game, there is a numerical countdown before each gate that will only progress if the user keeps the muscle relaxed.

Similar to the previous games, the player needs to respect the contraction and relaxation times, as otherwise the game does not advance.

Moreover, the game always presents a singular experience, as the five different gates are randomly distributed, according to the number of series and repetitions defined by the therapist beforehand.

Preliminary evaluation

As a first trial test, before testing the solution with actual rehabilitation patients, a testing session was organized with a convenience sample of participants. The goal was to evaluate their first impression while playing the games and identify any possible usability issues. Emphasis was given to understanding: i) if the mechanics of the games was easy to comprehend; ii) if the instructions were clear; and iii) if the users could read all the on-screen elements.

Methods

Ten people, 5 women and 5 men, with an average age of 33 years were recruited for this test. No specific recruitment criteria were used; it was assumed that anyone is a potential physiotherapy patient. Therefore, participants were randomly selected among our colleagues. Six researchers, two designers, and two administrative professionals were involved in the tests. Only one participant was undergoing physiotherapy treatments and another one had done so in the past. Participants were asked to complete the three different games, after watching a video of an exercise (a different exercise for each game). Participants were asked to place a Jawbone[3] bracelet on their wrist and were told that the games were controlled by the movement of their wrist.

The game itself was controlled by one of the facilitators, who had a mobile application to emulate the sensor's response, and thus trigger the elements to move. The chosen exercises involved ample arm movements, to enable the facilitator to easily identify them. The reason for using the Wizard-of-Oz method [1], was due to the limited availability of the EMG sensors to use as part of the tests. Moreover, since the main focus of this evaluation were the developed games and the user interaction promoted by them, it was enough to mock the detection of the movements, as long as the facilitators enforced the game mechanics through their use of the app (i.e., contraction and relaxation times).

Results

The developed games were successfull. Participants understood how to play with little to no help. Participants were extremely concentrated while playing the game and there were no clear signs of annoyance. The errors while performing the exercises (e.g. not knowing if there was a number of repetitions vs number of seconds) can be explained by participants inexperience. In a real context, participants would have already performed similar exercises at the clinic, together with a therapist, therefore these errors would be easily removed in a real setting.

Still, there is room for improvements. The first aspect is the lack of consistency between the game elements the player controls in a given game (raising bar, moving ball, barrier gates), and in the countdown made during different

[3] Jawbone is an activity monitor. Refer to: https://jawbone.com/ for further information.

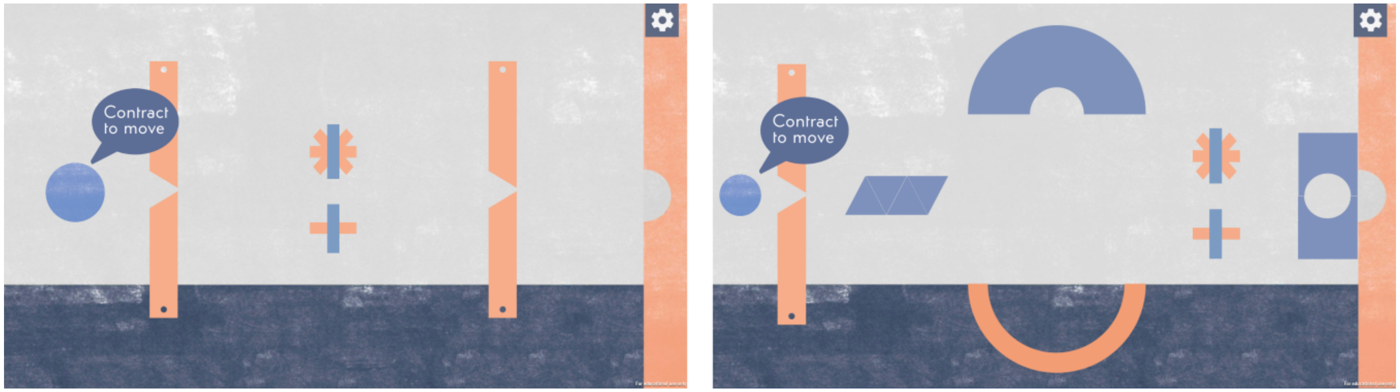

Figure 4: Gates Game with 3 repetitions/gates (left) and 5 repetitions/gates (right) - the number of repetitions the players needs to perform is defined by the physiotherapist.

games with different purposes (game 1 - contraction time, game 2 - relaxation time) or the lack of a countdown in the third game. It was also mentioned that gravity was an inconsistent element. Sound was pointed out as the missing component that could bring a new dimension to the games, even increasing their usability level.

The Wizard-of-Oz method was also a success as no user noticed that they were not controlling the game directly. While we performed the tests with participants with high technological literacy, and in some cases, even development background with inertial measurement units, none of them questioned how they could be moving the game with a proprietary wristband as the Jawbone.

Conclusions and Future Work

Three exercise-agnostic mobile games were developed and initially evaluated with potential users. The success of the evaluation suggests that exercise-agnostic games may cater for multiple exercises used in physical rehabilitation. Future work will focus on developing games and organizing feasibility pilots with patients and physiotherapists, in both clinic and home scenarios.

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