MEDINFO 2017: Precision Healthcare through Informatics
A.V. Gundlapalli et al. (Eds.)

doi:10.3233/978-1-61499-830-3-74

Serious Games for Parkinson's Disease Fine Motor Skills Rehabilitation Using Natural Interfaces

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Abstract

Parkinson's Disease rehabilitation can be long and boring being difficult to maintain patient engagement on therapy programs. Novel technologies are allowing computer games to be played throught natural interfaces. This paper presents the development and assessment of a system of serious games for fine motor skills rehabilitation using natural interfaces. The games were assessed throught a questionnaire that evaluated the game experience through seven components: immersion, flow, competence, tension, challenge and positive and negative affect. In addition, a conceptual framework for development of serious games for fine motor skills rehabilitation was proposed. The results from the quantitative questionnaire suggested that the player experience was positive on all components assessed. Also, player experience between the three games was statistically the same, implying that the games can be used with consistency in a physical therapy rehabilitation program.

Keywords:

Computer Games; Motor Skills; Rehabilitation

Introduction

Parkinson's Disease (PD) is one of the most common neurodegenerative disorders, affecting round 1% of world population over 60 years old [1]. Among all the symptoms related to the disease, tremors, movement stiffness, lack of attention and postural instability can be highlighted. Tremors can be very severe, impairing the hands and fine motor skills of the subject. Fine motor skills represent muscle, bones and nerves coordination to execute accurate movements. These movements use hand and fingers to grab, manipulate objects and tools like when using a pencil or scissors. These fine skills can be impaired due to lesions, diseases, or even stroke; although spine, nerve, or muscle injuries might cause some disturbance as well. Subjects with PD can show difficulty to speak, eat or write because they lost some of their fine motor control [2].

Most treatments for PD are based on administration of drugs, but there is also recovery and rehabilitation by physical therapy programs. Physical therapy programs help to contain symptoms of the disease throughout physical exercises. These exercises can stimulate the brain allowing neurons to create new connections to fulfill difficulties that were imposed by the disease [3]. These therapy programs can take a long time, as the disease has no cure, and the exercises proposed can be boring and repetitive [4]. That can contribute to a drop on patient adherence to treatment or even evasion from the therapy program.

Technology can bring more to people's lives than simply improve performance on doing tasks, it can provide joy and richness, improving the experience. A Serious Game (SG), is a game that can transmit a message, knowledge, skill, or a content to the player. In addition, it might improve the player experience through different kinds of interaction and on different contexts, e.g., health, training and education.

The main goal of serious games for health is to provide knowledge or enhance player skills as any other serious game but, in this case, it must serve a medical purpose. Serious games are being used in many health fields, from exergaming to surgery simulators. Videogames like Wii Fit and Kinect Sports have mainstreamed the genre among physical therapists. However, these games are not built for therapy and individuals need physiotherapy programs tailored to their needs. Also, this genre of games should have more flexibility to allow the therapy to be more personalized according to the subject's capacity and avoid further lesions [5].

Interaction in traditional games are mainly based on mouse and keyboard or joysticks. As computers decreased in size and cost and have growth in processing power, new platforms and interactions were developed. The possibility to create and interact with virtual worlds the same way we interact with physical objects has motivated many researchers to develop new technologies. In consequence, novel technologies that can track cerebral waves, eye movement, body movement, etc. are being developed. Movement sensors like the Microsoft Kinect or the Leap Motion allow the creation of natural interfaces. A natural interface is not an interface that is natural, but it makes the user perceive and use as natural. It is not a feature of a software or device to have a natural interface. The user must feel as natural while using that interface, through a natural interaction, using day-to-day gestures and movements.

Even when people with PD have access to a rehabilitation program with quality and qualified professionals, the program may be long and become unpleasant. In some cases, these individuals, may present lack of motivation during the program due to its degree of repeatability that causes tedium [4,6,7]. In addition, cases of depression and dementia on PD can withdraw these individuals from special care. The use of games has proved to be a good way to fight lack of motivation that results from repetitive exercises on therapy programs [8]. The works of [3, 7, 9, 10] are some that have explored development of serious games for health using movement sensors to help therapies for motor disorders. Although, there seems to be a lack of works focused on fine motor skills rehabilitation using hand movement sensors like Leap Motion. As an off the shelf device that can detect hand movements with low cost, Leap Motion should be explored as a tool for hand rehabilitation [6].

This paper describes the assessment of player experience in a system of serious games for health using natural interfaces. The games were tailored to help therapists on fine motor skills rehabilitation programs. A one-way ANOVA is used to analyze if all the prototypes can provide the same game experience regarding *immersion, flow, competence, positive affect, negative affect, tension and challenge*. Additionally, based on the development of three prototypes, we propose a conceptual framework for development of serious games for motor skills rehabilitation using the Leap Motion device.

Leap Motion

The Leap Motion is a USB device that can detect hand and finger movements in a 3D environment with high precision and performance. The device is relatively small and robust, with a width of 80mm, height of 12.7mm and depth of 30mm (Figure 1). It has three infra-red emitters and two infra-red (IR) sensors inside. Its field of view (FOV) is round 61cm^3 and it is shaped like a hemisphere. According to its website, the Leap Motion can track hand movements with an accuracy of 1/100mm, but [11] has found an accuracy of 0.7mm when tracking non-linear movements executed by a robotic hand. Nevertheless, it has higher accuracy than other devices on the market, e.g. Microsoft Kinect.

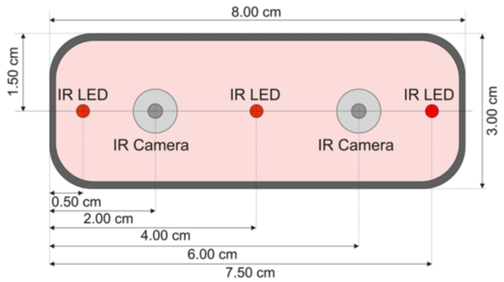

Figure 1 – A Representation of the Leap Motion Hardware Structure, Showing External Dimensions, Infra-Red Emitters and Sensor Positions [11].

Unity Game Engine

The Unity Game Engine was chosen mainly, because of its collection of tools and assets that allow rapid prototyping. Also, there is additional effort by Leap Motion developers to create bootstraps and tools for Unity. There is more documentation and also more graphic assets (prefabs) and scripts to use on prototypes. Moreover, Unity is the most used game engine by game developers according to data found on their public relations page.

Conceptual Framework

It is proposed a conceptual framework for the development of serious games with focus on motor skills rehabilitation using Leap Motion. This framework was based on a common architecture used to develop three prototypes. Basically, it has five layers: User layer, Input/Output layer, Game Engine layer, Database layer and Web Application layer. The framework proposed is illustrated in Figure 2.

The *User layer* is composed by the actors of the system: the player and the therapist. Both of the user profiles interact with the game trough the I/O layer, but only the therapist should use the Application layer.

The I/O layer is responsible for the interaction/interface with the user. It is composed by hardware elements, like the Leap Motion – responsible to provide hand and finger tracking data, Mouse and Keyboard, Sound and Display.

The Game Engine layer is responsible for all the game logic, since handling input/output to rendering the game. Usually, this can be done by a real game engine as Unity or Unreal. The components inside this layer are: *Leap Controller*, it process the tracking raw data to be consumed by other components and objects; Gesture Controller, it checks tracking data for gestures and control gesture actions like grabbing or pinching; *Game Controller*, responsible for game management like scores, times, rules, etc.; GUI Controller, it manages the graphical interface elements of the game, gathers information from Game Controller and Database to output relevant information for the player and therapist; *Game Settings*, it manages the game adjustments that can be controlled by the therapist such as time counter, spawn speed, gesture sensitivity, number of objects to be spawn, etc.; User Controller, it is responsible for user data, such as user profile, user therapy program and sessions; *Database Controller*, handles the persistence layer of the game serializing information and storing in the database.

The *Database layer* is responsible for storing the data that is collected after each session. The Application layer can be represented by a Web Application that consumes data stored on the database to provide insights and report patient progress throughout the program.

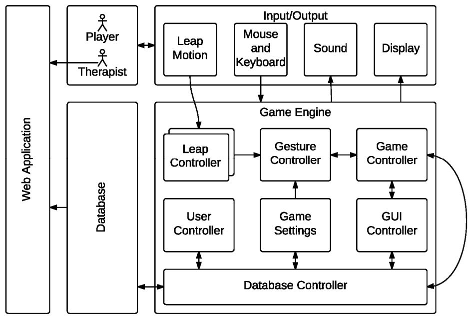

Figure 2 – Representation of a Framework for Development of Serious Games for Motor Skills Rehabilitation

This framework was created to cover the basic architecture for development of other serious games using leap motion. As three prototypes were developed using this conceptual approach, it can be argued that it can be used to develop more Leap Motion controlled serious games.

Prototypes

Three game prototypes were developed based on movements that were observed during rehabilitation sessions at the Rehabilitation unit of Hospital Universitário de Santa Maria (HUSM). In addition, physical therapy professors and professionals provided insights about fine motor skill exercises. These first prototypes were pitched to therapists, a game development professor and a design professor. Based on the considerations provided by those professionals, we iterated over the prototypes and refined them.

The prototypes were developed based on nature and farm life. This theme was chosen because the target audience is significantly composed by elders. The current generation of elders has at least some relation with nature and probably encountered a rural environment when young. Also, each game had a different metaphor that was chosen according to the gesture that was required to play in order to create affordance. The interaction has to make sense to the player, the gesture and the metaphor have to complete each other.

Game Prototype: Pinchicken

The mechanics of *Pinchiken* game is, basically, to pinch eggs that appear on the ground and drop it on the right chicken nest (Figure 3). The scene is composed by three chicken nests with chickens and eggs that keep falling on the ground. When the player pinch and egg, the game will highlight only one nest to drop the egg on. When the player succeeds moving the egg to the right nest, 10 points are awarded, a sound and a visual effect are played as feedback. When it is mistakenly placed, negative sound and visual feedback are played, but no points are awarded neither subtracted. Punishing the player is not the intention, because it can affect player motivation.

Figure 3 – Game 01: Pinchicken, Player Should use the Pinch Gesture to Grab Eggs.

Game Prototype: Finger-Hero

The prototype *Finger-Hero* is based on the mechanics of a blockbuster game called "Guitar-Hero". There are 4 lanes, each one has a flower at the end with a color (green, red, blue, yellow) and a thumb opposition gesture (index, middle, ring, pinky) associated. The game will randomly spawn bees that will move towards the flowers on each respective lane. The objective is to execute the correct opposition gesture when the bee is right above the flower. For example, if there is a blue bee on the third lane, as represented in Figure 4, the player should do the thumb opposition gesture with his ring finer when the bee is exactly over the blue flower. If he succeeds, 10 points are awarded and positive sound and visual feedback is given. Else if he misses only negative sound and visual feedback are given.

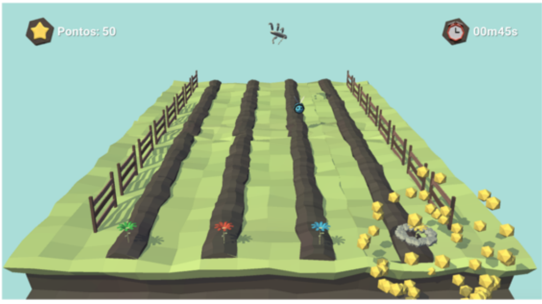

Figure 4 – Game 02: Finger-Hero, Player Should use Thumb Opposition Exercise to Play the Game.

Game Prototype: Grabduzeedo

On *Grabduzeedo* the player controls a spaceship with the hand and the tractor beam can be activated and deactivated using the grab and release gestures (Figure 5). The game will spawn sheep on a platform on the right side of the screen. The objective is to abduct the sheep, closing the hand (grabbing), and moving it to the platform with fences on the left. Just open the hand to release the sheep in place. When the sheep is placed inside the fence 10 points are awarded and positive sound and visual feedbacks are given. Otherwise, negative feedback is given, but no points are awarded or subtracted from the player.

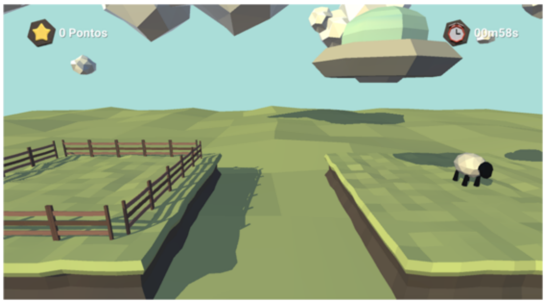

Figure 5 – Game 03: Grabduzeedo, Player Suse the Grab Gesture to Control the Spaceship's Tractor Beam.

Methods

Initial Setup

The experiments were conducted at the Rehabilitation Unit of HUSM, on a room with enough space and climate and light control. The last is extremely important because natural infrared light that is emitted from the sun can interfere on Leap Motion's tracking accuracy.

The setup includes a chair for the participant and desk to place the computer, the display and the Leap Motion device. The Leap motion was placed right in front of the display. Also, a camera was placed on a tripod in the corner of the room. The questionnaire and the consent form were printed in plain paper.

The game can finish when a countdown timer ends or when the player reaches a pre-defined maximum score. A time span of a minute and a half (1m30s) for each game was determined by the therapist as optimal to conduct the experiment. So, the participants had to sum the maximum points before the time ended. In addition, it was defined that the players would use only their dominant hand to play the games.

Game Experience Questionnaire (GEQ)

Game experience and common software experience are composed of different aspects and therefore they need to be assessed differently. The GEQ is an instrument to assess the overall game experience perceived by the player and it was proposed by [12]. They validated the questionnaire with 380 participants who played games of their own choice. The group was composed by 254 men and 120 women (6 null responses) who played games daily (29%), weekly (38%), monthly (13%), few times per year (12%) and hardly ever (8%). The instrument is composed of 4 modules: core module; in-game module; post-game module; and social module. The questions are answered using a Likert scale ranging from 0 to 4 (or from "not at all" to "extremely").

The core module has 33 questions and the result can be obtained by calculating the scores of seven components [12]: *Immersion* is related to the fantasy, aesthetics, and imagination; *Flow* represents the experience of losing track of time and loosing connection with the outside world; *Competence* express if the player was good, successful or skillful at the game; *Positive affect* represents if playing the game was fun or if it felt good; *Negative affect* is related to the player feeling bored, distracted or bad mood; *Tension* is related to how nervous, restless or annoyed the player felt; *Challenge* is related to how many effort the player think he put in the game or if he felt a time pressure.

The questionnaire and scoring system have some redundancies and spare items to prevent misunderstandings caused by translation. The in-game module has 14 questions (the questions are a mirror from the core module) and it is meant to be applied just after gameplay short breaks. The post-game module has 17 questions and assesses how the player felt after the whole gameplay session, its score is based on four components: *positive and negative experience, tiredness and returning to reality*. The social-presence module is meant for multiplayer games, aiming to understand how the player felt interacting with other player during gameplay through 17 questions.

For this study, only the core module was used. As the game sessions were short and single-player, the in-game, post-game and social-presence module were not required.

Participants

The participants were admitted for the experiment on a random and voluntary basis (with no monetary compensation) at the rehabilitation unit of HUSM. All the participants were from a physical therapy background: students, technicians, therapists and professors. Overall, we conducted the experiment with 20 healthy adults. According to [13] on a user experience or usability test only 5 people are sufficient to discover round 80% of the problems, but for quantitative purposes a number of 20 people is recommended. Also, [14] argues that most game evaluation works have a population of 11 to 20 people.

Procedure

First, all participants sat in a chair with the display and Leap Motion in front of them. They were instructed to sign the consent form needed for trials. Also, a brief explanation on how the experiment would proceed was given.

Before testing with the prototypes, the participants had a time to familiarize with the device and technology. A period to feel how the device tracks the hand, how far it reaches and how to interact with it. On this step, the participant interacted freely with the Leap Motion's built-in visualizer app.

After the participant was comfortable with the device, he proceeded to play the game. Exactly after each game had finished, the patient had to answer the questionnaire. This process was repeated for the other two games. The whole session took about 20 minutes, depending on each participant's speed to answer the questionnaire. In addition to the questionnaires, we recorded the scores of all the participants.

In order to analyze the data, GEQ-Scores were calculated. The score for each component is determined by the arithmetical average of the answers that are related to that component on GEQ's Manual. Then, the GEQ Scores of the games were compared with each other on every GEQ-Core component level. A one-way Analysis of Variance (ANOVA, $\alpha = 0.05$) was used to verify if GEQ scores had significate variances or if the game experience was the statistically the same across each game. The research hypothesis checked with ANOVA were:

- H_0 = The overall game experience for all games is the same;
- H_1 = At least one game has a different experience;

Results

The data from 37 questions was collected from 20 participants: 11 physical therapy students (55%), 1 professor (5%), 6 professionals (30%) and 2 technicians (10%); 16 Females (80%) and 4 Males (20%); Age ranging from 20 to 45 years old. Then, the score of each GEQ-Core component was calculated for each game: competence, immersion, flow, tension, challenge, negative and positive affect; and compared.

As it can be observed in Figure 6, optimal results were obtained for both positive and negative aspects of game experience for all the three games. Positive Affect, Immersion and Flow components had the best scores; Competence and Challenge presented a neutral/medium score while Tension; and Negative Affect had minimal score.

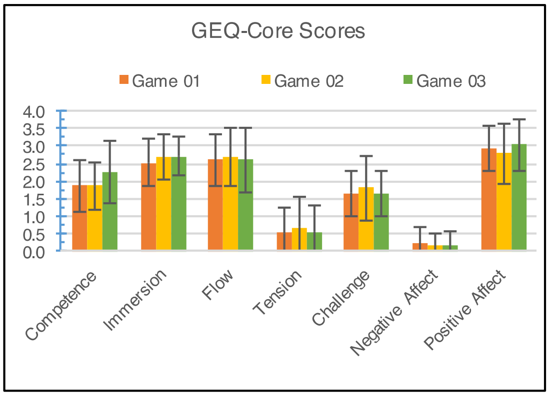

Figure 6 – GEQ-CORE Component Scores for each Game Prototype. The Y-Axis Represents the Scores and the X-Axis Represents each GEQ Component. Game 01 is Pinchicken, Game 02 is Finger-Hero and Game 03 is Grabduzeedo.

Player experience regarding Competence component resulted in statistically the same values for Game 01 (M=1.86±0.73) and Game 02 (M=1.87±0.67) and Game 03 (M=2.25±0.92). The ANOVA for all the components presented p-value superior to alpha, confirming the null hypothesis.

Discussion

It can be argued that the 'Competence' scores were positive because the games were somehow easy to play, allowing players to feel capable of completing the task. A slightly difference between values of Game 01 and Game 02 to Game 03 can be observed. That is because the gesture and interaction required to play the third game was much simpler than the others, requiring lower levels of coordination and dexterity to achieve the goal.

The best score values were from 'Positive Affect' component (Game 01 = 2.92±0.65; Game 02 = 2.78±0.85; Game 03±0.74) it represents the fun and joy experience by the player during gameplay. Also, flow (Game 01 = 2.62±0.75; Game 02 = 2.67±0.85; Game 03 = 2.6±0.92) and Immersion (Game 01 = 2.51±0.70; Game 02 = 2.66±0.66; Game 03 = 2.69±0.56) presented good values representing that the game kept the player focused, was aesthetic pleasant and that it impressed the players. It is said that a game achieved immersion and flow when the player loses track of time and has the feeling to be transported to another place.

Overall, the results obtained from analyses of GEQ data suggest that the system of serious games prototypes presented has good level of user experience and usability on all three prototypes.

Further analysis with ANOVA pointed that the game experience across the three prototypes is statistically the same. That is a positive outcome because the prototypes were designed to work as a system of serious games, not as standalone games. Hence, it is expected that the game experience of each game is similar or the same. It provides consistency for the system.

This work is limited to player experience assessment. Further work should be conducted to evaluate the functionality and the validity of the games as a tool for rehabilitation. Also, there is still some space for improving on aesthetical and mechanics aspects of the game. Moreover, a web application that consumes data from database could be built to help the therapist track patient progress.

Conclusion

In this work, the main contributions are the development of a system of serious games for fine motor skills rehabilitation using NI. The system allows therapy sessions to be customized to patient needs, and also adding more fun and engagement. It can replace exercises that are repetitive and boring, helping to control patient evasion from therapy programs.

It is also proposed a conceptual framework for development of serious games for fine motor skills rehabilitation using Leap Motion. framework worked as expected during the development of three game prototypes.

Results obtained from the questionnaires point that the experience of the three prototypes are similar, allowing the therapist to use them on therapies with consistency. Positive components presented high scores and negative components scored near zero. Also these results can support a physical therapist to validate the system as a tool for rehabilitation of fine motor skills.

Acknowledgements

This research was supported by CAPES. The participation and support of all the individuals during the assessment experiments are thankfully acknowledged.

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