Kinect-based virtual game for motor and cognitive rehabilitation: A pilot study for older adults

Zelai Sáenz-de-Urturi
DeustoTech Institute of Technology
DeustoTech-Life Unit
University of Deusto
zelai.saenz@deusto.es

Begoña García Zapirain
DeustoTech Institute of Technology
DeustoTech-Life Unit
University of Deusto
mbgarciazapi@deusto.es

Amaia Méndez Zorrilla
DeustoTech Institute of Technology
DeustoTech-Life Unit
University of Deusto
amaia.mendez@deusto.es

ABSTRACT
Physical rehabilitation is often necessary for individuals who suffer an injury or illness which causes a physical impairment, in order to restore movement and strength through supervised repetitive exercises. Alternatively, physical activity also improves cognitive performance and reduces cognitive decline. This tool focuses on therapeutic aspects of both cognitive and physical rehabilitation for older adults, as it improves memory by performing mental activities and physical rehabilitation at the same time.

To achieve this, a Kinect-based virtual game intended for Windows which enables users to control and interact intuitively with the computer without an intermediary controller has been developed. Furthermore, all the data generated during the session is stored in order to log each rehabilitation activity.

Preliminary tests have shown an increase in the users' motivation while using the tool. They also indicated the possible rehabilitation of 18 patients with motor disabilities and the maintenance of their cognitive impairment preventing its degeneration.

Categories and Subject Descriptors
H.5.1 [**Information Systems**]: Multimedia Information Systems—*Artificial, augmented, and virtual realities*; H.5.2 [**Information Systems**]: User Interfaces—*Input devices and strategies*

Keywords
Motor, cognitive, rehabilitation, virtual game, Kinect, older adults

1. INTRODUCTION
Many people suffer from an injury or illness which causes a physical impairment such as structural deviations, mobility of bone and joint functions, muscle power or movement functions. These physical impairments can affect every structure and function of the body, as described by the WHO (World Health Organization), and may hinder an individual's ability to perform daily self-care activities. Consequently, this reduces their participation in the community and can significantly limit employment and educational activities [1].

Furthermore, physical rehabilitation is often necessary for these individuals in order to restore movement and strength through supervised repetitive exercises. In a standard medical practice in Spain, physiotherapists work with one patient at a time and monitor whether their physical movements are reaching a specific standard, until the patient is able to regain an appropriate functioning. However, the number of exercises in a therapy session is relatively small [2]. A possible solution to this issue is specialized personnel intervention, but this would be extremely costly. Depending on the type of injury or condition the patient should follow an individual therapy regimen; however, 33% of the patients do not do the exercises as recommended. This may be due to several factors such as the lack of motivation or access to appropriate technological facilities [3].

In addition, individuals who suffer from brain injuries frequently acquire cognitive impairments, or thinking problems, that interfere with their safety and independence. The treatment method, known as cognitive rehabilitation, is designed to reduce cognitive dysfunction and/or assist individuals in compensating for its impact on daily living. The benefits of cognitive rehabilitation have been discussed in more than 700 published research studies [4].

Although larger and more detailed studies are needed, the research by Cay Anderson-Hanley *et al.* [5] suggests that simultaneous cognitive and physical exercise has greater potential for preventing cognitive decline, that is, combining physical and mental exercise by playing active games could have even more beneficial effects on cognition in older adults than normal exercise alone. Interactive physical and cognitive exercise over traditional exercise may garner added cognitive benefit, and perhaps prevent decline, all through the same effort required for exercise. Therefore, the system described in this article focuses on therapeutic aspects of both cognitive and physical rehabilitation.

The preliminary details of the Kineage rehabilitation sys-

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tem are as follows: Kinect-based 3D serious game intended for Windows has been developed, which enables users to control and interact intuitively with the computer without an intermediary controller. This virtual game will facilitate the physical rehabilitation of chronic patients and elderly or disabled people using virtual reality. Furthermore, it is specially oriented towards working on cognitive stimulation in the language area as a priority and it has been designed to be used in therapies driven by clinicians. In order to achieve the rehabilitation part of the system, observations from psychologists and physiotherapists were taken into consideration.
Serious games are an option for providing patients with exercise combined with entertainment, thus increasing their motivation [6].

2. MATERIALS AND METHODS

The proposed system uses Microsoft's Kinect motion sensor connected to a PC, with an integrated database and video instructions to form the video game. Kinect is a webcam-style add-on for the Windows operating system, which provides a natural user interface (NUI) allowing users to interact intuitively and without any intermediary device, such as a game controller. It captures users' full body movement in 3D virtual environment for interaction within game activities, that is, the user's body is the game controller operating in a 3D virtual space and multiple users can be tracked.

It is a sensor set on a horizontal bar with a small base, to be positioned below the video display. It has an RGB camera and a depth sensor, which provide full-body 3D motion capture capabilities. All this scans your body to identify your height and your movements. The Kinect tracking system has been evaluated successfully [7].

In this work, Microsoft Kinect SDK is used; an open-source library which can be used for testing and implementations. The Kinect sensor and its SDK provide a 3D virtual skeleton. This virtual skeleton consists of the positions of 20 joints and body parts (such as the wrists, knees, head and torso), and from here a 3D virtual avatar was generated.
The joints used during the movement are mapped directly into the values placed on the avatar puppet within the game's virtual world.

2.1 Participants

Eighteen users (12 women, 6 men) aged between 65 and 94 with an average age of 79.61 (SD = 8.90) were recruited from Misericordia, a low-income nursing home, for this study. This nursing home's physiotherapists chose the participants with the following criteria: sufficient cognitive level to understand the game and the instructions from the physiotherapists and, as physical conditions, having minimum movement in at least one of the arms. Two of them presented a visual deficit (presbyopia- age-associated eye condition) which implies sensitivity to light, and one of them had age-related macular degeneration. Furthermore, two other users use wheelchairs for their daily tasks and another one had Parkinson's disease.

2.2 Kineage Rehabilitation System

Firstly, and in order to make this rehabilitation system more general, it is possible to specify the typology of the user, that is, with or without any movement in their legs (use of a wheelchair), and also provides the player with the option of playing while standing up or sitting down. Additionally, users may have limited mobility in either arm (even total absence of movement in either of the two members); thus, the game is configured in such a way that the user can choose whether to play with the left arm, right arm or both.

At the beginning of the game, the users will be asked to enter their name, which will be referenced in the scores, in order to store any information related to the user during the game play. Then the users have to calibrate the sensor, in order to check their position, in the settings option from the main menu. From this menu the user can select whether he wants to play sitting down or not and which arm he is going to play with.

For the skeletal system calibration, users must stand about 1.5-2 meters away in front of the Kinect sensor with their arms up and hold this position without moving for a few seconds. Therefore, the sensor obtains the correct position of the user as the device automatically moves up and down. This calibration method is predetermined for the sensor and commercial games, which might not be appropriate for some users since they might not be able to complete this procedure [8]. In this case, and in order to take the physical limitations of the users into account, a set of configuration options have been designed to make the game easier to play, such as the option of changing the angle of the camera (allowing the user to tilt the device up or down to obtain a better image or more complete view of the player) simply by moving one arm up and down. Additionally, the choice of a game-mode has been set up, that is, the user can choose how to control the game, with the left hand, the right hand, or both.

The Kineage system is divided into two sections, devoted to physical and cognitive rehabilitation respectively.

2.2.1 Physical Rehabilitation

The primary goal of this section is to perform physical rehabilitation exercises while playing and having fun at the same time, as well as making physical therapy more effective for patients and more measurable for clinicians and physiotherapists. This part of the game consists of three different levels in which the user should collect various objects appearing on the screen by moving the arms, in order not to let the objects fall, thus promoting both the mobility of the user during the training and the cognitive process. The duration of each level can be adjusted by the physiotherapists to avoid fatigue during training. In the first level, the objects (cupcakes and bottles of wine) follow a vertical path. In the second level the number of these objects increases and in level three the objects follow a horizontal path. At the end of each level, the user will be awarded a piece of cake, until they obtain a whole cake as a final reward for finishing the three levels.

This game is played in a 3D virtual environment where the objects, bottles of wine and cupcakes, are falling to the floor. Every level has a different background picture of an environment. Players can see their individual arousal score indicated below, as well as the time remaining. In order to catch an object the player must make an arm movement to obtain it. If the player chooses the right-hand mode to play, the objects will only appear on the right side of the screen and vice versa. Figure 1 (a) shows a user playing the serious game at the 3rd level during the tests.

Additionally, various control parameters have been established, such as time per level, speed of the objects appearing on the screen, the number of objects or the path they follow, so that users make different movements with their arms. Depending on the characteristics of each user, these parameters can be changed in the main menu, turning it into a slow-motion gameplay, helping users during difficult passages. If the configured parameters do not provide a big enough-challenge (for instance, the patient makes faster progress than expected), the physiotherapist can adjust them easily for the next session. During the rehabilitation sessions, the system provides feedback (collected items, scores) as well as visual, auditory and textual feedback on the patient's performance.
After the session, physiotherapists and patients can take a look at the data stored in the patient's profile to determine the progress made.

2.2.2 *Cognitive Rehabilitation*

The main objective of this section is to improve the memory and psychomotor activity by performing activities, as well as encouraging them to do physical exercise. The system focuses specifically on the language area of the brain, which is mainly affected in the case of people suffering from dementia. Usually, details related to remembering specific pieces of information such as the names of people or objects are forgotten by the patient. Due to the importance of the language area, these mental exercises focus on the reasoning needed for word-classification activities using different semantic fields such as tools, kitchenware or furniture.

A range of exercises, in which the user must perform various physical motions in order to solve them, have been developed following the clinicians' recommendations. In these activities the user has to find items which can be found in a supermarket, a stationery store or a pharmacy, or relate numbers to their corresponding definition (1-one), amongst others. Dementia is a progressive deterioration in cognitive function, so the application aims to adapt to individuals' changing circumstances, if they become more cognitively impaired as they grow older, for instance.

All these exercises have been designed in a graphic way, in which the answers are images that appear on the screen. The objective is to choose the correct answers (images) by moving the correct arm and thus improving the psychomotor activity of the patient. See Figure 1 (b).

The application's objective is to reinforce mental answers by having them drilled into the user by carrying out motion controls. The iteration with the system is based on moving users their arms. As in the physical rehabilitation part, the game can be configured, depending on the cognitive state of each user, by adjusting the exposure time of the picture to memorize or the number of activities that will be performed.

(a) (b)

Figure 1: Users during the physical and cognitive rehabilitation

2.3 Procedure

Permission to carry out the study was obtained from the nursing home and the IRB Committee. Participants provided prior informed consent written in Spanish (the participant's first language) and were approved by the IRB to participate in the study. The participants were informed explicitly, precisely and unequivocally of each step in the process, the consequences of obtaining the data and the purpose of collecting it. After this, they were asked to sign the consent form and complete a general survey form. Testing took place in the participants' usual learning setting so that performance in the study would be subject to the same environmental influences and distractions that prevail in the situation for which the system is intended.

2.3.1 *Experimental Design*

A single subject design was drawn up to evaluate the physical rehabilitation system effects with an ABAB withdrawal, in which A is the no-intervention baseline phase and B the intervention phase. The effect had by playing this game was examined using 18 subjects suffering from upper-limb impairments. The game was played once daily and credibility was enhanced through the taping and recording of each session and written observations.

Regarding the cognitive rehabilitation the participants' cognitive impairment was measured before the intervention by the Mini Mental Status Examination (MMSE) ≥ 23 = Normal; 22-20 = Mild; 19-11 = Moderate; ≤ 10 = Severe. The average score for the 18 participants was 23.

2.3.2 *Baseline*

During the baseline phase the physiotherapist assigned the same exercise to each patient: raising the left and right arms above 130 degrees 10 times. A movement was considered correct if this was successfully achieved. The number of correct movements in each session was counted manually by the physiotherapist.

2.3.3 *Intervention*

In this phase, patients completed the third level of the game in which the pancakes and bottles of wine's path is horizontal and objects move across the upper part of the screen simulating 130 degrees with the arms raised, in order to gather them. As in the baseline phase, patients performed the exercise 10 times each. The physiotherapist did not interfere

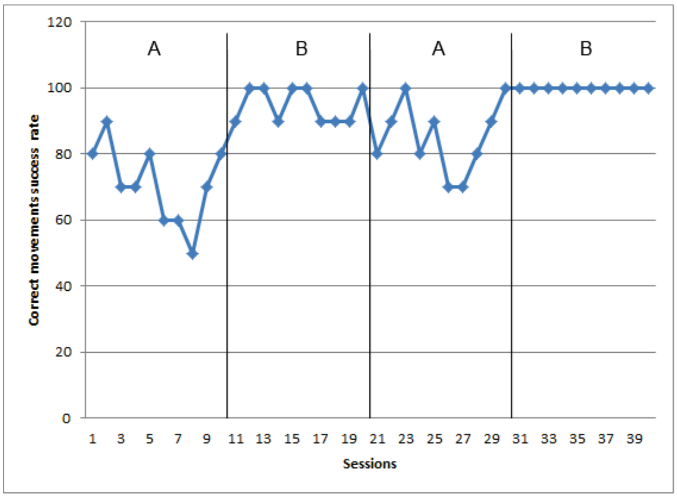

Figure 2: Number of correct movements after the rehabilitation program

in the game during the rehabilitation session and the number of correct movements was counted by the game when an object was collected.

During both phases (A and B) the success rate of the sessions was defined as the number of correct movements divided by 10 (total number of movements).

3. RESULTS

Figure 2 illustrates the experimental design and the data obtained for 18 subjects during the physical rehabilitation sessions. The baseline and intervention phases recorded the correct movements. The mean success rate of the 18 participants in the first baseline was 71 % and in the second baseline 85 %. During the intervention phases the mean in the first phase was 95 % and in the second one 100 %. A Kolmogorov-Smirnov test showed that the difference of success rates between the baseline and intervention phases was significant ($p < 0.05$).

Preliminary results obtained from the cognitive rehabilitation part after doing the activities included in the game regarding memory and language are encouraging, even when a more longitudinal experiment is needed. After performing these activities twice daily for 80 days, the MMSE test again showed a result of 23 scores for participants' average.

4. CONCLUSIONS

This study assessed the effectiveness of this rehabilitation system, which might facilitate autonomous physical rehabilitation prescribed by physiotherapists. This interactive system could help patients and physiotherapists to improve the physical therapy results due to the motivation the patients feel with the avatars while playing. This pilot study did not show an improvement in the cognitive impairment measured by the MMSE, but the impairment is maintained, that is, the cognitive performance is not declining and its progression is slow.

Preliminary tests have shown that the users' motivation is increasing while doing rehabilitation and, as the experts reported, individuals felt more relaxed when doing this kind of activity. In addition, this tool can be adapted if the mental and physical limitations of the users are taken into account.

This system was developed in a first iteration to be played in a nursing home, but looking at the results, the authors think it is possible to aim this game at people who live independently in their homes. In future work, researchers will include a monitoring module to assess the state of their patients and track their progress using a web platform. In this way, the patients' data does not necessarily have to be accessed locally.

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