Usage of VR Headsets for Rehabilitation Exergames

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Abstract. The work presented here is part of a large project aimed at finding new ways to tackle exergames used for physical rehabilitation. The preferred user group consists of physically impaired who normally cannot use commercially available games; our approach wants to fill a niche and allow them to get the same playing experience like healthy. Four exercises were implemented with the Blender Game engine and connected to a motion capture device (Kinect) via a modular middleware. The games incorporate special features that enhance weak user movements, such that the avatar reacts in the same way as for persons without physical restrictions. Additionally, virtual reality glasses have been integrated to achieve a more immersive feeling during play. In this work, we compare the results of preliminary user tests, performed with and without VR glasses. Test outcomes are good for motion amplification in some of the games but do not present generally better results when using the VR glasses.

Keywords: Kinect · Motion Capture · Virtual Reality · Rehabilitation · Exergame · Head Mounted Display · Physical Disability · Motor Function Impairments

1 Introduction

The main goal of our project is to improve the player's sensation of immersion and involvement while playing an exergame, with the special purpose of motivating people who suffer from severe physical impairments and chronical diseases. This is a great challenge, because people notice their physical impairments a lot when using games that are made for the broad mass. Our efforts are focused on implementations that let them forget about their restrictions and have fun, while performing movements that are normally arduous and exhausting but necessary, e.g. for rehabilitation or training. In this way, two objectives can be reached: entertainment and sports for the user.

To achieve this goal, we are currently developing an adventure-like exergaming environment that integrates the Kinect camera with the Blender Game Engine (BGE). The middleware that manages the communication between both is integrated in a modular container that also allows including other devices, such as an Android mobile phone and a Virtual Reality (VR) headset.

The Kinect camera has been proven an excellent medium to promote physical exercises [1]. The problem is, though, that physically impaired people cannot directly play the games offered on the market, which is stated frequently by affected users [2]. Therefore, the exergaming environment underlying the presented work is equipped with special functionalities that cope with physical limitations, e.g. the amplification of weak movements. This way, the player's virtual experience is enhanced and motivation increased. The objective of this work is to find out if the user experience would be even better when playing with a Head Mounted Display (HMD) that immerges the player fully into the game. Our assumption is that more immersion results in longer playing times and more effective treatments. This, for sure, should be tested in long term tests, here we just want to test the suitability for disabled people of wearing a headset and their performance in comparison to using a standard monitor. Four Mini-Games have been implemented to test different movements which are useful for wheelchair users suffering from degenerative muscle diseases. They have been tested for a group of disabled and a control group of healthy people.

Related Work.

Compared to EyeToy or Wii, the Kinect seems to be the more natural device and has a great potential to create enjoyable exercises with a low budget [3]. The authors of [4], which is the newest review found, claim that "technologies such as the Microsoft Kinect have the potential to incorporate complex and continually adaptive exercises requiring specific movements and track the extent to which these movements are indeed performed by the players”. Some examples of works similar to our approach are mentioned in the following.

REWIRE (Rehabilitative Way out in Responsive home Environments) [5] is a European project that develops a VR-based rehabilitation platform for home exercises. Multiple publications about adaptive games can be found from the consortium members [6, 7]. “Kinect-o-Therapy” was presented by [8]. The authors aimed to present a system that combines entertainment with exercise to motivate patients. The system is also based on four Mini-Games, implemented with the Unity 3D game engine. The authors of [9] propose one of the few systems found for children with disabilities. It is aimed at assisting patients with spastic diplegia and hemiparesis in their rehabilitation process.

Very few literature has been found about works that combine motion capture systems with VR for exergames. The authors of [10] proposed a system for gamifying physical therapy for stroke survivors with an immersive 3D environment. It combines the Kinect, an Oculus Rift goggle and a pair of haptic gloves, which adds the assessment of hands and fingers that the Kinect does not provide. In [11], an exergame environment for cycling is presented that combines the Kinect and an HMD, but the focus is clearly set on the immersive experience and not on motor rehabilitation purposes. Finally, the authors of [12] present “Astrojumper”, an immersive VR exergame developed to motivate players to engage in rigorous, full-body exercise. Nevertheless, these exercises are not meant for people with physical impairments.

Concluding, literature reveals that exergames realized with motion capture systems are promising and powerful, but still most works are aimed at restricted groups of patients. Also, to the best of our knowledge, real immersion with VR glasses has not been tested with disabled people, which means that the here presented work is the first of its kind.

2 The exergaming environment

The system is based on a modular middleware that joins different sensors, details can be found in [13-15]. The sensors currently included are a motion capture camera (Kinect), a smart phone and an HMD. Others, like e.g. a heart rate detector, could be easily added. The data captured by the sensors is transmitted via their middleware to a 3D video game engine. Here, the movements captured by Kinect are used to control an avatar, and the mobile phone enables wrist rotations not detectable by the camera.

The Kinect middleware has been implemented using version 1.8 of the Kinect for Windows SDK [16]. The spatial positions of 20 joints and the rotations of their bones are captured and transmitted via the OSC (Open Sound Control) protocol [17] to the game engine. The communication module for the HMD, Oculus Rift [18], is based on the OSVR (Open Source Virtual Reality) framework [19]. For game development, the Blender Game Engine (BGE) has been chosen [20]. New functionalities have been integrated as add-ons, as there are three different types of skeletons, auxiliary objects used to distinguish different types of movements and the virtual camera view for the HMD, as shown in Fig. 1 ("New HMD").

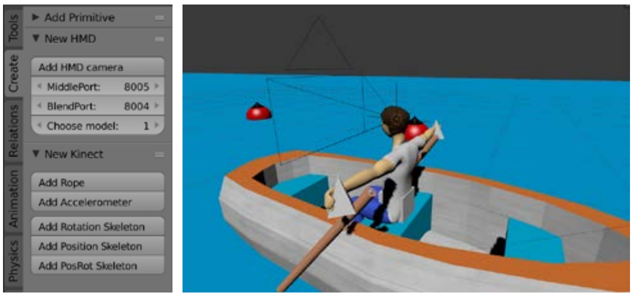

Fig. 1. Add-on (left), camera module attached to the avatar (right).

An internal script is requesting the position and rotation data of the HMD from the middleware 60 times/s and applies it to the virtual camera in real time. In this way, a stereovision image is created by the BGE that corresponds to the avatar's view. It is then sent through the middleware to the glasses, displaying the view to the player. Fig. 1 (right side) shows the avatar, with the camera attached to his head, the corresponding view is contained in Fig. 2.

Four mini-games have been implemented for testing the suitability of some selected movements as well as the special functionalities to enhance weak gestures.

Mini-Games description.

The implemented exercises should represent a variety of basic movements, which could be tested by wheelchair users with different diseases, so only upper limb movements have been included. According to our physiotherapist, the aim is to train basic corporal functionalities necessary to perform daily activities and improve quality of life. Therefore, exercises that require lateral body and arm movements with shoulder flexion have been implemented: rowing, climbing, hitting, and flying. In the future, further exercises for more precise wrist and forearm movements could be added. To analyze the different experiences, all games have been tested with and without the VR glasses; a visualization of the screens is given in Fig. 2 as normal and VR view.

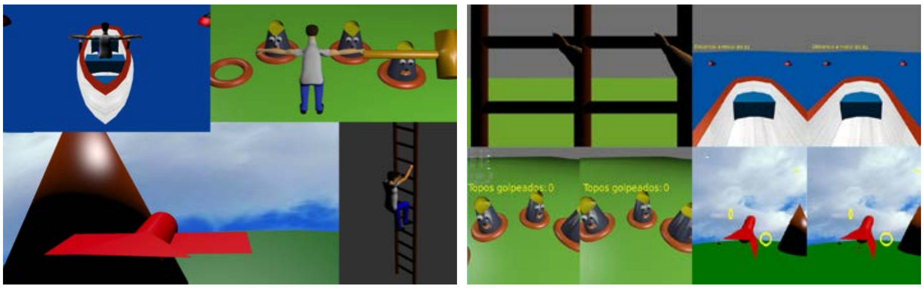

Fig. 2. Four mini-games in mono (left) and stereo view (right) as sent to the VR glasses. From left to right, top down. Left: The Boat, "Whack-a-mole", the Paper-Bird, and the Ladder. Right: the Ladder, the Boat, "Whack-a-mole", and the Paper-Bird.

The Ladder (climbing) challenges the player to reach the end of a long rung ladder by moving the arms (or just hands) up and down alternately. The avatar's arm is copying the user's movements until the moment the user reaches his personal upper limit. At this point, an animation is executed: the avatar grabs the bar and climbs a step, releasing the opposite hand. A counter measures the time needed to get up to the end. In VR view, the player only sees the next rung and the avatar's arms.

The Boat (rowing) shows the avatar inside a rowing boat with the rudders fixed to the hands. Its arms are reacting to the user's simultaneous forward-backwards arm or hand movement. When performed correctly, the boat progresses some meters (simulated by buoys moving past). The aim is to reach the goal as quickly as possible, the time is clocked and appears on the screen. Through the VR glasses, the player sees the frontal part of the boat, the water, and the hands of the avatar when they are moving in front of the body. When the finishing line is reached, a banner appears.

Whack-a-mole (hitting) is an imitation of the widely known homonymous game, where little moles, appearing randomly out of their holes, have to be caught. The player has to move the right arm up and down while pointing in the right direction. If a mole is hit with sufficient speed, it emits a funny suffering sound and disappears. The game gives two minutes of time to strike 20 moles, the number of scored moles is counted. In VR view, the player sees the holes quite near and has not the complete overview of the scene so that it is necessary to turn around more, which implies more exercise.

The Paper-Bird (flying) is the most sophisticated game regarding the movements to perform. The player is conducting a kind of hand-crafted bird that is progressing constantly forward by using arms and trunk. With the arms spread to both sides, the bird is flying straight ahead, lowering one arm produces a sideways turn. The forward and backward motion of the trunk is additionally causing an up and down movement of the bird. The aim is to fly the bird through some yellow rings scattered in the air, without any time limit. In VR view, the player does not see anything of the bird, just the sky, the landscape and the rings.

3 Tests and Results

19 participants (12 male), including 12 individuals with different disabilities, all but two wheelchair users (ages 5-50 years, see Table 1) and 8 children (ages 7-13 years) without any known physical impairments, volunteered to participate in the tests. The participants were recruited in Madrid, Spain, at the Neurological Muscular diseases Association (ASEM) and the Sports Integration Foundation (Fundación TAMBIEN). Approval was obtained from the Review Board at UPM (Universidad Politécnica de Madrid, Spain).

Table 1. Participant information of the target group

Disease	Ages (gender)
SMA (Spinal Muscular Atrophy) type 2	5 (m), 13 (m)
CP (Cerebral Palsy)	11 (m), 12 (m)
Hypertonia	12 (m)
BMD (Becker Muscular Dystrophy)	13 (m)
DMD (Duchenne Muscular Dystrophy)	15 (m), 16 (m)
FSH (Facioscapulohumeral Muscular Dystrophy)	43 (f), 49* (f)
PPS (Post-polio Syndrome)	50* (f)

* No wheelchair

The procedure of the trials has been as follows: Following informed consent, the volunteers (and their parents in case of children) were shortly introduced into our work and the reasons why we need them for the first trials were explained. Before playing, the maximum possible limb movements were recorded to calibrate the system. Then, the users played at first the Mini-Games with a standard monitor of 30 in, from a distance of about 1-2 m, to be in the best detection range for the Kinect. The second session was using the virtual headset. At the end, all participants were asked to fill out a short survey to learn about their experience.

Objective Playing Results.

In case of wheelchair users, the Kinect occasionally confused the armrest with the user's arms or the wheels with the user's legs, especially in case of small kids. Therefore, three subjects (both SMA and one CP) had to be excluded from the evaluation. The playing order was always the same: The Ladder, The Boat, Whack-a-mole and The Paper-Bird. Table 2 presents the average results for each game, Fig. 3 visualizes the distribution of individual times and scores.

Table 2. Average values per game

	Ladder	**Boat**	**Whack-a-mole**	**Paper-Bird**		
	Time to goal		Success rate	Time	Nº rings	
Target group	54.0 s	119.8 s	53%	200.6 s	2.6	Monitor
Control group	55.7 s	75.6 s	81%	124.0 s	5	
Target group	67 s	122 s*	44%	320 s**	4**	HMD
Control group	49 s	71 s	83%	-	7	

*5 users **3 users

Particular observations for each of the games were as follows:

The Ladder. The average times are nearly the same for tests performed with a standard monitor. Instead, using the headset, the target group (TG) performed slower than the control group (CG). This means, that the difficulty for both groups seemed to be similar, but the impaired participants struggled more with the VR view. Problems of skeleton detection and game reaction got more evident when the headset was used, this, in turn, led to more confusion, especially in combination with the 3D-experience.

The Boat. While this game was an easy exercise for the CG, some TG users had difficulties with the movement as the configuration turned out not to be sufficiently flexible to capture slightly different movements to the expected ones. Therefore, the TG needed about 50 s longer than the CG when playing with a HMD and 44 s longer when playing with a monitor. Some users were not able to make the game react in the right way in spite of having learned to play it formerly with the monitor view. One user quit the game due to boredom.

Whack-a-mole. As opposed to the other games, this one needs precision and good reaction times. Generally, the monitor view was easier to handle, because the whole scene is visible. In VR view, users found it difficult to find the appearing moles, however, two participants had more success than with the monitor version. With the monitor, the TG achieved an average score of 53%, while the CG got 81%. With the HMD, the TG fell down to 44% and the CG improved up to 83%. All participants finished the game.

The Paper-Bird. This game requires the most complicated body control and is even more difficult to play with VR headset, as the viewing range is restricted and the head control has to be added to the arm and body movements. Only 3 users of the TG played this game with the headset but longer than with the monitor, which can be evaluated as positive outcome as this game has no time limit like the Ladder and the Boat. If players endure longer, it means that they have fun and are motivated to achieve passing through the rings.

Overall, the users of the CG achieved generally better results in the games with HMD than with the standard monitor, while the target users had more difficulties.

Subjective Survey Results.

In the survey, the participants awarded 0 to 5 points to general aspects like diversion factor, the ease to play (game response) and aesthetics of each game. Regarding their experience with the VR glasses, the questions were focused on the feelings and if the users found it worth to use the headset.

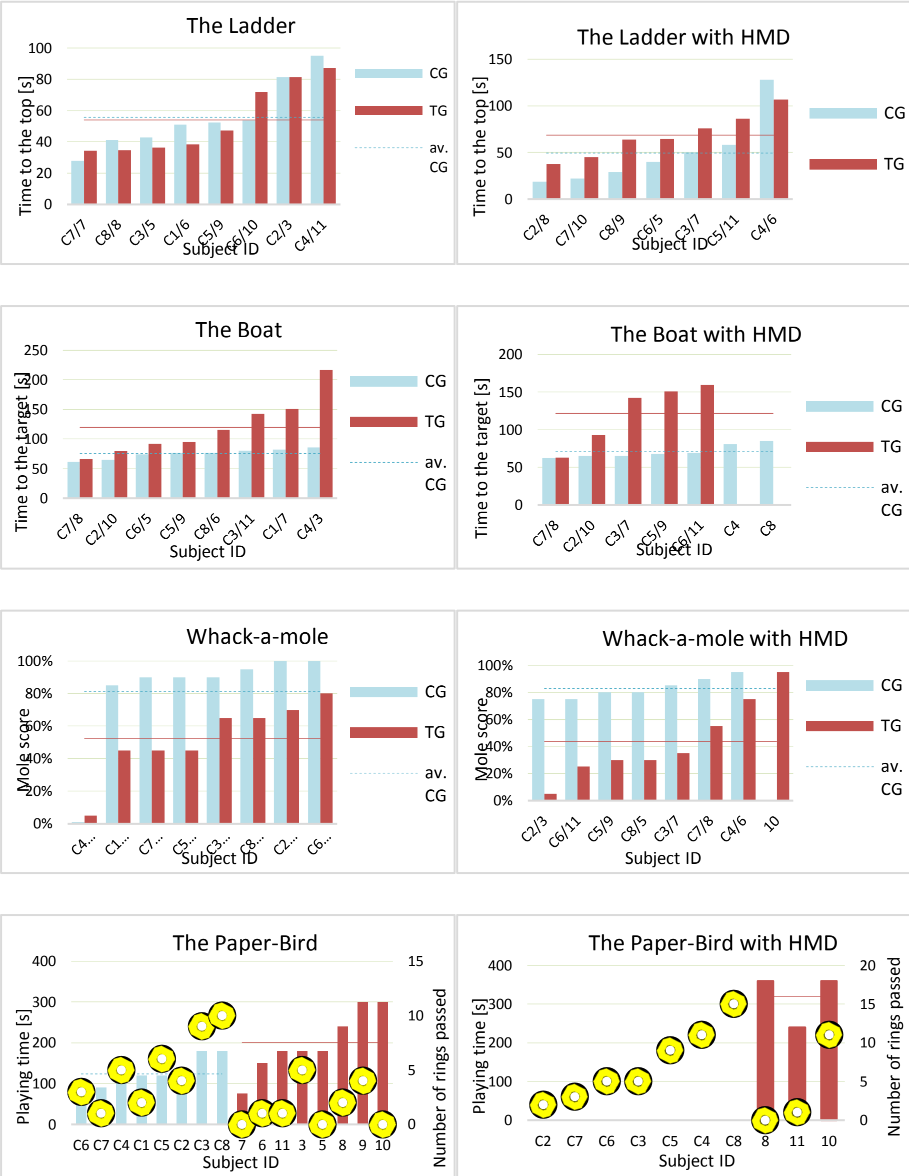

Fig. 3. Test results for a standard monitor (left) and with HMD (right)

The average evaluations for those questions are illustrated in Fig. 4 separately for both groups. The Ladder had the best acceptance for the TG, but all users commented the experience as positive. The Boat was the least funny one. Users complained about the VR experience because they saw a detached arm. The view was more monotonous than on the monitor. In Whack-a-mole, all participants stated that they had fun, and liked the action. The Paper-Bird had the worst acceptation for both groups, the movements were generally felt to be little intuitive. However, it wins in aesthetical aspects.

Nobody of the wheelchair users had had any sensation of dizziness, whereas the standing users felt some in the Paper-Bird. This could be due to a longer playing time and the change of the vision field provoked by the head movements, which are stronger than seated and quicker than those of the impaired participants.

The CG had more fun playing with the headset and was more likely to spend time and money for using VR glasses than the TG, although both prefer to use a smartphone if possible (due to the elevated price of VR glasses).

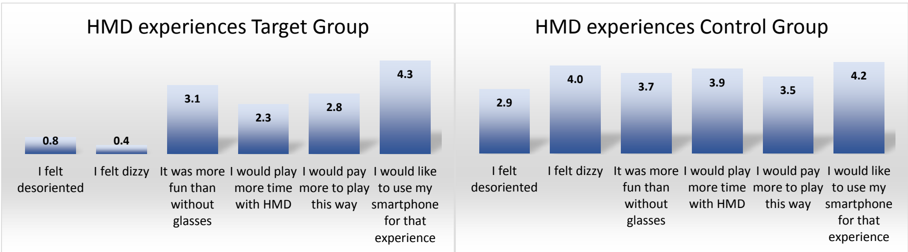

Fig. 4. Evaluation of the VR experiences (scoring from 0 to 5)

4 Conclusions

We are conscious of the fact that the group of tested persons is too inhomogeneous and the time too short to obtain meaningful results about the effectiveness of the games for the rehabilitation of certain affectations, but this was not the aim at this stage.

First, we wanted to learn about different types of physical restrictions apparent in different diseases, to see how long the disabled endure and if the selected movements are correctly detected depending on the different abilities. The outcome is that most games responded well to the tested users. However, users with muscle weakness in the arms got tired more quickly and reached much lower scores. Overall, the exercises were adequate, but the arm movements required in The Boat seemed to be difficult to perform and the detection rate was low if the movement was not performed sufficiently wide.

Second, we wanted to evaluate the interest of potential users in exergames of the presented characteristics by surveying their experience and observing their reactions. All users had fun and evaluated the games in general positively. Obviously, they liked the action game and the complicated flying game most, as they were highly motivated to pass through the rings. The most "boring" one was The Boat.

The third and most important objective was to test if the VR view has some kind of negative effect like dizziness, if the users are comfortable with the HMD and if they liked the experience more. The outcome was that standing users had more problems with dizziness than wheelchair users. Some complained about the restricted view and implementation errors. Nevertheless, the control group stated that they liked the VR experience more and showed a better game performance with the head set. The target group performed worse than using a standard monitor in spite of the flying game.

Altogether, the experience is positive, but the usefulness of the HMD for a better performance in the physical exercises could not be confirmed. The increased motivation could generally lead to longer playing times, which could lead to an improvement in fitness, but it is not clear if the users would improve the quality of movements. Polishing of the implementation and 3D visualization is necessary, as well as long-term studies, to find this out.

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