Virtual Reality Games Integration Module for Managing and Monitoring of Hand Therapy

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***Abstract*—Injuries to the hand function caused by overwork or neurological problems lead to the need for intense motor rehabilitation programs. Rehabilitation training is generally limited to the rehabilitation center and/or hospitals and patients are idle at home. We have developed a module for managing and monitoring virtual reality games, controlled by the Leap Motion Controller (LMC) sensor, for the rehabilitation of the manual function that can be used in a clinical and/or home environment. We tested our system with five adults with Cerebral Palsy (CP) that lasted 15 rehabilitation sessions and found that the system is viable for rehabilitation at home and that the participants enjoyed the experience and were motivated throughout the therapy. The results suggest that LMC and HMDs both can provide such positive experiences in adults with CP and these technologies can be immature for this peculiar audience, especially for using autonomously at home.**

Keywords—virtual reality, leap motion, game therapy, hand therapy, motor rehabilitation

I. INTRODUCTION

Therapeutic interventions using Virtual Reality (VR) games, such as those performed using the Nintendo Wii, Playstation and Microsoft Kinect video game consoles, are proving to be interesting for the rehabilitation of people with disabilities [1]-[4]. Such technologies have been used as alternatives to continue treatment at home, after hospital discharge, especially in places where access to therapy is limited due to geographical or financial restrictions [3], [4]. VR games for rehabilitation can be adapted, based on a clinical protocol, to offer task-oriented training with high repetition, thus being able to contribute to maximizing motor learning and neuroplasticity [3], [5]. Besides, these videogames can be used independently by the patient or with the simple help of a caregiver and they have adaptation for personal use at home.

Despite these potential benefits, the Nintendo Wii and Playstation require players to use a gamepad (Joystick) with buttons, which is difficult to manipulate by people with limitations in manual dexterity. Microsoft Kinect, in turn, allows gestural interaction without physical contact and, therefore, can provide a better gaming experience, without the need to manipulate the joystick. However, it is still a challenge to detect finer hand movements, for example, movements of grasping and releasing objects [1]. Other solutions using cameras or wearable technologies such as data gloves are some of the hand movement capture options most used in manual rehabilitation [6].

Nevertheless, most systems based on these techniques are unsuitable for use at home, as they are usually complicated and expensive devices that often require human intervention for more effective use. Furthermore, these technologies usually have a closed architecture, making it difficult or impossible for the therapist to tailor the levels of difficulty of the exercises to the needs of the patients. Therefore, there is a potential demand to design a manual function rehabilitation system for patients to use at home to exercise more precise and to have personalized movement training.

Constant improvements in motion tracking technologies have favored the emergence of more accurate, compact and inexpensive sensors. The Leap Motion Controller (LMC), for example, started to be commercialized in 2013, and since 2015 it has been investigated as a rehabilitation tool for aging and the disabled population [7]. Hence, only one work, still in the development phase, was found reporting the potential to use the LMC integrated with an online management and monitoring system [8]. We believe that a system with these characteristics may have the potential for use in home environments when the patient needs more personalized monitoring. This online intervention mechanism could minimize two significant problems that prevent many patients from receiving the appropriate therapy they need. First, economic factors in health systems, especially in developing countries, cause patients to be released earlier from the hospital and receive less outpatient therapy [9]. The second problem concerns the distance. For people who live a long way from a rehabilitation center, outpatient services become inaccessible [9]. The difficulty increases for people with neurological or orthopedic disabilities since to leave their homes and obtain reliable transport to cover any distance, no matter how short, can be very difficult to sustain for any period of time [9].

We are interested in creating and providing a low cost and simple handling system so that the therapist and patient can use it as a resource to support the rehabilitation treatment of manual function, even outside the clinical environment. Our system has a therapy management and monitoring module called AppTerapia (app) that allows the therapist to customize the levels of difficulty of the VR games for each patient and monitor the progress of patients over time. For example, it may be necessary that, for a specific patient, it is interesting to start training with the dominant hand and, only after a certain period of time, move on to training with the non-dominant hand. This aspect of the order of hand training is an important factor in manual function therapy, since VR games are often very repetitive and, since the patient starts the task with the non-dominant hand, this can be frustrating for him. AppTerapia contains a mechanism that allows the therapist to select the games of interest and, for each game, to determine the order of hand training, defining the sequence and time of activity. Besides, the performance of each patient (as a total of hits and errors) is collected and stored in a cloud database and can be viewed by the therapist from AppTerapia.

We tested our system with a physiotherapist and five adults with Cerebral Palsy with severe motor limitations, but with potential for upper limb movement, over 15 manual function therapy intervention sessions. We used AppTerapia to obtain data and evaluate the performance of participants over the 15 interventions using VR games, comparing the two modes of interaction, immersive and non-immersive, and a usability questionnaire (User Satisfaction Evaluation Questionnaire - USEQ) to assess the overall satisfaction of using games as a resource to support manual function rehabilitation. At the same time, the team of physiotherapists used Box and Blocks Test (BBT) and Jebsen-Taylor Hand Function Test (JTHFT) to quantify the gain in manual function before the start of the game program, in the eighth and at the end of the intervention.

Although our system is free and requires low-cost hardware that is easily found in the market (such as the Samsung Gear VR headset and the integrated LMC), we found some limitations of the technology adopted in our system and user security issues, especially when games are used immersively by people with trunk instability associated with lack of head control and general trunk flexion. In this paper, we report these limitations and propose solutions to deal with these issues. Despite the limitations, we believe that home rehabilitation is the future of rehabilitation.

II. LEAP MOTION CONTROLLER

The Leap Motion Controller (LMC) is a compact optical sensor device, 8cm wide by 3cm high. The upper part of the device is made of smoked glass in order to hide the two image sensors and infrared LEDs that work together to track the user's hand movements. The LMC works with an accuracy of up to 1/100mm and with no visible latency in its field of view. The viewing range of the LMC is 60 cm above and around the device. It is possible to use the LMC connected directly to the computer for non-immersive experiments. In this case, the video monitor is used as a display device (Fig.1a). In immersive experiments, Leap Motion is used coupled to a pair of VR glasses, such as a Gear VR, for example (Fig.1b).

Leap Motion allows measuring motor performance, such as reaction time, bimanual coordination and the sequence of movements performed with the hands and fingers. For this reason, this remote sensing technology has shown promise in the field of rehabilitation, since it does not require the patient to use any motion detection device (for example, gloves with force and feedback sensors). Therefore, it provides a new form of interaction between the user and the computer, allowing a more natural and touchless interaction. Hand dexterity in patients with upper limb motor dysfunctions can be assessed using scheduled tasks with graphic objects added in the virtual world.

Fig. 1. LMC modes of use.

III. BACKGROUND

Researchers from Canada [9] obtained, in 2013, one of the first commercially available LMC devices by pre-production order. The authors carried out a study of its sensitivity and precision, compared to Wiimote. The first version of the hardware and software had some limitations and was considered unsuitable for rehabilitation assistance. However, the improvement in the software for tracking and capturing movements, carried out in recent years, has made the LMC a good candidate to support motor rehabilitation.

In 2015, two years after the launch of the LMC on the market, works began to emerge to verify the feasibility of using the sensor in hand physiotherapy programs [8]-[10]. VirtualRehab Hands, invented by Evolv Rehab (manufacturer of medical devices) [12], was one of the pioneering projects in offering gaming activities using the LMC to allow users to practice fine hand motor skills. The system allows therapists to observe and evaluate recovering patients caused by strokes and Parkinson's disease. But, it is not available for free.

The idea of using games with LMC to assess the effectiveness of the device for hand rehabilitation has been addressed in other studies, being more expressive with post-stroke patients. [13] conducted a randomized clinical trial to compare the effectiveness of LMC in the rehabilitation of post-stroke patients. [14] investigated changes in upper limb motor function, quality of life and neck discomfort when using LMC with mirror therapy in chronic post-stroke patients. [15] investigated the efficacy of LMC, in its immersive version, in the function of the upper extremity in patients with ischemic stroke. [16] tested the effectiveness of LMC, integrated with the Playground 3D® game, for hand rehabilitation with three post-stroke patients. [17] reported the evolution of an 81-year-old man with chronic stroke who played interactive video games using the standard games from the Kinect One sensor integrated into the LMC. [18] modified the Fruit Ninja game to integrate the LMC and use it with chronic stroke patients.

Other studies with people with cerebral palsy, Parkinson's disease, autism and burns have also been conducted and have shown promising results in rehabilitation. [19] used LMC in upper limb rehabilitation, in order to compare the effectiveness of LMC with a conventional rehabilitation program in children and adolescents with juvenile idiopathic arthritis, cerebral palsy and brachial plexus birth injury. [20] defined a clinical trial protocol using LMC with patients with Parkinson's disease. [11] also evaluated the effectiveness of LMC used with serious games in the rehabilitation of patients in moderate stages of Parkinson's disease. [21] evaluated the effectiveness of rehabilitation for autistic children with a series of applications based on LMC in a school setting. [22] investigated if Leap Motion might improve the hands function with burns.

As can be seen, studies with LMC can benefit children, youth, adults and the elderly with developmental disorders associated or not, with cognitive or behavioral changes (as long as they can understand and execute the basic commands of the game), with the wide front of performance in an educational or a clinical environment. In our work, instead of focusing on developing games for specific levels of disability, we seek to find solutions that can be adapted for use by patients at different levels of recovery. A similar approach has been proposed in [23],[24], but not specifically for manual function training.

IV. System Design and Architecture

Our system, called GameVR, is composed of two main modules (Fig.2) therapy management and monitoring module (AppTerapia); b) VR-based game module.

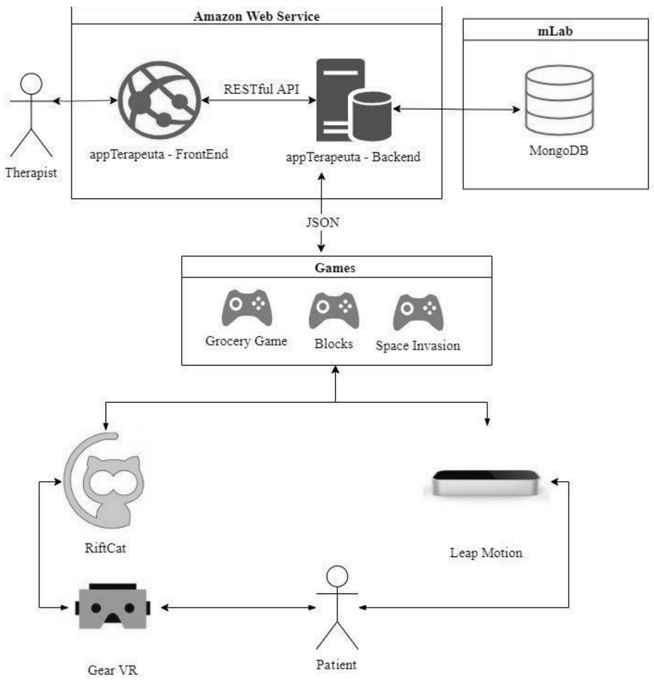

Fig. 2. System modules.

A. The AppTerapia

AppTerapia is a Web application made up of two parts: the front-end (user interface) and the back-end (business model), both responsible for the integration of games with a cloud database. The features of AppTerapia were based on the results of the requirements gathering phase, carried out during the first year of the project. A study was conducted to assess (with physiotherapists) whether the implemented resources were adequate and easy to use to support the allocation and monitoring of care plans for patients with disabilities.

The front-end was created with Ionic (mobile web development framework) from javascript. The back-end, in turn, uses nodeJS (a framework for developing client-server services). Both front-end and back-end communicate themselves via RESTfull architecture, being responsible for communicating with VR games and databases. Fig. 2 shows the flow of operations performed between the user-system.

AppTerapia is used by the therapist and allows the following operations: therapist registration and editing; registration, editing and removal of patients; communication tool with the patient (messages); creation and edition of the Gameterapia Plan; visualization of patient performance; sending patient performance reports; access to the catalog of games and equipment. When the therapist performs any of the operations listed above, the data is sent to the back-end via an HTTP request. The back-end receives, processes and stores the data in the database through a JSON file. The same process occurs when the patient uses the games, that is, at the end of a game, the data (gameID, immersiveMode, date, score, error, time) are sent to the back-end for storage in the database.

For each game enabled for a specific patient, the therapist can customize/edit the Gametherapy Plan, according to the options illustrated in Table I. Analysis reports are generated by AppTerapia. The reports provide information on: most played games, highest rated games, and player performance. The therapist can view a patient's playlist (Fig.3a). When selecting one of these options, the therapist views information about that specific move (Fig.3b): patient's name, date and time; hand training order (steps); game mode (headset or desktop); time spent at each stage; the number of correct answers (dominant hand and non-dominant hand); the number of errors (dominant hand and non-dominant hand).

TABLE I. Game Therapy Plan - Example

Settins	Options
Step 1	Dominant hand / Non-dominant hand
Step 2	Dominant hand / Non-dominant hand
Step 3	Alternating hands / Deactivate
Step 4	Crossing hands / Deactivate
Immersive mode	Activate / Deactivate
Time of game by step	Seconds

Fig. 3. Screens of the App Terapia

The therapist can also request that a more detailed report be sent to the registered email. In this case, a .csv file is generated that gathers all the previous information (of all patients or groups of them), added by the following information: age, pathology, dominant hand and non-dominant hand and the level of Gross Motor Function System (GMFCS).

B. VR-based game module

The VR-based game module consists of four games for manual function training (Fig.4).

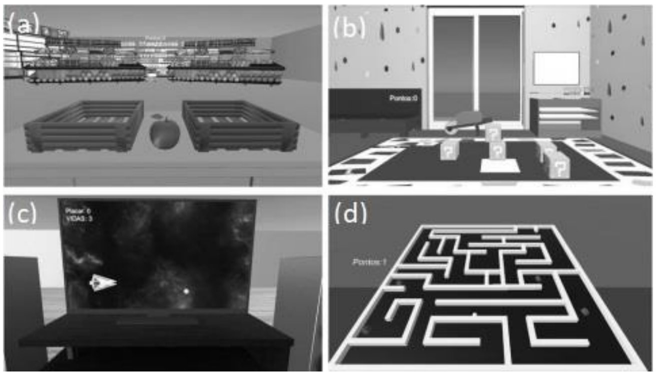

Fig. 4. Games developed: (a) Grocery Game; (b) Blocks Game; (c) Spaceship Game; (d) Maze Game;

Table II shows the objectives and levels of difficulty in each of the games presented. Difficulty levels can be customized, through AppTerapia, to the needs of each patient based on impairment and physical level of motor skills. For example, the therapist may define that for a given patient, the first stage of the Greengrocer game is performed only with the dominant hand; the second stage with only the non-dominant hand; the third step (if any) alternating hands; fourth step (if any) alternating hands with shoulder crossing.

TABLE II. DETAILS OF VR GAMES

Player goals	**Difficulty levels**
Fig. 4a. Grocery Game: To storage apples into their respective fruit baskets. Red apples must be put into the red basket and green apples must be put into the green basket.	Four levels: dominant hand (eg. right hand); non-dominant hand (eg. left hand); alternating hands (moving right hand to the right side and moving left hand to the left side); Crossing hands (moving right hand to the left side and moving the left hand to the right side).
Fig. 4b. Blocks Game: To pile as many blocks as possible in pre-established time.	Three levels: dominant hand (eg. right hand); non- dominant hand (eg. left right); alternating hands (moving right hand to the right side and moving left hand to the left side).
Fig. 4c. Spaceship Game: To control a spaceship avoiding the asteroids and to collect power for the spaceship to get into the final destination.	Two levels: dominant hand (eg. right hand); non-dominant hand (eg. left right).
Fig 4d. Maze Game: To balance a small ball on the gameboard to collect power. The player must avoid touching the walls of the maze to make the small balls to touch the powers spots (red spots).	Two levels: dominant hand (eg. right hand); non-dominant hand (eg. left right).

The games were developed in two interaction versions: desktop version, using the LMC connected to the computer with a video monitor, and headset version using the LMC attached to the Gear VR. The advantage of making both versions of the game available is that the first configuration (non-immersive), can be more comfortable for the patient who needs the physical presence of the therapist or caregiver to help him in the exercises proposed by the games within the virtual environment. On the other hand, the second (immersive) configuration can provide a greater immersion into the virtual environment. Immersion is important because it helps the patient to maintain focus and attention on the task, in addition to helping to increase the patient's motivation and engagement with the therapy.

V. EVALUATION

The purpose of this evaluation was to verify the usefulness of the data generated by AppTerapia, the usability of VR games and the performance of the participants after 15 sessions of interventions with five adults with Cerebral Palsy (CP) in an institution specialized in assisting these people.

A. Participants

Five adults with CP (2 men and 3 women), aged between 26 and 42 years old, were recruited through medical records review and regular visits to the Association. Participants were selected according to the following inclusion criteria: (1) informed consent, (2) having an upper limb disability, (3) being able to understand the game instructions; (6) present visual acuity that allows the identification of the graphic elements of the games. Exclusion criteria: having a low vision; be classified at level V of the GMFCS and MACS (Manual Ability Classification System) Scale. The therapist involved had two years of experience in the field of rehabilitation. He was already familiar with VR technologies, such as using a headset and LMC, for private use or professional deployment.

B. Data collection instruments

Data on top-rated games and player performance were obtained through AppTerapia. The player performance, obtained by AppTerapia, refers to the score according to the playing time. To measure manual function gain, physiotherapists used the Box and Block Test (BBT) [25] and Jebsen-Taylor Hand Function Test (JTHFT) [26] instruments, before the first session of the intervention program, in the eighth session and at the end of the last intervention session. These instruments are widely used in the literature to quantify motor tasks that involve different skills at runtime. The satisfaction of using the system was measured through the usability questionnaire (User Satisfaction Evaluation Questionnaire - USEQ) that was adapted for this study. Space in the interview was also left so that each participant could express their opinion about VR games and make suggestions for future improvements.

C. Equipments

The equipment used in the experiment was the same for all participants and consisted of: a Dell NVidia GeForce GTX 1060 Core i5 gamer notebook, 8GB, running Windows 10. In immersive experiments, the LMC was coupled to the Gear VR headset with a Galaxy S8 smartphone from Samsung. The Mobile App was used by the physiotherapist from an iOS6 smartphone.

D. Procedures

The study was approved by the Research Ethics Committee under opinion number 2,901,639 and conducted at the Association Our Dream of Qualification and Rehabilitation of People with Disabilities (Known in Brazil as Associação Nosso Sonho de Habilitação e Reabilitação de Pessoas com Deficiência), in the city of São Paulo, Brazil. Before starting the intervention program, all participants were registered with AppTerapia and their Gametherapy Plan was created by the study therapist. All participants also went on a pilot test during two 30-minute sessions, once a week, to receive training with the games and the LMC, before starting the intervention program. During this period, adjustments were made to the interface, such as changing colors, size of objects and inclusion of explanatory audios.

In all interventions, the participants were seated on a chair without a wheel and with an armrest in front of a table where the equipment was, always in the same room. The meetings took place twice a week, for two months, totaling 15 sessions. Up to two absences were admitted; so, the participation in, at least, 13 sessions was mandatory. Each session lasted about 15 to 20 minutes, with two different games being played per day. Four games were available; however, the maze game was excluded from the sessions, due to its high level of complexity. In each session, two games were played, one day being immersive (headset version) and the other non-immersive (desktop version). On the last day of the intervention, the participants evaluated the game through interviews and the application of USEQ.

E. Results and Discussions

First, we would like to discover, through AppTerapia, which of the games the participants scored the most. Nevertheless, we cannot compare the games with each other, as each has its own particular scoring scheme. For example, in the Grocery game, the player scores by placing an apple in the correct basket and the Block game the player scores when he manages to stack a tower of blocks. Obviously, it is faster to score in the game Groceries and, consequently, his score is higher. However, by Fig.5 it is possible to verify that, when comparing the games in the Immersive (I) and Non-Immersive (NI) version, we conclude that the group of participants scores more in the I version (1043 points) than in the NI version (651) in the game Groceries. In the Blocks game, the same thing happened, the score in the I version was 303 and in the NI version, it was 209. This result suggests that games in the I version are more comfortable to score since the playing time was the same considering the two I and NI versions. The game Spaceship was used only in the I version, as the NI version presented problems and was excluded from the study.

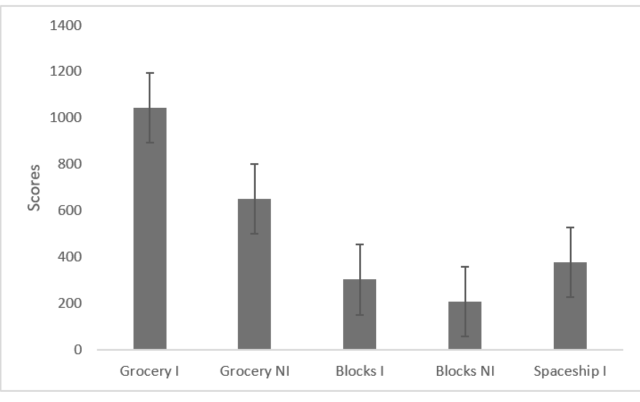

Fig. 5. Scores of games results by PC participants (Legends: I-Immersive and NI-No-Immersive)

Therefore, the present study corroborates with the works reported in the literature that immersive experiences (using HMDs), compared to non-immersive experiences (using flat screens), seem to be more exciting and pleasurable for increasing the sense of presence within the virtual environment. [27] assessed the feeling of the presence of elderly residents of nursing homes in a virtual recreational environment using Rift glasses and a flat screen and observed that increasing the immersive properties of the virtual environment with HMDs also increases the sense of presence and intrinsic motivation of the participant. [28] valued the efficiency of VR therapy (immersive versus non-immersive) for pain treatment in individuals with acute or chronic pain and they observed that immersive VR has the potential to reduce the adult acute and chronic pain compared to the conventional method.

The interest and engagement in therapy are important factors within the rehabilitation process, as they allow increasing the intensity of the exercises and, consequently, decreasing the treatment time. Therefore, home-based rehabilitation systems can benefit from these immersive technologies in order to increase the participant's engagement in therapy.

The data in Fig.6, obtained by AppTerapia, show that the participants had a gain of scores in the Grocery game over the 6 rehabilitation sessions carried out with this immersive game. We only consider sessions in which participants used the game in immersive mode, that is, using Gear VR. These data suggest that the participants had gained learning. However, analyzing the results of the BBT and JTHFT tests, it can be noted that no significant results were found with a value of p=0.05 (by Friedman's nonparametric test) for the grip strength assessments and in the JTHFT tasks, which indicates the stability of the motor condition in this population. In the BBT, there was a significant result for the non-dominant hand (p = 0.030) and improvement trends were observed without statistical confirmation for the dominant hand, with increasing values in the three evaluations (initial, intermediate and final).

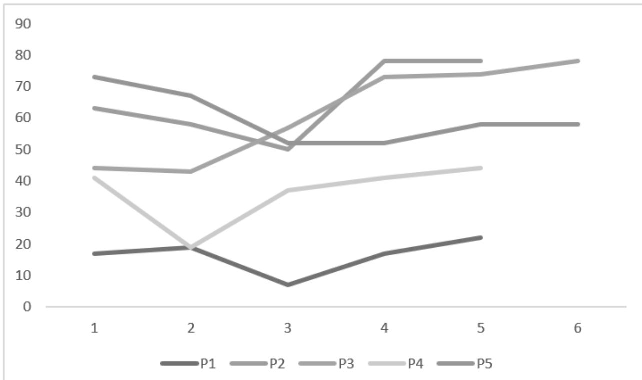

Fig. 6. Performance of participants over the 6 sessions with game Groceries in Immersive mode only.

The absence of significant results can be related to several factors, such as the age of the studied group, session time and intervention time, which are very variable. Previous studies focusing on the rehabilitation of people with CP vary the intervention time among 4 and 20 weeks. The time spent in VR also varies among 20 to 90 minutes and can be practiced from one to seven days a week [1], [2]. These data are probably influenced by the severity of CP, the more severe the less tolerance time to play.

The Short Questionnaire for Satisfaction Evaluation of Virtual Rehabilitation Systems, proposed by [29], was used to assess the usability of VR games (Table II). The responses of this questionnaire is illustred in Fig 7.

TABLE III. USABILITY QUESTIONNARIE

Questions	**Response (Not at All–Very Much)**
USEQ-1. Did you enjoy your experience with the system?	1 2 3 4 5
USEQ-2. Were you successful using the system?	1 2 3 4 5
USEQ-3. Were you able to control the system?	1 2 3 4 5
USEQ-4. Is the information provided by the system clear?	1 2 3 4 5
USEQ-5. Did you feel discomfort during your experience with the system?	1 2 3 4 5
USEQ-6. Do you think that this system will be helpful for your rehabilitation?	1 2 3 4 5

Fig.7 shows that the participants enjoyed the experience (USEQ-1); and that it was successful (USEQ-2) and useful for rehabilitation (USEQ-6); the participants thought they were able to control the games using LMC (USEQ-3); the information provided by the game interface is clear (USEQ-4), but they felt discomfort at some point (USEQ-5). When asked, they answered that they sometimes felt the weight of the Gear VR glasses; one of the participants felt nausea and another was unable to use the immersive mode without permanent support from the therapist.

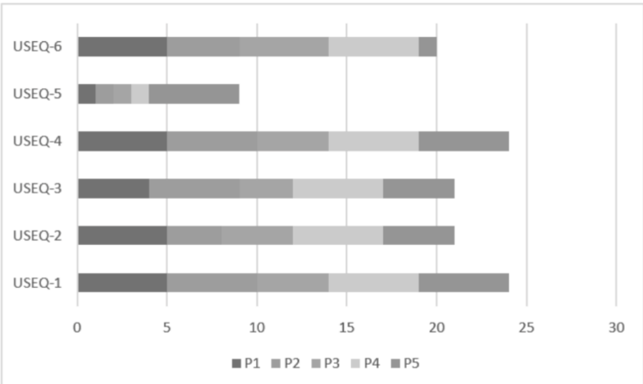

Fig. 7. Usability results.

F. Technical Limitations

During the tests, it was possible to notice several technical limitations concerning the technological apparatus chosen in this research. The LMC device can be integrated into several HMD devices such as Rift glasses, HTC Vive and Gear VR. Gear VR is a relatively cheaper option compared to other models. However, it is not possible to integrate the LMC directly with the Gear VR smartphone. It is necessary to run our games on the computer, where the LMC is plugged, and use specific software called Vridge, to transfer the images of the games from the computer to the smartphone, frame by frame. This procedure requires a dedicated wi-fi network of, at least, 5GHz to ensure good transmission of the frames of the images in real-time. Otherwise, the game can cause nausea in the user due to the inevitable delays between the physical movement of the head and the computer that responds to this tracked movement.

Vridge only works online in a private access account, that is, Internet access is required, with login and password, and it is mandatory to use the SteamVR environment to emulate the Oculo App (Samsung) and, thus, send the images from the computer to the smartphone. The problem is that the developers of Vridge and Oculo App release constant updates, making the wi-fi network system specially generated for transmission of image frames have to be manually reconfigured. Only people with technical knowledge can rebuild the wi-fi network. Therefore, the use of the system, in this technological configuration, may not be as efficient for patients to use at home.

As future work, we intend to compare the performance of our serious games integrated with the other two models of HMDs (Rift glasses and HTC Vive). We hope that, with these HMD models, the problems of transmitting images in real-time will be overcome, since the device allows the direct transmission of images from the computer to the headset via USB cable and not via wi-fi, eliminating the need of dedicated network infrastructure.

In addition, it was observed that both the LMC and the smartphone built into the Gear VR, when used in environments without air conditioning, overheat and turn off automatically and without notice. This problem affects not only patients who want to perform therapy at home, but also in clinics or laboratories that do not provide this infrastructure. Brazil is a tropical country, where most of the time, the average temperature is high, between 27º and 32º, reaching 37 degrees C in some cities. Below 33º C, the LMC performed well, but above that and in a closed and/or stuffy environment, the device's function is severely compromised due to overheating, when used for more than 20 minutes. However, we highlight the need for further studies on the use of equipment in different open and closed environments, with /without air conditioning, to verify our hypothesis.

Finally, for people with low trunk stability, when the game is used in immersive mode (with HMD), it is necessary to have help from the therapist or a family member to support the participant, even if he is sitting in the chair with an armrest. This is because one of the participants tried to rotate the trunk to place his hands on the target in the game and this can be dangerous enough to make the participant fall from the chair. This event shows that the level of immersion in the game is high, as the participant did not realize that he almost fell off the chair.

VI. CONCLUSION

With the ultimate goal of developing a motor rehabilitation system for use in a clinical and home environment, the results obtained in our experiments are very encouraging and justify further investigation of the use of the LMC device, integrated with the management and monitoring remote module. Our AppTerapia worked as expected, allowing us to configure the game's difficulty levels for the patient and collect data on the gaming experience that can be monitored by the therapist remotely. Moreover, at this stage of development, it is still necessary to use appropriate instruments to quantify the motor tasks that involve manual function skills at run time. We intend in future studies to use the LMC to assist in this motor assessment, as soon as it allows obtaining precise data of the movement of the hands and fingers.

The results also suggest that HMDs can provide very positive experiences for adults with CP, but also that current technology may still be immature for this peculiar audience, especially for use in their homes autonomously. Therefore, the use of VR games at home for neurological rehabilitation shows great promise. However, the development of rehabilitation programs based on exergames at home remains challenging in terms of adherence, user compliance, supervision, access and cost.

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REFERENCES

[1] C. Rathinam, V. Mohan, J. Peirson, J. Skinner, K.S. Nethaji, I. Kuhn, "Effectiveness of virtual reality in the treatment of hand function in children with cerebral palsy: a systematic review". Journal of Hand Therapy, vol. 32, n. 4,2019, pp. 426-434.

[2] J. Wu, P.D. Loprinzi, Z. Ren, "The Rehabilitative Effects of Virtual Reality Games on Balance Performance among Children with Cerebral Palsy: A Meta-Analysis of Randomized Controlled Trials". International journal of environmental research and public health, vol. 16, n. 21, 2019, pp. 1-13.

[3] A. Perrochon, B. Borel, D. Istrate, M. Compagnat, J.C. Daviet, "Exercise-based games interventions at home in individuals with a neurological disease: a systematic review and meta-analysis", in Annals of physical and rehabilitation medicine, vol. 62, n.5, 2019, pp. 366-378.

[4] E. Pietrzak, C. Cotea, S. Pullman, "Using commercial video games for upper limb stroke rehabilitation: is this the way of the future?", Topics in stroke rehabilitation, vol. 21, n.2, 2014, pp. 152-162.

[5] M.F. Levin, P.L. Weiss, E.A. Keshner, "Emergence of virtual reality as a tool for upper limb rehabilitation: incorporation of motor control and motor learning principles". Physical therapy, vol. 95, n.3, 2015, pp. 415-425.

[6] A. Rashid, O. Hasan, "Wearable technologies for hand joints monitoring for rehabilitation: A survey". Microelectronics Journal, vol. 88, 2019, pp. 173-183.

[7] Ultraleap. Available in https://www.ultraleap.com/. Accessed on April 20, 2020.

[8] Z. Liu, Zhang Y, Rau P.L.P, Choe P, Gulrez P, "Leap-motion based online interactive system for hand rehabilitation", in International Conference on Cross-Cultural Design, Springer, Cham, 2015.

[9] K.F. Li, A.M. Sevcenco, E. Yan, "Telerehabilitation using low-cost video game controllers", in Seventh IEEE International Conference on Complex, Intelligent, and Software Intensive Systems, 2013, pp. 136-143).

[10] M. Iosa, G. Morone, A. Fusco, M. Cstagnoli, F.R. Fusco, "Leap motion controlled videogame-based therapy for rehabilitation of elderly patients with subacute stroke: a feasibility pilot study". Topics in stroke rehabilitation, vol, 22, n. 4, 2015, pp. 306-316.

[11] P. Fernández-Gonzales, M. Carratalá-Tejada, E. Monge-Pereira, S. Collado-Vázquez, P.S.H. Baeza, A. Cuesta-Rueda, E.D.Oña-Simbaña, A. Jardón-Huerte, F. Molina-Rueda, C.B.B. Qiorós, J.C. Miangolarra-Page, R. Cano-de-la-Cuerda, "Leap motion controlled video game-based therapy for upper limb rehabilitation in patients with Parkinson's disease: a feasibility study". Journal of neuroengineering and rehabilitation, vol. 16, n. 1, 2019, pp. 133.

[12] Evolv Rehabilitation Technologies S.L. Available in: https://evolvrehab.com/virtualrehab/virtualrehabhands/. Accessed on April 20, 2020.

[13] J. Cannell, E. Jovic, A. Rathjen, K. Lane, A.M. Tyson, M.L. Callisaya, M.L. Bird, "The efficacy of interactive, motion capture-based rehabilitation on functional outcomes in an inpatient stroke population: a randomized controlled trial". Clinical rehabilitation, vol. 32, n.2, 2018, pp. 191-200.

[14] H.S. Choi, W.S. Shin, D.H. Bang, "Mirror therapy using gesture recognition for upper limb function, neck discomfort, and quality of life after chronic stroke: A single-blind randomized controlled trial". Medical science monitor: international medical journal of experimental and clinical research, vol. 25, 2019, 3271.

[15] M.N. Ögün, R. Kurul, M.F. Yasar, S.A. Turkoglu, S. Avci, N. Yildiz, "Effect of leap motion-based 3D immersive virtual reality usage on upper extremity function in ischemic stroke patients". Arquivos de neuro-psiquiatria, vol. 77, n. 10, 2019, pp. 681-688.

[16] N.M. Soares, G.M. Pereira, R.I.N Figueiredo, G.S. Morais, S.G. de Melo, "Terapia baseada em realidade virtual usando o Leap Motion Controller para reabilitação do membro superior após acidente vascular cerebral". Scientia Medica, vol. 27, n. 2, 2017, pp. 1-7.

[17] I.M. Moldovan, L. Tric, R. Ursu, A. Podar, A.D. Călin, A.C. Cantea, C.A. Mihaiu, "Virtual rehabilitation programme using the MIRA platform, Kinect and Leap Motion sensors in an 81 years old patient with ischemic stroke", in IEEE E-Health and Bioengineering Conference (EHB), 2017, pp. 325-328.

[18] M. Khademi, H. Mousavi Hondori, A. McKenzie, L. Dodakian, C.V. Lopes, S.C. Cramer, "Free-hand interaction with leap motion controller for stroke rehabilitation", in ACM conference on Human factors in computing systems, 2014, pp. 1663-1668.

[19] E.D. Oña, C. Balaguer, R. Cano-de la Cuerda, S. Collado-Vázquez, A. Jardón, "Effectiveness of serious games for leap motion on the functionality of the upper limb in Parkinson's disease: a feasibility study". Computational intelligence and neuroscience, vol. 2018, 2018, pp. 1-17.

[20] E. Tarakci, N. Arman, D. Tarakci, O. Kasapcopur, "Leap Motion Controller–based training for upper extremity rehabilitation in children and adolescents with physical disabilities: A randomized controlled trial". Journal of Hand Therapy, vol. 33, n.2, 2019, pp. 220-228.e1.

[21] G. Zhu, S. Cai, Y. Ma, E. Liu, "A series of leap motion-based matching games for enhancing the fine motor skills of children with autism", in IEEE 15th International Conference on Advanced Learning Technologies, 2015, pp. 430-431.

[22] Y.T. Wu, K.H. Chen, S.L. Ban, K.Y. Tung, L.R. Chen, "Evaluation of leap motion control for hand rehabilitation in burn patients: An experience in the dust explosion disaster in Formosa Fun Coast". Burns, vol. 45, n. 1, 2019, pp. 157-164.

[23] G. Alankus, "Motion-Based Video Games for Stroke Rehabilitation with Reduced Compensatory Motions, Doctoral Dissertation, Department of Computer Science and Engineering, Washington University in St. Louis, 2011.

[24] S. Ponte, S. Gabrielli, J. Jonsdottir, M. Morando, S. Dellepiane, "Monitoring game-based motor rehabilitation of patients at home for better plans of care and quality of life", in 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), 2015, pp. 3941-3944.

[25] V. Mathiowetz, G. Volland, N. Kashman, K. Weber, "Adult norms for the Box and Block Test of manual dexterity". American Journal of Occupational Therapy, vol. 39, n. 6, 1985, pp. 386-391.

[26] R.H. Jebsen, N.E.A.L. Taylor, R.B. Trieschmann, M.J. Trotter, L.A. Howard, "An objective and standardized test of hand function". Archives of physical medicine and rehabilitation, vol. 50, n. 6, 1969, pp. 311-319.

[27] J.R. Bruun-Pedersen, S. Serafin, L.B. Kofoed, "Going outside while staying inside—exercise motivation with immersive vs. non–immersive recreational virtual environment augmentation for older adult nursing home residents", in IEEE International Conference on Healthcare Informatics (ICHI), 2016, pp. 216-226.

[28] S. Shahrbanian, X. Ma, N. Aghaei, N. Korner-Bitensky, K. Moshiri, M.J. Simmonds, "Use of virtual reality (immersive vs. non immersive) for pain management in children and adults: A systematic review of evidence from randomized controlled trials". Eur J Exp Biol, vol. 2, n. 5, 2012, pp. 1408-22.

[29] J.A. Gil-Gómez, P. Manzano-Hernández, S. Albiol-Pérez, C. Aula-Valero, H. Gil-Gómez, J.A. Lozano-Quilis, "USEQ: a short questionnaire for satisfaction evaluation of virtual rehabilitation systems". Sensors, vol. 17, n. 7, 2017, 1589.