A TELEREHABILITATION PROGRAM BY VIRTUAL REALITY-VIDEO GAMES IMPROVES BALANCE AND POSTURAL CONTROL IN MULTIPLE SCLEROSIS PATIENTS

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ABSTRACT

BACKGROUND: Balance and postural control (PC) disorders are frequent motor disorder symptoms associated with multiple sclerosis (MS).

OBJECTIVE: To demonstrate the potential improvements in balance and PC among patients with MS who complete a virtual reality telerehabilitation program that represents a feasible alternative to physical therapy for situations in which conventional treatment is not available.

METHODS: 50 patients was recruited. Control group (n=25) received physiotherapy treatment twice a week (40 min per session). Experimental group (n=25) received telerehabilitation treatment using the Xbox 360® console monitored via videoconference. Experimental group attended 40 sessions, four sessions per week (20 min per session).The treatment schedule lasted 10 weeks for both groups. A computerised dynamic posturography and clinical outcomes (Berg Balance and Tinettti scales) were used at baseline and at the end of the treatment.

RESULTS: Results showed an improvement over general balance in both groups. Visual preference, the contribution of vestibular information, mean response time and Tinetti test yielded significant differences in the experimental group. An ANOVA revealed significant between-group post-treatment differences in the composite equilibrium score, Berg and Tinetti scales in the experimental group.

CONCLUSION: We suggest that our virtual reality program enables anticipatory PC and response mechanisms and might serve as a successful therapeutic alternative in situations in which conventional therapy is not readily available.

Key Words: Balance. Multiple Sclerosis. Telerehabilitation. Video games. Virtual reality.

INTRODUCTION

Multiple sclerosis (MS) is a chronic inflammatory demyelinating disease of the central nervous system (CNS) of unknown aetiology and multifactorial origin. MS is the most common chronic neurological disease in young adults in Europe and North America. Balance and postural control (PC) disorders are among the most frequent motor disorder symptoms associated with MS, as these symptoms are present in 20% of patients with MS at onset and chronic in 80% of cases (Cattaneo et al., 2009). Most patients report that balance and gait difficulties are the leading causes of disability affecting their quality of life (WHO, 2008; Matsuda et al., 2001).

Neurorehabilitation programs are among the most popular therapies aimed at reducing the disabilities and social disadvantages that result from MS. The delivery of these services must be profitable, equitable, accessible, sustainable, and of high quality. Many of the sequelae of neurological diseases are treated on an outpatient basis in hospitals but these resources could be limited and deficient in the clinical setting because of the time-constrained nature of rehabilitation. In addition, most patients with MS have difficulties related to mobility, geographical location, or both that prevent them from receiving treatment at a rehabilitation centre. Furthermore, personnel and material resources are needed to provide such treatment, which increases the cost of therapy and the difficulty of providing continuoustreatment.

In response to this situation, interest has recently increased with regard to the development of eHealth projects. In the context of eHealth, telerehabilitation (TR) is the delivery of rehabilitation services via electronic systems using information and communication technologies (Cano-de la Cuerda et al., 2010). TR extends rehabilitative care beyond the hospital setting in an eco-friendly environment, helping to detect new limitations and evaluate the effectiveness of the intervention with regard to the activities of daily living (ADLs) at a sustainable cost (Cano-de la Cuerda et al., 2010). Different TR platforms have been applied but their application remains rare in MS treatment (Gregory et al., 2011).

Recently, studies related to the use of virtual reality (VR) and video game consoles have proliferated in the field of neurorehabilitation. Interactive multimedia technologies offer certain advantages over traditional rehabilitation treatments either due to accessibility issues, geography, or treatment availability, providing motivational activities, therapeutic adherence and treatment compliance (Burke et al., 2009).

This study aims to demonstrate the potential improvements in balance and PC among patients with MS who complete a VR-TR program that represents a feasible alternative to physical therapy for situations in which conventional treatment is not available.

METHODS

Patients

The Neurology Unit at San Carlos University Hospital (Spain) recruited 50 patients with MS in according with the revised McDonald criteria (Mc Donald et al., 2001). Recruitment was conducted using consecutive non-probability sampling and based on the following inclusion criteria: a) age between 20 and 60 years; b) confirmed diagnosis of MS for over 2 years based on McDonald criteria; c) medically stable during the 6 months prior to baseline; d) Impaired balance associated with demyelinated lesions in the cerebellum and its connections demonstrated by Magnetic Resonance Imaging; e) Expanded Disability Status Scale(EDSS)score ranging from 3 to 5; f) Hauser ambulatory index value higher than 4; g) absence of cognitive impairment according to the mini mental state examination test (MMES ≥24; h) no visual deficits; e) internet connection at home. The level of experience with consoles and video games was not a criterion for the recruitment of patients. The exclusion criteria were: a) diagnosed with another disease or pathological condition that affects balance; b) had a relapse in the month prior to baseline or during the intervention process, c) received an intravenous or oral steroid cycle prior to beginning the evaluation protocol and within the 4-month duration of the project intervention.

According to criteria of availability and accessibility to different rehabilitation centres and under an agreement with the hospital, patients who did not receive conventional physiotherapy treatment were included in the experimental group (EG) based on at least one the following criteria: listed on the waiting list; limited geographic accessibility; unable to reconcile working hours and therapy schedule; or dependent on others to arrive at the treatment centre. Of the 50 participants enrolled, 23 met these availability and accessibility problems, so they were included in the EG. The remaining participants (n = 27) were randomly distributed into two treatment groups using QuickCalcs from GraphPad-Software®. Due to the equipment availability criterion, two participants were added to the EG; thus, 25 were included in the final sample.

Intervention

The control group (CG; n = 25) received physiotherapy treatment twice a week (40 min per session) at the MS Madrid Association and Foundation. The treatment was based on low-loads strength exercises (10 min per session), propioception exercises on unstable surfaces and gait facilitation exercises (20 min per session), and, finally, muscle-tendon stretching (10 min per session), (Patti et al., 2002). In all cases, fatigue self-perceived was taken into account with an analogue visual scale.

Participants in the EG (n = 25) received individual TR treatments using the Xbox360® console with Microsoft®Kinect following a protocol specifically designed for this purpose.

Kinect uses a set of infrared sensors to recognise the physical position and size of the patient and a multi-array microphone detects voice and extracts ambient sound. The Kinect system enables users to create a digital skeleton (Figure 1). Participants use 3D motion-capture technology to control their avatar via hands-free bodily movement.

Physiotherapists from the Rey Juan Carlos University (Spain) with experience in rehabilitating patients with MS designed the gaming protocol. An exercise protocol was initially developed from seven games that are compatible with Kinect®; three games were discarded due to their gaming difficulty and high degree of physical requirements. A second protocol was designed and tested in participants with MS with similar characteristics to the sample; an additional game was discarded because it caused excessive fatigue in participants. The final conclusive and reliable treatment gaming protocol consisted of three games: Kinect Sports®, Joy Ride® and Adventures®. The activities included in the gaming protocol were based on the recommendations of Cattaneo et al (Cattaneo et al., 2007).

The protocol proposed tasks such as throwing and hitting objects with one's hands and feet, hitting and receiving balls with different body parts, dodging objects, overcoming obstacles, imitating postures, or managing virtual elements that favour key aspects of PC in different positions across a stepwise gradient of difficulty (Figure 2). The software raises the gaming difficulty level depending on patient results and progress.

EG attended 40 sessions at intervals of four sessions per week. There was a progressive increment based on individual patients' fatigue level, up to 20 minutes per session. The home television sets of patients were used as the interface for the video games. Patients were advised to conduct the gaming sessions when another person was at home to minimise the potential risks associated with the treatment protocol. A physiotherapist monitored and supervised all interventions using online meetings via videoconferencing to avoid adverse events.

The treatment schedule lasted 10 weeks for both groups.

Measures

The equipment of computerised dynamic posturography (CDP) Smart Equitest® (NeuroCom International Inc., OR, USA) was used at baseline and at the end of the treatment protocol. CDP is a quantitative method used to evaluate and treat balance disorders (Sturnieks et al., 2008; Oliveira et al., 2011).

The Sensory Organisation Test (SOT) and the Motor Control Test (MCT) were used. SOT is considered as the “gold standard” for studying PC (Barona-de Guzman, 2003) with a sensitivity of 95% (Furman, 1995), and a specificity of 92% (Di Fabio, 1995). Sensory systems are used in a combined and variable manner to calculate the degree of functional impairment and the compensation of the different systems involved in balance control. In the SOT, participants must maintain a stable COG in three consecutive 20-s series for all six conditions in the test. In the first three conditions, the platform remained fixed. Individuals participated with their eyes open, closed, and with a mobile visual environment referenced to postural oscillations in Conditions 1 (SOT1), 2 (SOT2), and 3 (SOT3), respectively. Conditions 4 (SOT4), 5 (SOT5), and 6 (SOT6) repeated the visual conditions of the first three tests and added a platform movement referenced to the anteroposterior oscillation of the participant with the ankle-foot angle remaining constant, thereby negating proprioceptive sensory input (Equitest System, 2005).

MCT assesses the ability of the automatic motor system to quickly recover following an unexpected external disturbance. Sequences of small, medium, or large platform translations in forward and backward directions elicit automatic postural responses (Equitest System, 2005). Participants keep their eyes open, and the display remains stationary throughout the MCT. The translation of the surface in one horizontal direction displaces the COG away from centre in the opposite direction relative to the support base. To restore normal balance, patient COG must be quickly moved back to the centre position. Each translation occurred at a constant velocity; therefore, they transferred constant forward or backward angular momentum to participants' bodies.

The dependent variables for the SOT included the composite equilibrium score (CES), sensory analysis, and sensory ratios. CES quantified the COG sway or postural stability in each of the six sensory conditions across three trials. The effective use of individual sensory inputs was determined from the overall pattern of scores across the six conditions. The CES and the weighted average of all 6 individual scores (with the first two conditions carrying a weight of 1/14 and the other four conditions carrying a weight of 3/14) characterised overall level of performance. Values close to 100% indicate controlled balancing, and those close to 0% indicate a fall.

The sensory analysis depicts the sensory ratios computed from the average equilibrium scores obtained from specific sensory test condition pairs. Somatosensory ratio (SR; [SOT2/SOT1] x 100) was used to assess participant ability to use the input from the somatosensory system to control balance. Visual ratio (VR; [SOT4/SOT1] x 100) assessed patient ability to use the input from the visual system to maintain balance. The vestibular ratio (VEST; [SOT5/SOT1] x 100) assessed the ability to use the input from the vestibular system to maintain balance, and the visual preference ratio (PREF; [SOT 3+6/SOT 2+5] x 100) assessed the degree to which patient relies on visual information to maintain balance, even when the information is incorrect (Nallegowda et al., 2003; Nashner et al., 1982).

The latency (ms) between translation onset and the initiation of the mechanical postural reaction response were calculated from the MCT. Latency scores are displayed only for medium and large translations. Higher scores mean a worse performance.

As clinical outcomes, the Berg Balance (BBS) and Tinetti scales were used. BBS consists of 14 functional items which are scored using an ordinal scale. It is performance based and has a scale of 0-4 for each item (higher score for independent performance) with a maximum score of 56. A score of 45 or less indicates a greater risk of falls. An acceptable concurrent validity of the BBS has been reported (Cattaneo et al., 2006) and its contribution to identify fallers (Nilsagard et al., 2009) in the context of the EM patients.

The Tinetti assessment tool is an easily administered task-oriented test that measures gait and balance abilities. The test is scored on the patient’s ability to perform specific tasks. Scoring of the Tinetti test is done on a three point ordinal scale with a range of 0 to 2. A score of 0 represents the most impairment, while a 2 would represent independence of the patient. The individual scores are then combined to form three measures; an overall gait assessment score, an overall balance assessment score, and a gait and balance score.

The maximum score for the gait component is 12 points. The maximum score for the balance component is 16 points. The maximum total score is 28 points. In general, patients who score below 19 are at a high risk for falls. Scores in the range of 19-24 indicate that the patient has a risk for falls. Soyuer et al suggest the usefull of Tinetti test to measure postural control and gait disturbances in EM patients (Sayuer et al., 2006)

Assessments were done by an independent evaluator blinded to the intervention applied to the patient. The CDPs and clinical outcomes were conducted at the Motion Analysis Laboratory at Rey Juan Carlos University. All participants in this research were informed of the protocol’s objectives and risks. Patients who met the inclusion criteria volunteered for this research by providing written consent. The study followed the Helsinki declaration and was approved by the Regional Ethical Comitee in Madrid (11/099-E).

Data analyses

Power calculation to determine sample size was not taking into account due to the number of participants in EG was established by the number of video games available. The data analyses were performed using the software package SPSS Version 19.0. The first analysis addressed the features and regularities of the dataset using descriptive statistics of the qualitative variables and the quantitative variables. The Kolmogorov-Smirnov test was used to determine whether the study variables were normally distributed. An independent-samples t-test was performed for each quantitative variable to determine the homogeneity of the sample. A Levene's test p-value less than 0.05 was considered significant. A paired-samples t-test was used to analyse the pre- and post-intervention differences in the balance measurement variables (SOT, sensory analysis, and MCT) within groups. An analysis of variance (ANOVA) was used to compare the pre- and post-intervention differences using the group parameters as the between-subject factor and the study variables as within-subject factors. Variables that did not meet the homogeneity criteria were analysed using an ANOVA with the baseline variable as an additional covariate. The significance threshold was set at $p \leq 0.05$.

RESULTS

Forty-seven patients (27 women and 20 men) between the ages of 28 and 60 years completed this study. Two participants in the CG dropped out, and one in the EG dropped out due to a relapse. The mean age of the CG (N = 23) was 42.78 ± 7.38 years (mean ± SD), with 10.86 ± 5.40 years since MS diagnosis. The mean age of the EG (N = 24) was 39.69 ± 8.13 years, with 9.68 ± 6.76 years since MS diagnosis. Table 1 displays sociodemographic variables, the data related to progress and EDSS scores. Table 2 shows CDP baseline and clinical values. Both groups were homogeneous at baseline for all variables analysed. Compliance of the patients to the protocols was satisfactory for both interventions, achieving adhesion values above 80% of the total sessions purposed for both groups.

Pre- and post-intervention within-group comparisons

A paired-samples t-test was used to analyse the CES percentages of the EG from pre- to post-intervention. The results indicated significant differences, with an increase of 8.21 points from the pre-treatment baseline to the post-treatment evaluation ($P < .001$). Conversely, this test was not significant for the CG ($P = .123$; Table 3).

The sensorial analysis of the SOT results provided information on the participation and use of each sensory system with regard to maintaining proper balance. Furthermore, the results of the t-tests of visual preference and the contribution of vestibular information yielded significant differences ($P < .001$) in the EG. Conversely, significant differences were not found with regard to the contribution of visual and somatosensory information ($P > .05$). Furthermore, only the contribution of the somatosensory input source significantly differed in the CG ($P = .043$).

In addition, the MCT t-test results for the EG revealed significant differences between baseline and post-intervention ($P = .005$); specifically, mean response time decreased over time. No significant differences were found in this regard for the CG.

BBS achieved significant differences between baseline and post-intervention in both groups ($P < .001$ and $P= .02$ for EG and CG, respectively). Tinetti test differences were only found in the EG ($P < .001$).

ANOVA analysis

An ANOVA revealed significant, between-group post-treatment differences in the CES percentage from the SOT ($F = 37.873$, $P < .001$).

Moreover, an ANOVA yielded significant between-intervention-group differences in the contribution of the vestibular system ($F = 12.156$, $P < .001$). In addition, significant differences were found with regard to the ability to accept incorrect visual information expressed by the visual conflict parameter ($F = 15.05$, $P < .000$). Furthermore, an ANOVA did not reveal significant between-group differences with regard to the contribution of the visual system ($F = 2.64$, $P = .11$) or use of somatosensory information ($F = .117$, $P = .734$) in the maintenance of balance and stability.

ANOVA on the MCT revealed significant between-group differences in participant response time. Response time was a measure of PC recovery to unexpected stimuli that altered its stability ($F = 9.89$, $P = .003$).

In addition, ANOVA on the BBS ($F = 29.896$, $P < .001$) and Tinetti ($F = 46.898$, $P < .001$) scores revealed significant between-group differences in the EG, achieving higher values. The statistical accuracy of these variables is shown in Table 4.

DISCUSSION

To our knowledge, this article is the first to evaluate the implementation of a TR program using a virtual in-home therapy to improve balance and PC in patients with MS. Previous authors have studied the effect of semi-immersive VR video game systems on PC and balance disorders in adult patients with various neurological conditions (Baram et al., 2006; Yen et al., 2011; Cikajlo et al., 2012). However, few studies evaluated the balance and PC of patients with MS using VR systems (Baram et al., 2006; Nilsagård et al., 2012; Brichetto et al., 2013). Importantly, all of the studies cited above were conducted in the context of outpatient rehabilitation except for Cikajlo et al. (Cikajlo et al., 2012), who conducted their study with patients with stroke.

The results of this study demonstrated improvements in the balance and PC of patients with MS after completing either a TR program using video game VR technology or a conventional rehabilitation program. With regard to our objectives, a TR program might be an important alternative to standard rehabilitation treatments for the balance and PC of patients with MS who have problems with mobility, geographical access, or both. The study revealed significant improvements in the EG related to overall balance, vestibular and visual preference sensory inputs, and improved automatic postural response.

No participants achieved a CES above 70% at baseline. This cut-off score is the normal minimum value (i.e., the value achieved by 95% of the age-matched population without symptoms or a history of disequilibrium) (Alguacil et al., 2012). After the intervention, only participants in the EG reached CES above 70%.

Initially, the CES evaluation showed significant within-group and between-group improvements in the EG and not the CG. Importantly, Peterson et al. (Peterson et al., 2003) described a possible learning effect and found a 10% increase in the equilibrium capacity related to repeated exposure to the SOT. Likewise, Guskiewicz et al. (Guskiewicz et al., 1997) specified that a change of 6.83 in the CES over baseline is needed. Fatigue is an important symptom of MS and may mask the results; therefore, we decided not to repeat the posturography tests. However, the mean values in our study exceeded that cut-off; thus, we concluded that the improvements occurred due to the experimental intervention. An 8.20-point increase occurred from the baseline in the EG.

Improved balance and PC in the EG might be related to the motor training principles addressed by Shumway-Cook (Shumway-Cook et al., 2007):

a) Increasing the level of practice in a distributed manner. In the intervention program that this study proposes, the treatment time per week was similar across both groups; however, the level of distributed practice increased for patients in the EG (four sessions of 20 min/week of virtual therapy vs. two sessions of 40 min/week of outpatient therapy). Schmidt and Lee (Schmidt and Lee, 2005) established the importance of the distributed practice level, stating that the ratio of enhanced functionality or task performance varies linearly with the amount of distributed practice. Similarly, Piron et al. (Piron et al., 2009) and Cano et al. (Cano-de la Cuerda et al., 2010) suggested that TR programs increase the level of distributed practice versus traditional outpatient therapy based primarily on extensive practice sessions on specific days in patients with neurological disorders. Furthermore, we conducted a distributed practice to control the onset of fatigue during gaming, which can decisively influence the learning capacity and motor performance of patients with MS.

b) Increasing functional task repetition. French et al. (French et al., 2007) discussed the importance of functional task repetition with regard to PC and balance training in patients with neurological disorders. In turn, Burke et al. (Burke et al., 2006) proposed using the multiple possibilities offered by VR-based video games to increase patient level of effort and the difficulty of the practice, not only to repeat functional tasks but also to perform and learn by changing the various parameters related to the proposed tasks. Therefore, the aim is to propose learning strategies based on the concept “to repeat without repeating”, thereby increasing the level of demand and the difficulty of different games that progressively challenge patient balance and PC.

c) Sensory feedback modality used. Furthermore, several authors have cited the activation of the sensory information integration processes as the principle required to treat stability disorders in patients with MS. These processes enable the possibility of generating suitable motor responses to ensure the maintenance of balance and PC (Smania et al., 2008; Pavlou et al., 2004). Thus, the sensory analysis obtained through the SOT allows one to identify the degree of participation of the various sensory feedback forms in relation to the treatment modalities of the EG and CG. We did not find significant between-group differences with regard to the use of somatosensory inputs; however, significant increments were observed after the conventional therapy in the CG. In our study, the use of VR does not seem to improve somatosensory aspects; thus, although the platform might improve body schema integration, it does not appear to improve proprioception. No significant between-group differences were found with regard to the use of visual information. This result might be related to the fact that vision is the default sensory mode for recognising the environment in patients with MS. In real and virtual instable situations, the reference sensory system determines bodily orientation in space with regard to the environment and the demands of the task (Kuno et al., 1999).

With respect to the use of vestibular information, however, the results of this research showed that virtual training improves the ability to use these inputs to maintain balance and PC. These results were not observed in the CG. Pavlou et al. (Pavlou et al., 2004) showed how the visual-vestibular conflict considerably compromises the maintenance of balance and PC and increases the use of vestibular information integration in healthy participants. This finding might be related to the angular displacement of the head when trying to adapt one's gaze to bodily movement trajectories and interact with objects in a virtual environment.

In addition, a better visual preference parameter response was observed in the EG compared with the CG. Patients with MS lose stability while viewing erroneous optokinetic stimuli in an open and changing visual environment. As a result, VR training offers the possibility of integrating multiple visual inputs across different visual field levels with stimuli that have high variability in their direction, path, and speed, thereby significantly increasing the number of reliable peripheral visual stimuli.

Moreover, balance and PC involve not only maintaining stability but also recovering from disequilibrium. Thus, the activation of the automatic response mechanisms that ensure the recovery of stability is needed to prevent falling. The results of the CDP MCT revealed a significant decrease in the response time to unexpected disruptions in the EG but not the CG. Authors such as Kuno et al. (Kuno et al., 1999) have reported that balancing the body in virtual environments is proportional to the velocity of the perceived visual stimulus, and COG stabilisation depends on the fast and accurate integration of visual inputs. Thus, contrary to conventional therapy in which the environment remains constant or is modified with minor variations, virtual environments are dynamically configured and variable (Adamovich et al., 2009; Reed-Jones et al., 2008). Therefore, the visual demands of the environment require one to constantly readjust the perceived spatial and temporal information. The constant readjustment of visual information required for recovering stability also necessitates constant feedback. In this respect, video game and VR systems inform the participants about their movements and their degree of accuracy, and the results of their actions on the environment allow them to train their adaptive reflex responses to ensure the restoration of balance and PC (Green et al., 2012).

Patients included in this study presented a great risk of falls (scores at BBS $\leq$ 45) at baseline. Both therapies showed benefits over BBS scores, decreasing this risk over time but only the TR program based on a VR showed significant differences. In this sense, the risk of falls evaluated by Tinetti test also achieved significant improvements in the EG.

Our results demonstrated that a TR program based on a VR system allows one to optimise the sensory information processing and integration systems necessary to maintain the balance and PC of people with MS. In addition, we suggest that the VR program discussed in this research enables anticipatory PC and response mechanisms and might serve as a successful therapeutic alternative in situations in which conventional therapy is not readily available. Additional research is needed to evaluate the ability of these systems to treat other symptoms associated with MS, evaluate the effect of these programs by analysing their cost-effectiveness and to determine if these clinical improvements are perceived as a better health-related quality of life in this population.

Study limitations

This research has several limitations. First, participants were selected using non-probabilistic sampling; a discretionary sample was used with pre-set criteria including area of residence, access to rehabilitation services, and whether rehabilitation treatment was available. Second, the research was not blind; however, an independent evaluator assessed balance and PC. Third, no follow-up was performed to conclude that the improvements remained stable over time. Fourth, the size of the treatment effect was not evaluated because number of patients needed to treat was not determined. Finally, the VR system proposed activities were not specifically designed to serve a rehabilitative purpose. However, experts in treating MS developed the exercise protocol according to criteria of playability with the aim of adjusting the protocol to the balance and PC of patients with MS.

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FIGURE 1. VIRTUAL AVATAR IN A KINECT® VIDEOGAME

FIGURE 2. A MULTIPLE SCLEROSIS PATIENT PRACTICING THE HOME-EXERCISE TELEREHABILITATION PROGRAM