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Time performance and CoP displacement of hemiplegic subjects in a virtual reality game task: short and long-term effects of a training protocol

Desempenho de tempo e deslocamento do centro de pressão em hemiplégicos em uma tarefa de jogo de realidade virtual: efeitos de curto e longo prazo de um protocolo de treinamento

Desempeño de tiempo y desplazamiento del centro de presión en hemipléjicos en una tarea de juego de realidad virtual: efectos de curto y longo plazo de un protocolo de capacitación

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ABSTRACT | Video games with virtual interaction have been successfully used in physical therapy programs, although there is a lack of knowledge regarding evidence involving clinical results. This study aimed to evaluate learning and some parameters of the center of pressure (COP) displacement of a *Nintendo Wii Fit* task in hemiplegic and healthy subjects immediately after a rehabilitation training program and after a 3-month washout period. Twenty subjects being 10 hemiplegic and 10 healthy performed three assessments over different periods; Pre, Post and 3-months after rehabilitation training. Participants were positioned on the Wii Balance Board®. The game task performed (Ski Slalom® game) involved mediolateral movements. During the task's execution, the Wii Balance Board® was placed on a force plate (AMTI OR-6, USA). As such, COP data displacement could be collected during the game. After the training, the hemiplegic subjects showed no change in COP sway pattern and this condition persisted after three months. However, both groups improved their time performance to finish the task after training and maintained the improvement in performance after 3-months. COP displacement of hemiplegic subjects did not change after training, healthy subjects were able to reduce their mediolateral and anteroposterior COP displacement.

Keywords | Rehabilitation; User-Computer Interface; Hemiplegia; kinetics.

RESUMO | Jogos de vídeo game com interação virtual têm sido utilizados com sucesso em programas de tratamento fisioterapêuticos, embora, existam lacunas de conhecimento de evidências com relação a resultados clínicos. Esse estudo teve como objetivo avaliar parâmetros do centro de pressão (COP) e o desempenho em uma tarefa do *Nintendo Wii Fit* em sujeitos hemiplégicos e saudáveis imediatamente após um programa de treinamento e após um período de 3 meses sem treino. Vinte sujeitos, 10 hemiplégicos e 10 saudáveis foram avaliados em 3 diferentes momentos Pré, Pós e 3 Meses após o treinamento. Os participantes foram posicionados sob a Wii Balance Board®. O jogo executado (Ski Slalom® game) envolvia deslocamento no sentido médio-lateral. Durante a execução, a Wii Balance Board® foi colocada sob uma plataforma de força. Então, os dados de deslocamento do COP puderam ser coletados durante a realização do jogo. Após o treinamento, os sujeitos hemiplégicos não alteraram o padrão de deslocamento do COP. Entretanto, ambos os grupos melhoraram o tempo de execução da tarefa e mantiveram a melhora após 3 meses. Apesar disso, os sujeitos hemiplégicos não reduziram o deslocamento do COP e os sujeitos assintomáticos reduziram o deslocamento do COP no sentido mediolateral e anteroposterior.

Descritores | Reabilitação; Interface Usuário-Computador; Hemiplegia; Cinética.

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RESUMEN | Se utilizan juegos de videojuego con interacción virtual con suceso en programas de tratamientos terapéuticos, aunque existan déficits de conocimiento de evidencias en relación a resultados clínicos. Este estudio tuvo como objetivo evaluar parámetros del centro de presión (COP) y el desempeño en una tarea del *Nintendo Wii Fit* en sujetos hemipléjicos y saludables inmediatamente después de un programa de capacitación y después de un período de 3 meses sin entrenamiento. Se evaluaron veinte sujetos, 10 hemipléjicos y 10 saludables, en 3 diferentes momentos: pre, pos y 3 meses después del entrenamiento. Se posicionaron los participantes sobre la Wii Balance Board®. El juego ejecutado (Ski Slalom® game) se trataba del desplazamiento en el sentido medio-lateral. Durante la ejecución, se colocó la Wii Balance Board® en una plataforma de fuerza. Entonces, los datos de desplazamiento del COP pudieron ser colectados durante la realización del juego. Después de la capacitación, los sujetos hemipléjicos no alteraron el patrón de desplazamiento del COP. Sin embargo, ambos los grupos mejoraron el tiempo de ejecución de la tarea y mantuvieron la mejora después de 3 meses. A pesar de esto, el desplazamiento del COP de los sujetos hemipléjicos no disminuyó, y los sujetos asintomáticos tuvieron su desplazamiento reducido en el sentido mediolateral y anteroposterior.

Palabras clave | Rehabilitación; Interfaz Usuario-Computador; Hemiplejia; Cinética

INTRODUCTION

Hemiplegia is the most common motor disability found in post stroke patients and after a traumatic brain injury[1,2]. The injuries of the upper motor neurons disturb motor control coordination, resulting in spasticity. The inappropriate distribution of weight between the lower limbs caused by spasticity reduces postural control as most body weight is asymmetrically concentrated[3]. Therefore, the posture and the biomechanics of body weight bearing are dramatically changed, increasing the risk of falls and reducing functional capacity in hemiplegic subjects[4,5].

Besides spasticity, neurologic injuries after strokes or a traumatic brain injury often induce cognitive losses, which require specific rehabilitation techniques with exercises focused on both motor and cognitive training[6].

Virtual reality (VR), emerges as a potential rehabilitation tool for neurological subjects[7]. It can provide an adequate and controlled environment in which the subjects might be able to exercise themselves[8]. Immersion in virtual reality systems, however, requires special interaction devices, which can make the application demanding and expensive in the daily clinical environment. As an alternative, game consoles with virtual interaction have been successfully used in physical therapy programs[9]. Despite the lack of knowledge providing evidence regarding its clinical results, an increasing number of physiotherapists are adopting game consoles as a VR rehabilitation tool because they are cheap, easy to use and provide the sensation of immersion to the subject[9-12].

Previous studies have used force plate signals to measure postural control reactions and have provided consistent evidence about the effects of virtual reality treatment on neurologic subjects[11,13]. The Center of Pressure Root Mean Square (COP-RMS) amplitude[14] measures the mean absolute displacement around the mean COP and has been used by several researchers to assess postural control[11,15,16].

Although neuromotor rehabilitation is likely to be helpful for subjects with physical impairments, recovered motor abilities and postural control improvements can be easily lost after a period without training[17]. Unfortunately, the exact period over time in which those motor loses might occur is not well determined[17]. Thus, learning exercises involving functional tasks that shift patients' outputs should always target on long-term motor improvements.

Therefore, this study aimed to evaluate the learning performance (timed performance) and some parameters of the COP during a *Nintendo Wii Fit* task in hemiplegic subjects and healthy subjects immediately after a 10-session rehabilitation training program and again after a 3-month washout period, respectively, to identify the short and long-term effects of the training.

METHODOLOGY

Sample

Twenty male adults were selected and divided into control a group (CG, n=10) and a hemiplegic group

(HG, n=10), with mean 35.2 SD 8.7 and mean 31.3 SD 2.9 years of age, respectively. Power calculations for this study were performed using preliminary data (5 individuals) from a pilot study for root mean square of the mediolateral and anteroposterior components of COP and displacement velocity of the mediolateral and anteroposterior components of COP. The parameter (root mean square of the mediolateral component of COP) with the highest standard deviation (5.86) and the smallest difference between groups was used (7.2mm). The sample size was determined based on predicted power to detect a difference of 7.2mm between the groups with an alpha of 0.05 and 80% power. Based on calculations made in sample power (SPSS Inc. Chicago, IL, USA), a minimum sample size of 10 subjects per group was indicated. The mean height and mass of the participants was 1.72 SD 0.03m and 74.5 SD 5.1 kg for HG and 1.74 SD 0.04m and 71.3 SD 3.8kg for CG. None of the participants reported more than recreational experience in sports and had never experienced the Nintendo Wii Fit® game console. To be included in HG the participants must have been hemiplegic for more than 6 months (Table 1); and have a score of 19 or greater on the Mini Mental State Examination (MMSE)[18]; have scores of 36 or higher on the Berg Balance Scale[19] and perform the "Timed Up and Go" test in less than 20 seconds[20]. In addition, individuals with high physical activity levels, with disabilities that might restrict any of the assessments; with lower limb muscle hypertonia greater than 3 on the Modified Ashworth Tonus Scale[21] and visual impairments with no correction, were not included in the study.

Table 1. Sample characterization

Pathology	N° of participants	Hemiplegic side
TBI	6	3 Right/3 Left
STROKE	4	2 Right/2 Left

Procedure

All procedures were approved by the local ethics committee. All participants agreed to participate in the study and signed informed consent forms.

Assessments

Upon arrival in the laboratory, each participant was familiarized with the experimental set-up. After filling out a questionnaire with some personal data the first assessment (Pre) started. The subject was positioned barefoot on the Wii Balance Board®, which makes a connection between the movements of the lower limbs of the subject to the console of the virtual reality task. The image of the game task was projected on to a 59in x 70in screen, positioned 2 meters in front of the subject. The game used was a simulation of a downhill ski run mostly composed by mediolateral movements (Ski Slalom® game). During the task, the subject and the Wii Balance Board® were placed on a force plate (AMTI OR6-6, USA) operating at 200Hz. Both the kinetic data of ground reaction forces and the timed performance of 3 trials, provided by the game console, were measured and a 30-second rest interval was given between each trial.

After Pre assessment, the subjects started a training protocol, which was implemented in a dark room specifically designed for virtual reality immersion activities. All participants performed the 10-session training protocol of 30 minutes each, including a resting time of about 10 minutes, two times a week over 5 consecutive weeks.

During the training, many virtual reality interaction games from the Nintendo Wii Fit® package, including the Wii Balance Board®, were used to develop not only challenging but also playful sessions. Nevertheless, all games had the same objective, to produce mediolateral movements. At the end of the 10-session training protocol, a second evaluation (Post), identical to the first, was performed. In addition, three months after the second assessment, a third evaluation (3-month) was made to verify the long-term effects of the training protocol. During the 3-month washout period, participants had no contact with virtual reality games.

Data analyses

The Root Mean Square (RMS) of the mediolateral and anteroposterior components of COP and the velocity of displacement of the mediolateral and anteroposterior components of COP were calculated in MatLab® routines (Mathworks, v. 9.0), and used to investigate postural stability during the VR task. A 5th order Butterworth low-pass filter (10 Hz) was used in the data preparation. The RMS and displacement velocity values were obtained by calculating COP displacement according to Duarte and Freitas[14].

An ANOVA for repeated measures with Tukey *Post Hoc* test was used to determine the differences related to the Pre, Post and 3-Month trials. All data was analyzed using the software Statistical Package for the Social Sciences (SPSS, Chicago, Illinois) v.18.0, and the significance level was α = 0.05.

RESULTS

Both groups improved significantly in their respective time performances to finish the task after the training protocol and maintained the improvement over time (after 3 months) (Figure 1).

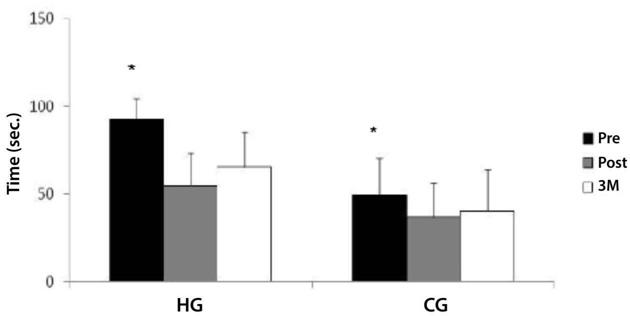

Figure 1. Black, gray and white bars represent respectively Pre, Post and 3-Month assessments (*) p<0.05 between assessments (For both groups Pre was different from Post and 3-Month (3M))

The COP displacement in the mediolateral component was higher for the CG in the Pre assessment compared to HG, while in Post and 3-month assessments the difference disappeared. On the other hand, although the COP displacement of the CG diminished after the Pre assessment, no differences were found between the Post and 3-month measurements. The HG did not change COP displacement in the assessments (Figure 2). Similar results were found when the anteroposterior component was analyzed (Figure 3).

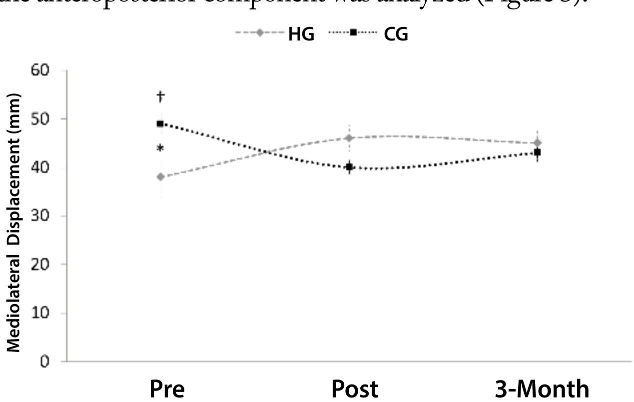

Figure 2. Mean mediolateral COP displacement. The Symbols indicate the differences between groups in Pre assessment (*) and between assessments (Pre different from Post and 3-Month) (†) (P<0.05)

There were no differences between groups and time regarding the velocity of displacement of the COP in both the mediolateral and anteroposterior components (Figure 4 and 5).

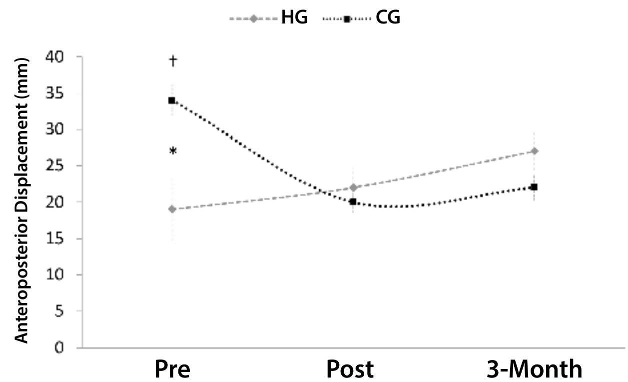

Figure 3. Mean anteroposterior COP displacement. The Symbols indicate the differences between groups in Pre assessment (*) and between assessments (Pre different from Post and 3-Month) (†) (P<0.05)

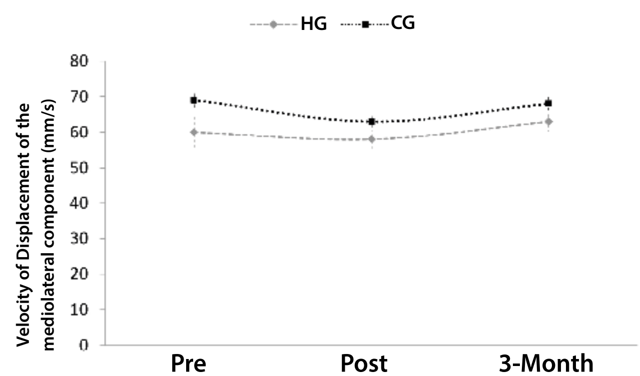

Figure 4. Mean mediolateral velocity of COP displacement

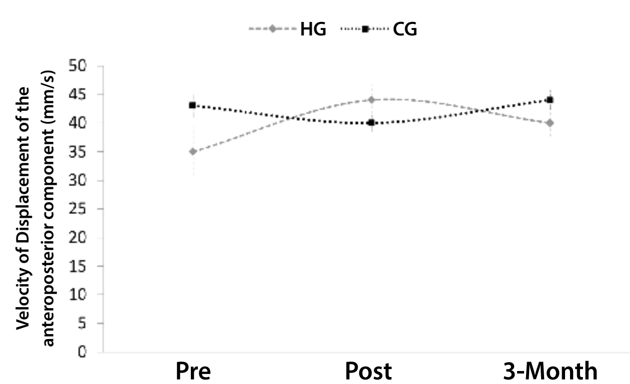

Figure 5. Mean anteroposterior velocity of COP displacement

DISCUSSION

The use of virtual reality for training postural stability is increasingly widespread in clinic environments[21,22].

However, there is a lack of studies that provide evidence of its effectiveness, particularly related to the maintenance of motor learning improvement over time. Thus, the purpose of this study was to evaluate the COP parameters and timed performance in a VR gaming task to compare young individuals and hemiplegic subjects' outputs after a 10-session training protocol using the Nintendo Wii Fit, and the motor learning retention 3 months after its application.

When comparing pre to immediate post assessment in the control group, there was a reduction in the mediolateral and anteroposterior COP displacement. According to Palmieri et al.[15] a smaller COP displacement represents a greater ability to maintain balance. Therefore, our results suggest that training with virtual reality games changed the COP pattern displacement to preserve the standing position, which could improve the postural stability of the young subjects[11]. However, the velocity of COP displacement remained similar between assessments and between groups.

Recent studies have shown that healthy individuals can improve their postural stability skills within a single virtual reality session[23]. Hatzitaki and Konstadakos (2007)[24], demonstrated that healthy subjects standing on a standard balance rehabilitation device built on two force platforms, showing the amount of force applied to each foot in a real-time visual feedback, were able to improve the body weight distribution between the lower limbs. However, the results do not provide information on whether the improvements related to weight distribution were maintained just as an immediate effect or over time, as was found in our study.

Michalski[13] reported a decrease in the COP mediolateral displacement of healthy individuals after a 10-session training protocol with Wii Fit. However, no data regarding the long-term effects of COP displacement improvement were measured. In our study, we also found a decrease in the COP mediolateral displacement immediately after the 10-session training protocol in healthy subjects. Moreover, this decrease was maintained in the 3-Month follow up assessment, with no significant losses to the motor skills acquired during the training.

When considering kinetic data related to task performance, it was noted that a decrease in mediolateral and anteroposterior COP displacement revealed a shorter time to accomplish the task. In other words, the COP signal representation of what is supposed to be a better balance, measured by a lower displacement of the COP, can also suggest an increased efficiency to perform the task by those subjects.

Some balance tests, such as Timed Up and Go, correlates the time of the task performance, considering the subject's functional motor accuracy, indicating that the faster a task is performed, the better the functional fitness and stability is [25,26]. Therefore, considering these arguments, the reduction of time required to perform the game task suggests a development of postural control strategies that enable stability improvements which seem to be related to the displacement area of the COP and not to the velocity of the COP displacement.

In the control group the comparison between pre, post and 3-Month assessments revealed a decrease in mediolateral COP displacement, suggesting effects of training over time. Similar effects were reported by Elion et al.[27], who found beneficial effects of virtual reality therapy in healthy subjects after 24 hours, 4 weeks and 12 weeks of a training session using the CAREN (Computer Environment Assisted Rehabilitation) system. Nevertheless, up to the present date we have not noticed evidence of the effects of training in VR environments over time using a low cost, clinical virtual reality system such as the Nintendo Wii. Moreover, the maintenance of similar COP displacement levels just after the training and over three months demonstrates that there was no loss of the acquired skills.

Despite the significant results found in the healthy group related to mediolateral and anteroposterior COP displacements, no difference was found between the Pre and Post assessments in the hemiplegic group, which indicates that the benefits obtained by the healthy group do not apply to the hemiplegic group.

Barcala et al.[28] analyzed the balance of hemiparetic subjects after ten training sessions utilizing the Wii Fit system and a force plate. The authors found a decrease in COP displacement. However, the measurement of COP was held in a *quasi-static* setup, which does not include displacement movements. Dynamic activities are supposed to be more challenging for maintaining postural stability than static tests and are well-known as the major cause of falls in the elderly and in individuals with neurological impairments such as the asymmetric dynamic body weight bearing[29]. In fact, effects of dynamic training may not be accurately measured well in quasi-static situations. Yang et al.[26] showed that postural control skills learned during dynamic activities might not be related to the maintenance of static postural stability.

Furthermore, Cho et al.[30] evaluated the stability of hemiparetic patients using posturography after training in VR software and found no significant results regarding the mediolateral displacement of the COP[30]. Contradictorily, Pavão et al.[31] found an increase in mediolateral and anteroposterior COP displacement of one hemiplegic subject submitted to virtual reality training in a similar study. Thus, the lack of methodological control clearly creates an evidence gap regarding the effectiveness of VR as a tool to improve quasi-static balance control.

Despite the maintenance of mediolateral and anteroposterior COP displacement after training, both groups improved their timed performance. One possible explanation for this fact is that the fear of falling while performing the VR activity for the first time in an unfamiliar laboratory environment could influence balance due to stress factors with a tendency to remain with stricter COP displacements in order not to exceed the base of support limits, which could lead to a loss of stability[32].

Another explanation is that attention improved. Some studies[33] have shown that task performances can be modified by training. After training, motor task performance usually requires less attention and reaches automaticity when a skill is performed with little demand on attentional resources. Non-automated tasks require significant attention to ensure that performance is maintained[33]. Thus, the period of training seemed to be able to improve the attention of the participants.

Throughout the training sessions, both groups became used to the virtual environment and developed strategies to improve motor performance during the task, which was related to better times for performing the task. These considerations should be taken carefully, as one may also consider that retained motor skills can be measured by several methods with different accuracies. In addition, we cannot confirm how long these abilities can be maintained for and if they would be useful for improving hemiplegic performance in a real dynamic situation with an eminent risk of fall.

There was no statistically significant difference in the mediolateral and anteroposterior COP displacement comparing Pre to 3-Month neither immediate Post to 3-Month assessments. These evidences lead us to consider that the VR protocol used was not an effective training protocol to modify the COP pattern displacement in hemiplegic individuals.

Based on the kinetic data results, this study suggests that the training protocol with a mediolateral dynamic task using VR games may not be an effective alternative to improve COP pattern displacements and the body asymmetry in hemiplegic subjects. However, it is important to consider the lack of a kinematic analysis of this study, which together with the kinetic data could be more accurate for revealing improvements or changes in movement pattern and symmetry related to body segments after the training protocol.

Limitations to find homogeneous samples may also decrease statistical power and, consequently, the accuracy of the results. Therefore, future studies with longer periods of training and assessments, comparing hemiplegic with and without the VR training could gather reliable information regarding the effectiveness of this rehabilitative approach.

CONCLUSION

Virtual reality training reduced the timed performance of hemiplegic and healthy subjects after a 10-session training protocol. Improvement was maintained 3-months after the application of the exercises. However, the COP displacement of the hemiplegic patients did not change after the VR training; only healthy subjects were able to reduce their mediolateral and anteroposterior COP displacement, in both short and long-term evaluations. The velocity of the COP displacement was not different between groups and between assessments of both mediolateral and anteroposterior components.

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