DOI: 10.1590/1809-2950/19027628042021

Dynamical stability of post-stroke volunteers during soccer headers simulated by a digital game

Estabilidade dinâmica de pessoas com AVE durante o movimento de cabeceio simulado em um jogo digital

Estabilidad dinámica de personas con ACV durante el movimiento de cabeceo simulado en un juego digital

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ABSTRACT | Postural stability is a goal of physical therapy treatment which can be achieved by bilateral weight transfer exercises. Digital games come as an alternative to performing these exercises, and their evaluation still needs improvement. We proposed using biomechanical variables to assess postural stability behavior. We aimed to investigate dynamic postural stability during soccer headers simulated by a digital game with different speed requirements. For this, 16 post-stroke volunteers (12 men and 4 women with a mean age of 56 years) and 16 healthy volunteers, paired by sex and age, participated in the experimental collection, in which they were subjected to the digital game "*Cabeceio*" (Soccer Heading), which has five speed levels, from slowest to the fastest, lasting 30 seconds each. From the kinematic signals, we could estimate our indicators of interest: the area of the base of support and the margin of stability, the latter defined as the smallest distance between the edges of the base of support and the vertical projection of the extrapolated CM, considering CM speed. The values of the base of support failed to differ between game speed levels, but did so between groups. The margin of stability failed to differ between levels and groups. The speed levels of the game possibly failed to encourage volunteers to pursue different strategies to maintain dynamic stability, such as taking a step. Although they maintained different support bases, post-stroke individuals adopted a smaller base of support than healthy ones.

Keywords | Stroke; Posture; Rehabilitation; Postural Balance; Video Games.

RESUMO | A estabilidade postural é um objetivo de tratamento na fisioterapia que pode ser alcançado por meio de exercícios de transferência de peso bilateral. Os jogos digitais surgem como alternativa para execução desses exercícios, mas sua avaliação ainda necessita de aprimoramento. Propõe-se aqui o uso de variáveis biomecânicas para verificar o comportamento da estabilidade postural dinâmica durante um movimento de cabeceio, simulado por um jogo digital com diferentes exigências de velocidades. Para isso, 16 voluntários pós-acidente vascular encefálico (AVE) – 12 homens e 4 mulheres, com idade média de 56 anos – e 16 hígidos pareados por sexo e idade participaram da coleta experimental, na qual eles foram submetidos ao jogo digital "cabeceio", que tem cinco níveis de velocidade, do mais lento ao mais rápido, com duração de 30 segundos cada. A partir dos sinais cinemáticos foi possível calcular os indicadores de interesse, a área da base de suporte e a margem de estabilidade, definida como a menor distância

Study conducted at the Laboratory of Human Motricity (LaMH) of the Graduate Program in Health Technology at the Pontifícia Universidade Católica do Paraná (PUCPR) – Curitiba (PR), Brazil.
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Source of funding: Coordination for the Improvement of Higher Education Personnel (Capes) – Conflict of interests: Nothing to declare – Presentation: Aug. 13th, 2019 – Accepted for publication: Nov. 22nd, 2021 – Approved by the Research Ethics Committee: No. 2.919.827.

entre as bordas da base de suporte e a projeção vertical do centro de massa (CM) extrapolado, que considera a velocidade do CM. Os valores da base de suporte não apresentaram diferenças entre os níveis de velocidade do jogo, mas sim entre grupos. A margem de estabilidade não diferiu entre níveis e grupos. Os níveis de velocidade do jogo, possivelmente, não estimularam os voluntários a buscar estratégias diferentes para manter a estabilidade, como dar um passo, mas os fizeram adotar bases de suporte diferentes, sendo que indivíduos com AVE adotaram uma base de suporte menor do que a dos hígidos.
Descritores | AVC; Postura; Reabilitação; Equilíbrio Postural; Jogos de Vídeo.

RESUMEN | La estabilidad postural es el objetivo del tratamiento en fisioterapia que puede lograrse mediante ejercicios de traslado de peso bilateral. Los juegos digitales son una alternativa para realizar estos ejercicios, pero aún necesita mejorar su evaluación. Se propone el uso de variables biomecánicas para verificar el comportamiento de estabilidad postural dinámica durante el movimiento de cabeceo, simulado por un juego digital con diferentes requerimientos de velocidad. Para ello, 16 voluntarios pos-accidente cerebrovascular (ACV) –12 hombres y 4 mujeres, con edad media de 56 años– y 16 individuos sanos pareados por sexo y edad participaron de la recolección experimental, en la que fueron sometidos al juego digital "cabeceo", que cuenta con cinco niveles de velocidad, del más lento al más rápido, con una duración de 30 segundos cada uno. A partir de las señales cinemáticas fue posible calcular los indicadores de interés, el área de base de apoyo y el margen de estabilidad, definido como la menor distancia entre los bordes de la base de apoyo y la proyección vertical del centro de masa (CM) extrapolado, que considera la velocidad del CM. Los valores de la base de apoyo no mostraron diferencias entre niveles de velocidad de juego, pero sí entre grupos. El margen de estabilidad no difirió entre niveles y grupos. Los niveles de velocidad de juego posiblemente no animaron a los voluntarios a buscar diferentes estrategias para mantener la estabilidad, como dar un paso, pero les hicieron adoptar diferentes bases de apoyo, llevando a los individuos con ACV a emplear una base de apoyo menor que la de los individuos sanos.
Palabras clave | ACV; Postura; Rehabilitación; Equilibrio Postural; Juegos de Video.

INTRODUCTION

Research considers stroke as the leading cause of functional disabilities in the West, resulting in sensory, cognitive, language, perception, and, more notoriously, motor impairments[1] such as hemiparesis–characterized by the partial loss of motor function in the hemisphere opposite to the brain injury[2]. These deficits directly affect the control involved in maintaining postures[3], thus enhancing affected individuals' fall risk[2].

Therefore, improving postural control is one of the main objectives of physical therapy, employing a variety of exercises that prioritize the repetition of progressively difficult functional tasks to favor neuroplasticity[4]. However, according to physical therapists' reports, maintaining patients' motivation for long periods of therapy can be difficult, requiring resources that increasingly challenge their abilities[5].

With the advancement of technology, digital gaming systems have been considered as an interesting therapeutic alternative[6], since their main advantage is their ability to provide greater motivation and engagement in the practice of repetitive tasks[7]. Evidence shows that digital games have contributed to different purposes, such as improved balance[8], mobility[9], functionality[10], and gait[11].

Clinical trials and functional scales usually measure such results. However, such research is subject to some limitations, such as the subjectivity of its scales, whose accuracy is directly related to their application by an experienced professional[12], and its evaluations, which fail to provide more detailed information about the motor strategies employed in the tasks since they only take place before and after interventions.

On the other hand, research focused on biomechanical approaches can record quantitative data during posture maintenance and movement performance. Kinematic resources can provide us with the center of mass and force platforms, the pressure center, for example. Although we can obtain different measurements via these resources, the vertical projection of the center of mass (CM) is the kinematic variable most used to investigate the postural control of healthy individuals[13] and those with neurological disorders[14]. That is why we are dedicated to studying it.

In postural stability analyses, the limits of the base of support (BoS) generally correlate with the horizontal projection of the CM (pCM)[15]. For example, a study analyzing pCM displacement within the BoS found that individuals with Parkinson's disease explored their stability limits less than healthy individuals, suggesting a more weakened postural control[16].

To analyze postural stability in dynamic tasks, we proposed an indicator, called margin of stability (MoS)[17], which considers not only the position of the pCM in relation to the BoS, but also its velocity, indicating whether individuals' CMs move away from or into the BoS.

In this context, this study aims to investigate dynamic postural stability during a head movement simulated by a digital game with different speed requirements. We chose this movement because it stimulated bilateral weight transfer, an exercise used in physical therapy to achieve postural stability in post-stroke patients. We elected MoS to investigate dynamic stability and test our hypothesis that post-stroke individuals show a lower margin of stability than healthy individuals.

METHODOLOGY

Participants

The sample of this study was composed of 16 post-stroke individuals from patient lists of rehabilitation hospitals in the municipality of Curitiba, state of Paraná, and 16 healthy individuals from the academic community. All participants signed the informed consent form.

The inclusion criteria for the post-stroke volunteers were: a post-stroke evolution greater than four weeks–including people in the subacute and chronic phases[18]; individuals aged 20 complete years or older; and the ability to walk at least six meters without human help, even if assisted by orthoses or auxiliary devices. On the other hand, the inclusion criteria for healthy volunteers were: same gender and age group than the post-stroke participants; and a maximum score on the Berg balance scale. Table 1 shows the characteristics of our sample.

Table 1. Sample characterization

Characteristic	Post-stroke group (n=16)	Healthy group (n=16)	p-value
Gender (male/female)	12/4	12/4	-
Age (years)	57 (±9)	57 (±9)	1
Body mass (kg)	72 (±20)	75 (±21)	0.598
Height (m)	1.66 (±1)	1.67 (±1)	0.049
BMI (kg/m^2)	28 (±3)	28 (±5)	0.296
Dominance (right/left)	14/2	16/0	-
Berg (0-56)	44 (±1)	56 (±0)	-

BMI: body mass index; p-value: Student's *t*-test for independent samples.
Values shown as mean (standard deviation).

To characterize post-stroke volunteers' clinical condition, tests and functional scales were used to evaluate the deficits that can influence these individuals' postural control. Static and dynamic balance were assessed by Berg scales and the Mini-Balance Evaluation Systems Test (MiniBESTest); hip adductor, and plantar, elbow, and wrist flexor spasticity in the paretic limbs, by the modified Ashworth scale; the motor recovery stage of arms, wrists, lower limbs, and ankles, by the Brunnstrom scale; and tiredness perception, by the Borg scale. Table 2 shows the clinical and demographic characteristics of the post-stroke group.

Table 2. Clinical characterization of the post-stroke group

Characteristic	Stroke group (n=16)
Stroke etiology (ischemic/hemorrhagic)	10/6
Time after the stroke (months)	35 (±10)
Hemiparesis (right/left)	10/6
Dominance (right/left)	14/2
Borg (0-10)	2 (±1)
Berg (0-56)	44 (±1)
MiniBESTest (0–28)	14 (±8)
Brunnstrom arm (1-7)	3 (±2)
Brunnstrom wrist (1-6)	4 (±2)
Brunnstrom lower limb (1-6)	5 (±1)
Brunnstrom ankle (1-6)	4 (±2)
Paretic plantar flexor spasticity (0/1/1+/2/3/4)	6/5/4/1/0/0
Paretic hip adductor spasticity (0/1/1+/2/3/4)	14/2/0/0/0/0
Paretic elbow flexor spasticity (0/1/1+/2/3/4)	6/4/6/0/0/0
Paretic wrist flexor spasticity (0/1/1+/2/3/4)	3/10/3/0/0/0

Values shown as mean (standard deviation); values separated by bars (/) indicate number of volunteers.

Experimental procedures

Post-stroke volunteers visited the Human Motricity Laboratory (LaMH) of the Graduate Program in Health Technology at the Pontifícia Universidade Católica do Paraná (PUCPR) twice, with a maximum interval of up to five days between visits. We dedicated volunteers' first visit to evaluating and familiarizing ourselves with them. Their second visit was reserved for experimental collection via the digital game, prior to which volunteers had their body segments delimited by reflective markers. Then, participants were instructed to stand on a strip of kraft paper, so their feet could be outlined with a pen. Then, the paper was removed, and the volunteers, positioned two meters away from a stand with a 49' LG TV screen and a Kinect sensor®, 140 and 95cm from the floor, respectively. Before playing, the movement of the digital game was shown. Healthy volunteers only undertook the experimental stage.

Cabeceio, the digital game used in this study, stimulates latero-lateral trunk inclination and weight transfer onto the paretic lower limb by simulating, via a Microsoft Kinect®, the heading of a ball in a soccer field. This game contains five speed levels: (1) very slow; (2) slow; (3) moderate; (4) fast, and (5) very fast, which control how often balls are thrown. At level 1, six balls are thrown; at level 2, eight; at level 3, 10; at level 4, 15; and at level 5, 18 balls, thrown every 2.7s. Volunteers progressively played each of the five speeds for 30s.

Data acquisition

To collect kinematic data, the Vicon Nexus 2.7 motion capture system (Vicon Motion Systems LTD., 2018) was used, consisting of six Vicon® Bonita B10 infrared radiation cameras with 100Hz acquisition frequency. The plug-in-gait lower body biomechanical model was adopted and combined with additional markers bilaterally positioned in the following anatomical landmarks: the distal phalanx of the middle finger, the styloid process of the ulna, lateral epicondyle of the humerus, the acromion, and the jugular notch.

The anthropometric measurements of volunteers' feet were extracted from the kraft paper contours, which assessed the distances between the anatomical middle of the heel, tip of the distal phalanx of the first metatarsal, and tip of the distal phalanx of the fifth metatarsal.

Signal processing

Kinematic data were processed in the Matlab environment (R2016a, The Mathworks, Natick, USA). Coordinate signals and angles from the markers were filtered by a second-order low-pass Butterworth filter with a 6Hz cut-off frequency, as determined from a previous residual analysis. CM estimation was based on Tisserand et al.[19], who proposed a simplified model with nine body segments delimited by markers in the anatomical positions mentioned above. The mass percentiles for each body segment were described by Dumas, Chèze, and Verriest[20].

The extrapolated center of mass (xCM) was estimated according to the following equation[16]:

$$\overrightarrow{xCM} = \overrightarrow{pCM} + \frac{\overrightarrow{v}}{\sqrt{g/l}} \quad \text{(I)}$$

In which $\overrightarrow{xCM}$ is the extrapolated center of mass; $\overrightarrow{pCM}$, the projection of the CM on the BoS plane; $\vec{v}$, the speed of the $\overrightarrow{pCM}$; g, the acceleration of gravity; and l, the distance between the midpoints of the ankle and hip joints.

The absolute MoS value corresponds to the shortest vector distance between the xCM and BoS boundaries[17]. MoS values are positive if the xCM is within the BoS, and negative, if outside it.

In this study, BoS was defined in two ways: (1) if both feet were on the ground, the BoS consisted of the polygon formed by the outer edges of the feet and the lines that join their vertices; and (2) if only one of the feet were on the ground, BoS consisted of the triangle delimiting the foot. Based on the feet measurements (in cm), each vertex angle was estimated via the bisector formed by the line connecting the markers positioned in the middle of the calcaneus and in the head of the second metatarsal, for reference over time (Figure 1).

Finally, the indicators of interest for this study were obtained: the mean, minimum, and maximum values of area of BoS and MoS for each speed level played

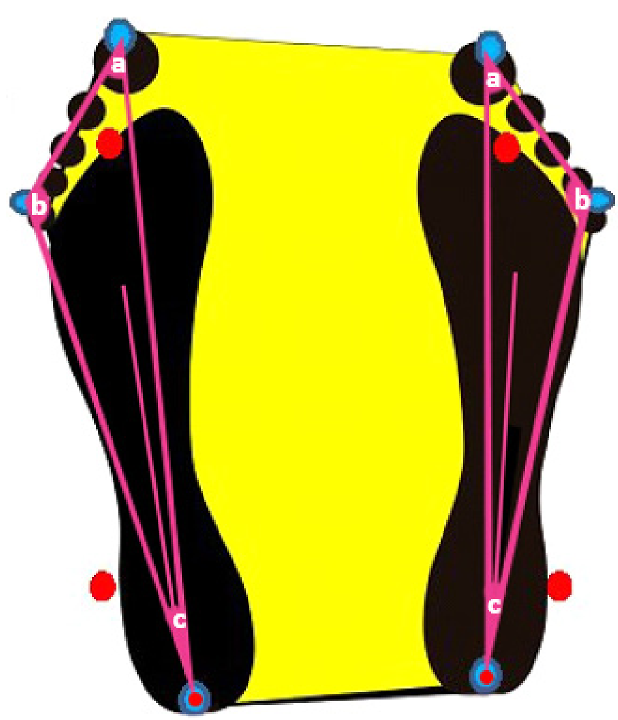

Figure 1. Base of support (BoS).

Yellow hexagon: BoS; blue dots: measured dots on kraft paper; red dots: reflective markers; pink lines: right triangles; pink line in the center of the feet: bisector; a, b, c: angles of the triangle vertices.

Statistical analysis

Data were analyzed on IBM SPSS (version 21.0). Shapiro-Wilk test indicated an abnormal distribution of data. Thus, nonparametric tests were chosen. The Mann-Whitney test was used to compare the groups. The Friedman test was used for the differences between game levels for each group and, when differences were identified, the Bonferroni correction (post hoc – $p<0.005$) was used. For the other tests a 95% confidence interval (α =0.05) was assumed.

RESULTS

Figure 2 shows BoS area values. We found no significant difference between speed levels, but we observed differences between the groups, indicating that post-stroke individuals adopted a lower BoS than healthy ones during the game.

Figure 3 shows the MoS values which failed to differ between speed levels and groups, indicating that the shortest distance between xCM and BoS remained similar between post-stroke and healthy individuals.

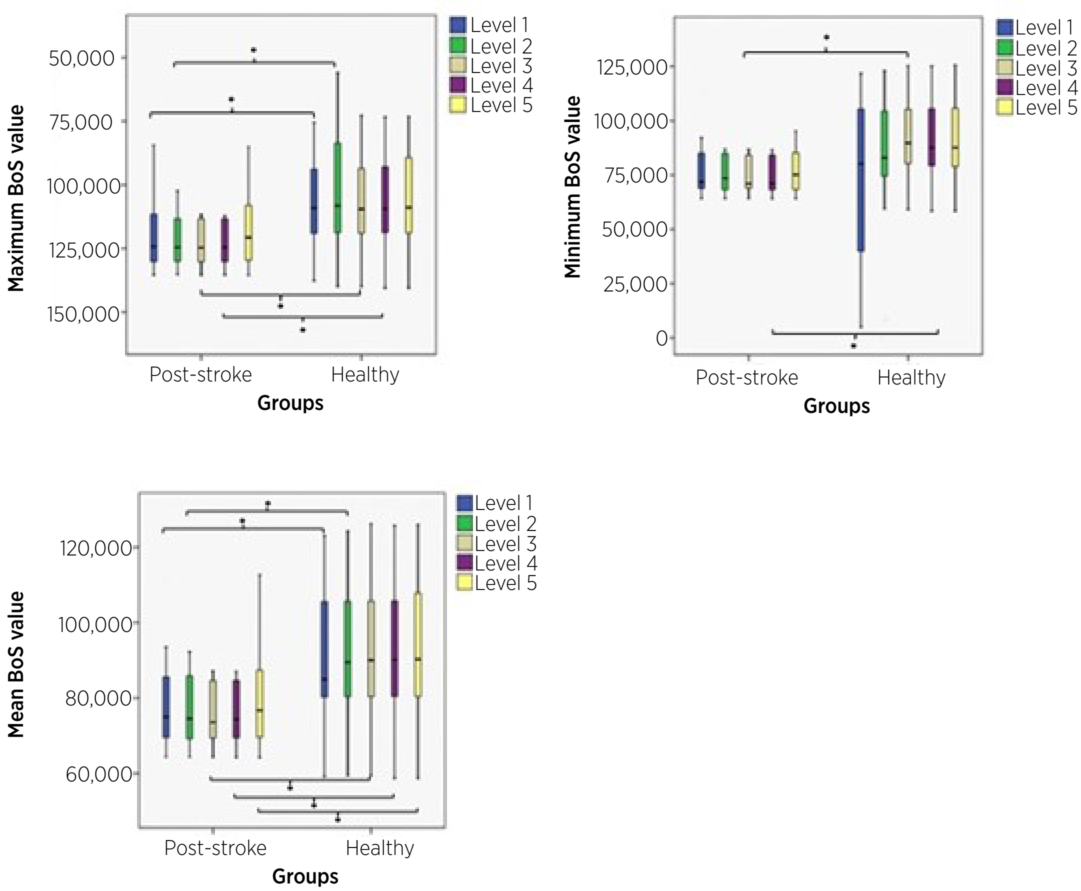

Figure 2. Support base area (BoS) values in mm^2.
The lines inside the boxes correspond to the median, and the edges of the boxes, to the first and fourth quartiles. Error bars represent the range between minimum and maximum values. Horizontal lines with an asterisk (*) indicate statistical significance in the Mann-Whitney test.

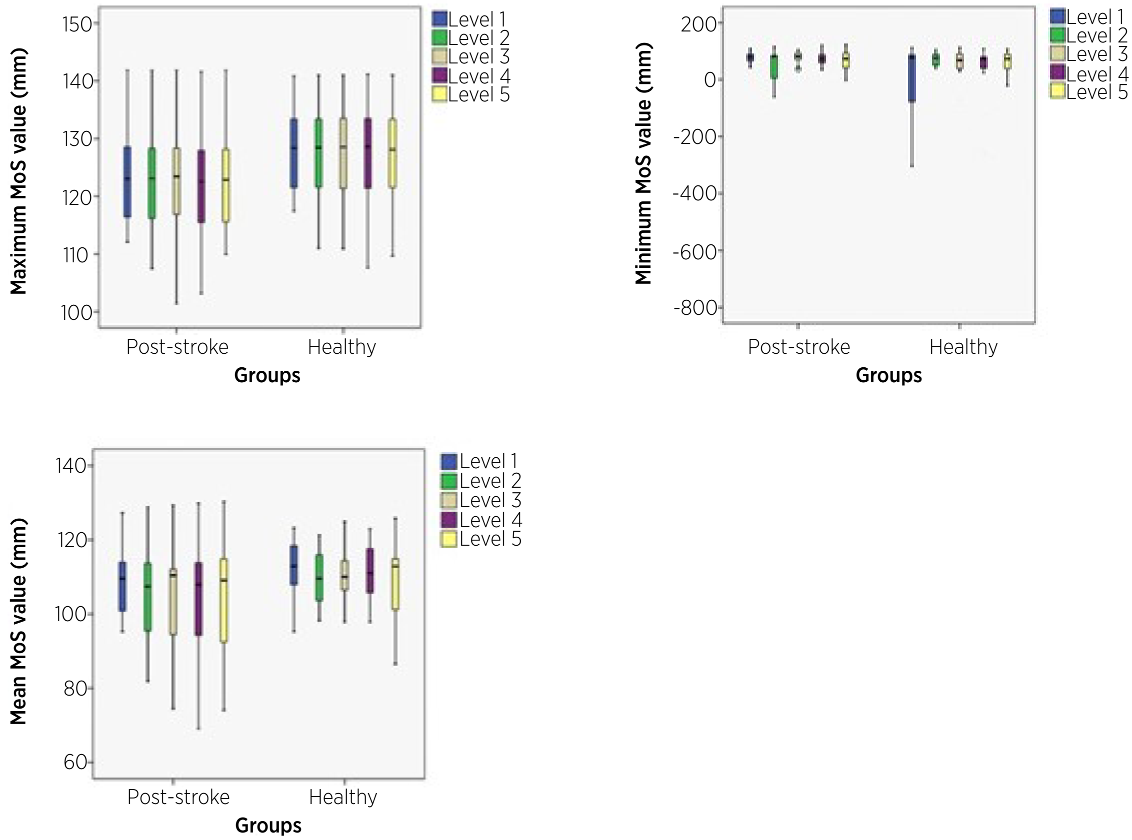

Figure 3. Margin of stability (MoS) values in mm.
The lines inside the boxes correspond to the median and the edges of the boxes, to the first and fourth quartiles. Error bars represent the range between minimum and maximum values.

DISCUSSION

In this study, we observed that BoS areas failed to change for the speed levels of the digital game, despite the increasing speed at which the balls were thrown with each level. A possible explanation for this is that the game may have failed to challenge post-stroke and healthy volunteers into changing their BoS by raising their feet, for example, in attempting to seek a strategy to maintain their dynamic postural stability. MoS measurements also reflect this behavior.

The post-stroke group showed lower BoS values than the healthy one (Figure 2). We assume that post-stroke volunteers had difficulty increasing their BoS area during the game due to impairment caused by hemiparesis and the synergistic extensor pattern of their lower limbs[18], which made them assume a "comfortable" position when standing, keeping their feet closer to each other and, consequently, relying more on their non-paretic lower limbs to maintain stability.

We found the same MoS measurements for both groups (Figure 3), results which reject our hypothesis. Considering that, to maintain biped stability, volunteers should maintain the vertical projection of their centers of mass (pCM) within the BoS and that lower MoS values indicate an extrapolated center of mass (xCM) closer to BoS limits[17], we expected post-stroke individuals to exhibit this behavior, reflecting a worse postural control than healthy volunteers. The smaller BoS area in the post-stroke group possibly influenced this effect.

CONCLUSION

Both post-stroke and healthy individuals kept BoS and MoS areas unchanged while heading balls at all the speed levels of the digital game. However, comparing both groups showed that post-stroke volunteers' had lower BoS areas than healthy ones.

ACKNOWLEDGMENTS

The complete study was funded by the Coordination for the Improvement of Higher Education Personnel (CAPES). The authors thank the volunteers who agreed to participate in this study, Marcos P.R. de Castro for programming the digital game, and all the members of the research group who collaborated to its development.

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