Aging Clinical and Experimental Research (2020) 32:907–912
https://doi.org/10.1007/s40520-019-01270-y

ORIGINAL ARTICLE

Motor–cognitive dual-task performance of older women evaluated using Wii Balance Board

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Received: 13 May 2019 / Accepted: 4 July 2019 / Published online: 22 July 2019

Abstract

Background Single- and dual-tasks are influenced by age-related impaired postural balance. Aim of this study was to analyze the Center of Pressure (CoP) oscillation during static balance in the presence or absence of cognitive task on older women.

Methods Thirty-one healthy older women were assessed in a stand quiet position with open/closed eyes (single-task, OE and CE) and with cognitive task (dual-task, DT) through Wii Balance Board. Sway area, total displacement and CoP oscillation (CO) based on the number of times that CoP traveled through anteroposterior and mediolateral directions. Friedman test was used to compare OE, CE and DT. Dual-task interference percentage was used to quantify the cognitive load on balance whereas Spearman correlation coefficient was used to assess the association of cognitive domains and CO.

Results The CO was significantly higher in DT than in single-tasks and participants were unable to maintain their limits of stability in mediolateral direction. The cost of DT interference was 30.5%, which is partially explained by the deviation of attention from postural control to spatial and temporal orientation.

Conclusion Our findings show that cognitive load during DT impairs balance in mediolateral direction, thus indicating the use of WBB to assess cognitive interference on postural control.

Keywords Center of pressure · Balance · Dual-task · Aging · Executive function

Introduction

Postural control is a task of maintaining human body position in the space, and depends on the interaction between neural and musculoskeletal systems (sensorimotor pathways) [1–3]. The attention needed to maintain postural control during any task may vary according to several factors, such as postural task, age, and balancing skills [4–6]. Wollesen and Voelcker-Rehage [5] describe the need of greater control and attention in automatic tasks (e. g. standing up and walking)

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with advanced age such people over the 65 years old. Dual-task is used to determine the relationship between two tasks simultaneously (e.g. motor–motor, motor–cognitive and cognitive–cognitive) [4–9]. Since advanced age requires greater attention during automatic tasks [5], the association to another simultaneous task can be explored as dual-task. Automatic tasks, such as quiet standing, are impaired during simultaneous cognitive task, which increases postural sway and results in a dual-task cost enhancement. These findings indicate the interference that the motor task suffers by the secondary cognitive task [5, 6].

Postural balance may be measured through Center of Pressure (CoP) coordinates (pressure applied over an area on a force plate) to identify variation in postural stability, which is the gold standard assessment [1, 2, 10–12]. Although these measures are widely used to observe the CoP oscillation on the support base in laboratory assessment [2, 10, 11], the equipment is often expensive, difficult to transport, and doesn't always allows us to train the assessed person. For this reason, similar equipment, the Wii Balance Board (Nintendo®), is used to evaluate postural balance assessment and training, [10, 11, 13]. Wii Balance Board (WBB) can be used as an instrument to measure CoP and to train balance skills, allowing the assessment and training possibilities necessary for interventions with the dual task paradigm. Therefore, we hypothesize that the WBB could be used to assess postural stability control and balance maintenance strategies of older women while solving a cognitive task. In order to test this hypothesis, the aim of this study was to analyze the center of pressure distribution of older women through WBB during single- and dual-task, since the hormonal decline in these subjects seems to diminish neuroplasticity, reflecting poor ability to perform dual-task [9].

Method

Study design

Cross-sectional study with single arm analysis following the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement [14].

Procedures were carried out at the State University of Montes Claros (Minas Gerais, Brazil) from October (2016) to July (2017). All participants were informed about the procedures, requirements, risks and benefits before signing a consent form to participate in the study, which was approved by University's local ethics committee (no 1.365.041/2015).

Participants

Sixty healthy older adults living in the city of Montes Claros (Brazil) were eligible to participate in a longitudinal research project called "Physical exercise, physical and mental health of older adults". Participants were recruited through posters displayed at surroundings of the university and clinics. The inclusion criteria were (1) ≥ 60 years old, (2) preserved communication ability, and (3) independent ambulation. Participants were excluded if they present (1) use of psychotropic drugs, (2) diagnosed neurodegenerative diseases, (3) severe cognitive impairment, (4) acute musculoskeletal injury, and (5) labyrinthitis or other vestibular disorders. These items were ascertained through the history taken.

Mini mental state examination (MMSE) was used to quantify cognitive decline according to the educational level. The cutoff score is 13 points for illiterates, 18 for low-middle school (up to 8 years) and 26 for highly schooled individuals (over 8 years) [15, 16]. Illiterate individuals with preserved calculation abilities remained in the sample. MMSE is divided into category: temporal orientation (5 points), spatial orientation (5 points), recording (3 points), calculation (5 points), recent memory (3 points) and language (9 points). The final score is the sum of the points obtained in each category totaling 30 points.

Instrument

The platform *WBB* (Nintendo®, Kyoto, Japan) with a sampling frequency of 40 Hz was used to obtain anteroposterior (CoP_{ap}) and mediolateral (CoP_{ml}) CoP displacement along one minute (30 s of adaptation to posture and 30 s of signal collection).

WBB has four load sensors at each corner and sends the acquired signal to the computer via Bluetooth [10, 11, 13]. The CoP_{ap} and CoP_{ml} values were obtained in control and experimental conditions (as described in the next section).

A programming routine using LabVIEW® software version 8.5 (National Instruments, Texas, USA) was designed for data acquisition and reading on a computer. Data obtained were analyzed through specific programming routines developed in Matlab® (MathWorks Inc., USA), which was also used for all statistical procedures. A Fourier transform spectral analysis was performed and all data were filtered by 3rd order Butterworth low-pass filter with a cutoff frequency of 12 Hz.

Procedures

Participants were asked to stand comfortably with their feet spread apart on the WBB not surpassing shoulders width. We analyzed the postural balance (computerized posturography) of participants in different tasks on the same day. Firstly, individuals were asked to stand in a quiet position with open/closed eyes (simple tasks) while postural balance was assessed. Two bouts of assessments were performed with open (OE) and closed eyes (CE) in a predefined order. It was established as control condition or baseline. Secondly participants stood with their arms along the body while looking at a visual reference point marked on the wall (2 m of distance) with OE and partially repeated under closed eyes condition [10, 11]. Lastly, postural balance was assessed in experimental condition determined as Dual-task. DT was established as cognitive task while simultaneous postural control. The cognitive task consisted of subtracting seven out of a hundred [17]. As people with cognitive impairment have poor postural balance [18], this test may help us to understand how postural balance is controlled by healthy people undergoing cognitive load. Experimental condition was performed once to avoid learning effect. Subtractions started after 5 s of collection, with 5 s of interval between each subtraction. Participants were asked to perform the calculation mentally, since the speech could influence the test.

Data processing

The Sway Area (SA cm^2) and Total Displacement (TD cm) were determined based on the CoP values over time. CoP oscillation (CO) was determined according to the number of times that both CoP_{ml} and CoP_{ap} were displayed on the surface of WBB (length 45 cm × 26.5 cm). The CO was arranged into maps to display the distribution by WBB surface area.

Statistical analysis

Data normality was tested using Lilliefors test. As non-normal distribution was reached, non-parametric tests were performed. SA and TD in different conditions were described using descriptive values, while CO across trials (OE, CE and DT) was analyzed according to coefficient of variation (CV). Then the Friedman test was used ($\alpha < 0.01$). A pairwise comparison was performed using Bonferroni post hoc test which corrects critical values from Wilcoxon *W* test after an adjustment to compensate multiple comparisons ($\alpha < 0.0033$). Data are shown as mean, standard deviation, median, minimum and maximum. The effect of dual-task on standing up was described in percentage of dual-task interference, calculated according to Rochester et al. [19]. Spearman correlation coefficient was calculated to analyze the correlation between mediolateral CO and each MMSE category (temporal orientation, spatial orientation, recording, calculation, recent memory and language) ($\alpha < 0.05$). The classification of adopted correlation degrees was: 0.9–1 (very high correlation); 0.7–0.9 (high correlation); 0.5–0.7 (moderate correlation); 0.3–0.5 (low correlation); and 0–0.3 (low or no correlation) [20].

Results

From an initial group of sixty older adults assessed for eligibility, eighteen declined to participate, three did not meet the inclusion criteria, and seven were men, leaving the present study with 31 older women. Sample characteristics are shown in Table 1. SA and the TD were used to explain postural balance of participants. Mean SA was not significantly different between OE ($2.36 \pm 0.63 cm^2$), CE (2.60 ± 0.83 cm^2) and DT (2.70 ± 0.88 cm^2) conditions ($p = 0.09$). Similarly, mean TD was not significantly different ($p = 0.68$) in any condition (OE, 118.82 ± 39.66 cm; CE, 120.50 ± 56.83 cm; and DT, 123.46 ± 72.38 cm).

CO was analyzed according to maps designed to represent postural balance oscillation across the WBB surface in all conditions (OE, CE, and DT) (Fig. 1). There was a statistically significant difference between DT (higher oscillation) and single-tasks (OE and CE) ($p < 0.01$). However, there was no difference between OE and CE ($p = 0.45$) in either direction (CP_{ml} and CP_{ap}). Our results showed a higher dispersion in the CO during DT than single-tasks (OE and CE).

The difference in CO was quantified by calculating the limits of stability that corresponds to 66% of height and 72% of the length of support base in the platform (17.82 cm × 23.76 cm) (Table 2). There was a statistically significant difference between DT in comparison to OE and CE conditions ($p < 0.01$) only in mediolateral direction. There was no difference between OE and CE ($p = 0.06$). Therefore, participants showed high oscillation in mediolateral direction in DT condition, showing an impaired postural control with cognitive load. These results were confirmed by calculation of dual-task cost that showed 30.5% of interference on postural balance performance.

Spearman coefficient identified a correlation between CO and two categories of MMSE. These findings showed a low negative correlation with temporal ($r = -0.43$, $p = 0.02$) and spatial orientation ($r = -0.40$, $p = 0.03$).

Table 1 Anthropometric and global cognition values are presented as mean and standard deviation

	Older women
Age (years)	66 ± 7
Weight (kg)	62.00 ± 9.57
Height (cm)	1.55 ± 0.05
BMI (kg/m^2)	25.81 ± 4.45
MMSE (score)	25.13 ± 2.35
Scholarity	21 H; 9 L; 1 I

MMSE mini-mental of status examination, *BMI* body mass index, *H* higher (more than 8 years), *L* low (less than 8 years), *I* illiterate

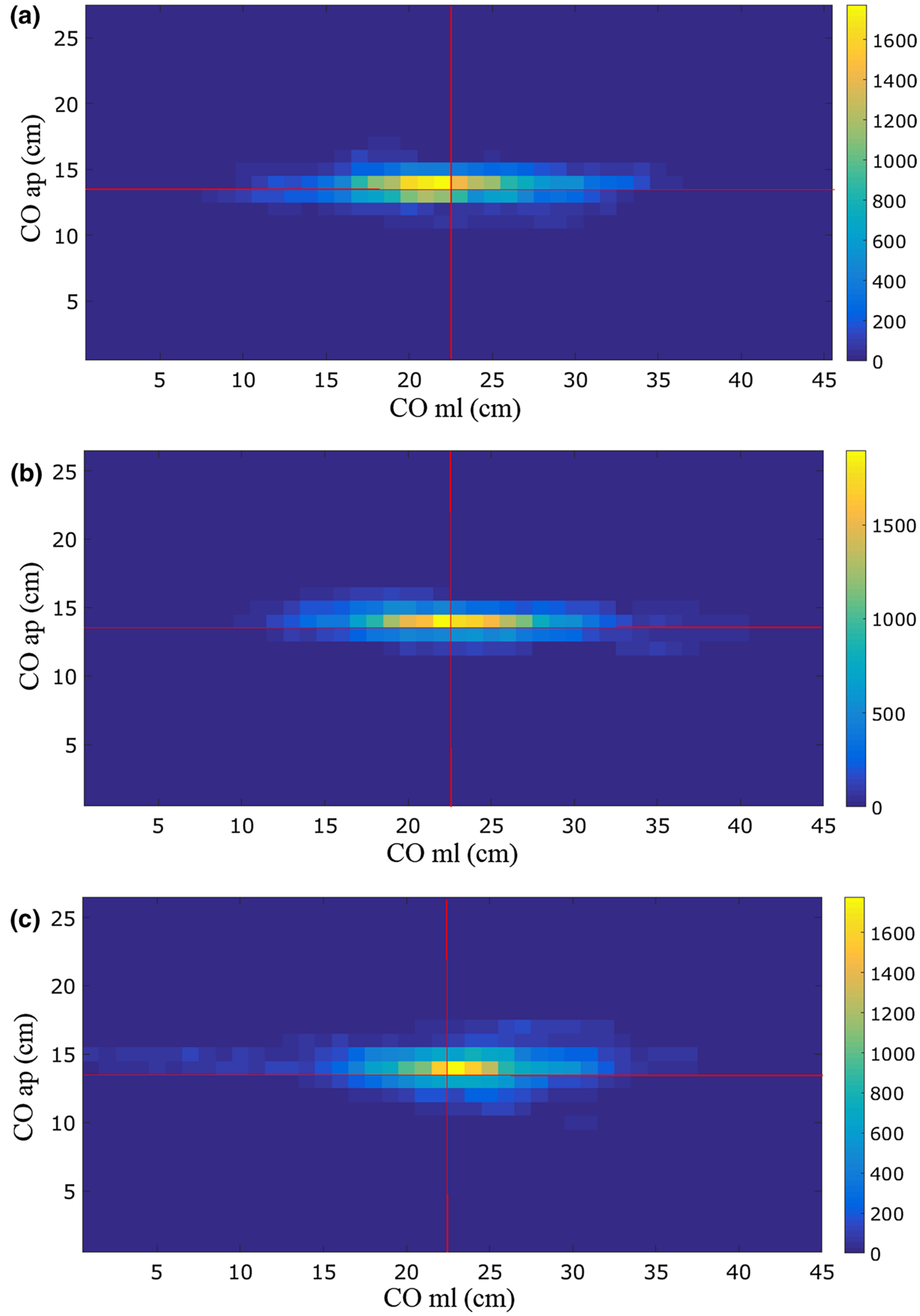

Fig. 1 CO maps during postural balance assessment of the 31 older women. **a** Open eyes (OE), **b** closed eyes (CE), **c** Dual-task (DT)

Table 2 Median values (minimum, maximum) of CO in the anteroposterior and mediolateral directions

	OE	CE	DT	*p* value
CO_{ap}	5 (1, 8)	5 (1, 9)	7 (1, 11)	0.24
CO_{ml}	23 (4, 36)*	21 (5, 41)**	25 (8, 43)	< 0.01

CO_{ap} center of pressure oscillation in anteroposterior direction, CO_{ml} center of pressure oscillation in mediolateral direction, *OE* open eyes, *CE* closed eyes, *DT* dual-task

*$p < 0.01$ between DT and EO; **$p < 0.01$ between DT and EC

Discussion

Higher oscillation of CoP in mediolateral direction during standing position with cognitive load was the most important finding of this study. Standing is considered an automatic-task to maintain postural control, with few degrees of attention and cognitive involvement [21, 22]. However, even an automatic-task when performed simultaneously with cognitive task can be impaired and result in loss on balance and control. Studies describe the age-related peripheral and central changes results in the decrease of neuromotor ability required to maintain postural balance while standing up or walking [5, 6]. In this sense, older adults require more attention to control posture, which explains their impairment of postural balance in DT [4, 9, 10, 12, 22]. In alignments with this reasoning, our results indicate that WBB is able to detect cognitive interference on postural control in older women.

Apparently, the variables (area and total displacement) do not allow quantification of CoP variability over time when compared to CO maps obtained by CoP displacement in the anteroposterior direction versus in the mediolateral direction. CO allowed to identify the location (right and left) and directions (anteroposterior and mediolateral) evidencing a strategy to maintain balance and poor stability and postural control during DT. CO occurred throughout the WBB surface area exceeding the limits of stability (determined according feet positioning and area of stability) [2]. Therefore, our findings show a higher oscillation of older women happens even in an everyday dual-task, since the aim of the cognitive task is to withdraw attention from the postural task.

Dual-tasks require executive function, attention, motor planning and processing of environmental stimuli, suggesting prefrontal cortex activation in response to the complexity task [7, 19, 22]. Older women in this study had difficulty allocating adequate attention to dual-task to maintain balance, although it has been hypothesized that balance is prioritized at the expense of cognitive performance [7, 8]. It is important to note the nature of stimulus, which must be considered because the complexity of cognitive or motor tasks may influence neural competition. Mujdeci et al. [3] presented different strategies to control posture during dual-task according to cognitive or motor demand. Higher neural mechanisms are prioritized for the cognitive task when the complexity of motor activity is simple. On the other hand, when the vestibular system is challenged, cognitive attention is suppressed while postural control is prioritized. In the present study, the participants reduced postural balance during dual-task, although it was one of the less complex tasks while performing another easy task (subtraction of seven from 100).

Several studies have concluded that age-related impairment of balance, especially in the mediolateral (ML) direction, plays an important role in coping with the physical challenges of daily living which may lead to falls and hip fractures [1, 5, 10, 12]. WBB provides data that allow us to calculate the dual-task cost. Based on this finding it is possible to not only assess cognitive interference on motor control but also manage the rehabilitation.

Interestingly, the effect of dual-task on postural control was in line with changes in the limits of stability that may cause falls. The findings of dual-task interference can be explained due to an age-related reduction in executive function and physical capability with implications for standing up along with cognitive demand, compromising the postural adjustment [19, 21]. According to our dual-task interference calculation, the cost of DT was 30.5%, which may represent the deviation of attention during the competing neural pathways. The high mediolateral CO may have occurred with an adaptation of participants regarding a greater difficulty in dual-task with cognitive demands, which are cognitive functions modulated by the prefrontal, temporal and parietal cortex [23, 24]. Interestingly, these brain regions play a crucial role in motor control and body orientation in a space. Therefore, we suppose that these brain areas require 30.5% of selective attention during postural DT, considering the negative correlation found between spatial and temporal orientation with the mediolateral CO.

Our data suggests that the results obtained with the application of the Wii Balance Board (Nintendo) are reliable an in line with the current understand in DT function, and that given its easy-of-use, portability cost and accessibility, could be a valuable tool in clinical practice [10, 11], thus enables the evaluation and training balance with a focus on dual-tasks.

Our study results have important clinical application, once the two major geriatric problems, cognitive and gait were addressed [25]. The Wii Balance Board may be applying in hospitals and geriatric clinics, trying to detect impairment of gait variables and cognition. A better understanding of the DT function and gait impairments may help health professionals to develop interventions to prevent falls and dementia, promoting a disability-free life expectancy.

One limitation of our study is the cross-sectional design which does not allow us to draw conclusions about causality. In addition, a synchronized data collection (e. g. electromyography and/or electroencephalography) could improve the interpretation of results and confirm or refuse some dual-task neural pathways. We encourage future studies to address these tools and try to investigate these mechanisms. Finally, the participants of this study showed different levels of education, which may decrease the power of our results.

Conclusions

The present study showed that cognitive load during dual-task impairs postural control more than visual deprivation of older women in standing up. The increase of CoP oscillation in mediolateral direction was observed beyond the limits of stability area.

Funding Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (Capes), Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), Fundação de Amparo à Pesquisa do Estado do Rio de Janeiro (FAPERJ) e do Estado de Minas Gerais (FAPEMG) supported this work.

Compliance with ethical standards

Conflict of interest Authors certify have no conflict of interest with any financial organization regarding the material discussed in the manuscript.

Ethical approval The study was approved by University's local ethics committee (no 1.365.041/2015). All procedures performed in studies involving human participants were in accordance with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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