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RESEARCH ARTICLE

Does selective attention demand affect the physiological complexity of postural control in faller community-dwelling older adults?

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Abstract

Background: The physiological complexity of postural control during selective attention demand can be used as an innovative method to identify faller community-dwelling older. **Objective:** To analyze the effect of selective attention on the complexity of postural control in faller community-dwelling older adults. **Methods:** A total of 57 older adults (60 to 80 years) were divided between the faller group (Fallers n = 21) and the non-faller group (Non-fallers n = 36). An inertial sensor (Physilog® 5, GaitUp, Switzerland) was positioned over the second sacral vertebra to collect the participant's body sway in the anteroposterior (AP) and mediolateral (ML) directions during the monochromatic and color Stroop test versions. The postural control's complexity was calculated using MATLAB codes, employing the refined composite multiscale fuzzy entropy method. Statistical Package for Social Sciences was used to analyze the effects of interaction, group, and condition effects using linear mixed models with an alpha of 5%. **Results:** No significant interaction effects were observed in the AP ($F = 0.18$; $p = 0.66$) and ML ($F = 0.00$; $p = 0.99$) directions. No group effect was observed in the AP ($F = 1.23$; $p = 0.26$) and ML ($F = 1.76$; $p = 0.18$) directions. No condition effect was found in the AP ($F = 0.06$; $p = 0.80$) and ML ($F = 3.54$; $p = 0.06$) directions. **Conclusion:** Once-only faller community-dwelling older adults did not evidence worse physiological complexity than the non-fallers during selective attention demand in the upright standing posture.

Keywords: Older adults; dual task; selective attention; Stroop test; entropy; physiological complexity.

BACKGROUND

Postural control is one of the main aspects addressed in fall prevention programs for older adults[1]. The ability to maintain the position, orientation, and balance of the body in preserving position[2] is commonly investigated in this population, especially in older adults who have fallen at least one time in the last six[3] or 12 months[4,5]. However, some evidence suggests that once-only fallers older adults have functional characteristics such as balance, vision, proprioception, muscle strength, reaction time, gait variability, and somatosensory system, more like non-fallers than those who have fallen two or more falls in a previous 12-month period[4-6]. Changes in the base of support (bipedal, unipedal, and tandem) and visual stimulus deprivation (eyes closed) are commonly used in protocols for assessing postural control[7]. Also, cognitive tasks are used to test an individual's ability to perform dual-task activities while maintaining postural control[8-10]. The Stroop test is one of the most used to assess the individual's selective attention, i.e., the ability to inhibit the interference of a concurrent cognitive task with another primary cognitive demand while sitting posture[11].

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Differently, older adults were asked to step back and remain upright, standing on the force platform while performing the Stroop. The older participants showed a greater trajectory and total oscillation area of the center of pressure than younger individuals after this dual task[8]. Similarly, the dynamic of the center of pressure is commonly acquired by employing force platforms[12], and traditional methods are used to summarize the data only from the perspective of linear analysis or even considering only a time scale at a time[13]. Although these types of analyses help understand the postural control of older people, especially those with self-reported falls, they cannot evidence the physiological complexity of the postural control system during the quiet upright standing posture[14]. Physiological complexity, on the other hand, evidences the degree of irregularity of a time series over multiple time scales, showing that the more irregular the time series, the greater the entropic behavior of the measured physiological data[14,15]. The refined composite multiscale fuzzy entropy is a nonlinear analysis method capable of characterizing the complexity of multivariate physiological signals over multiple time scales[16].

Considering the physiological complexity of postural control as an innovative method to assess selective attention, this study analyzed whether this type of cognitive attentional demand affects the complexity of postural control in faller community-dwelling older adults. The premises of this study were that: (i) faller older adults would present worse physiological complexity of postural control during both Stroop test conditions when compared to non-faller older adults; (ii) participants from both groups (fallers and non-fallers) would present a reduction (worsening) of postural control's complexity during the performance of the colored version of the Stroop test (selective attention) compared to the monochromatic version.

METHODS

Study Design

This quasi-experimental cross-sectional study was developed following the recommendations of the World Health Organization, the declaration of the World Medical Association of Helsinki, and approved by the Research Ethics Committee of the University of Pernambuco (CAAE number: 71192017.0.0000.5207; protocol number: 2.415.658). The sample came from a more extensive project named "EQUIDOSO - Study on Falls in Older Adults", previously conducted by our research group.

Participants

A total of 57 community-dwelling older adults aged between 60 and 80 years participated in this study. The demographic and anthropometric characteristics of the sample are shown in Table 1. The group of faller older adults was composed of 21 participants who reported having suffered at most one fall in the last 12 months. The group of non-fallers older adults was composed of 36 participants with a self-report of no falls in the same period. This study defined a fall as "an unexpected event in which the individual ended up on the ground or at a lower level"[17]. For this, participants were asked whether, in the last 12 months, they had experienced any falls, for example, because of a slip, trip, misstep, or unexpected loss of balance that brought them to the floor or a lower level than before the fall.

Table 1. Demographic, anthropometric, cognitive function and postural control complexity index of faller and non-faller older adults

Variables	Fallers $n = 21$	Non-fallers $n = 36$	*Between-group* p-value
Demographic measures	**Absolute frequency (relative frequency)**		
Female (n; %)	18 (36.7 %)	31 (63.6 %)	--
Male (n; %)	3 (37.5 %)	5 (62.5 %)	--
	Mean (standard deviation)		
Age (years)	66 (5)	67 (4)	0.230*
Anthropometric measures			
Body mass (kg)	69.95 (10.22)	69.49 (14.41)	0.898*
Height (m)	1.53 (0.06)	1.56 (0.07)	0.129*
Body mass index (kg/m²)	29.62 (4.04)	28.19 (5.03)	0.275*
Selective attention (cognitive function)	**Estimated marginal average (CI 95%)**		
Monochromatic Stroop test in sitting	39.71 (35.20 – 44.22)	34.87 (31.42 – 38.31)	0.093§
Color Stroop Test in sitting	81.42 (67.35 – 95.47)	88.95 (78.21 – 99.69)	0.397§
Within-group p-value	< 0.001§	< 0.001§	
Monochromatic Stroop test in an upright standing posture	44.96 (37.63 – 52.30)	35.14 (29.54 – 40.75)	0.037§
Color Stroop Test in an upright standing posture	72.77 (61.91 – 83.63)	80.65 (72.35 – 88.94)	0.253§
Within-group p-value	< 0.001§	< 0.001§	
Complexity index	**Estimated marginal mean (CI 95%)**		
Anteriorposterior direction			
Monochromatic Stroop test in an upright standing posture	2.91 (2.73 – 3.08)	2.85 (2.72 – 2.99)	0.635§
Color Stroop Test in an upright standing posture	2.96 (2.79 – 3.13)	2.84 (2.71 – 2.97)	0.277§
Within-group p-value	0.668§	0.879§	
Mediolateral direction			
Monochromatic Stroop test in an upright standing posture	3.05 (2.82 – 3.28)	2.94 (2.76 – 3.11)	0.421§
Color Stroop Test in an upright standing posture	2.89 (2.72 – 3.05)	2.77 (2.64 – 2.90)	0.254§
Within-group p-value	0.241§	0.123§	

Note: BW: Black and white; *Mann-Uhitney U test; §Generalized Linear Mixed Models with Bonferroni post hoc.

Data acquisition

The Stroop test is a neuropsychological test used to assess the ability to inhibit cognitive interference that occurs when the processing of a specific stimulus concurrently with the processing of another cognitive stimulus. In the most usual version of the test, in a seated position, individuals are asked to read three different tables as quickly as possible, with names and colors; a card is printed with words in black and white (monochromatic); the second with colored spots; and the third condition is called "color-word", i.e., the words are printed on the card with different colors to the printed text[11]. In our study, we used the version with only two cards: monochromatic (black and white) and words printed in colors different from the color names. Two A4 size cards (210 x 297 mm; wide x high) with a non-reflective white background were used to perform the test.

On one of the cards, the names of different colors were printed in black; this version was called the monochromatic Stroop test (MST). On the other card were printed the names of colors that did not match their actual colors; this version was called the color Stroop test (CST). The order of execution of the test versions was performed randomly. The participant was asked to read, as quickly as possible, all the names of the colors presented on the card in all versions of the test. The participant was asked to read, as quickly as possible, the name of the color printed in black (MST) or the name of the colors with which the name was printed on the card and not the colors that were printed (CST).

During the conventional version, the participant was seated in a chair with a backrest and, on a table directly in front of them, each test card was randomly presented. During the standing version, the participant should remain in a quiet upright posture, with arms along the body, feet separated according to the width of their shoulders, and facing forward, parallel to the floor. Each card was held by the evaluator at a distance of 1 meter and the participant's eye level so that they could be read according to each test condition, i.e., MST or CST. In both versions of the test (sitting and standing), the instructor timed the time each participant took to read all the color names printed on each of the two cards[11].

An inertial sensor (Physilog® 5, Gait Up, Lausanne, Switzerland) was fixed on the spinous process of the participant's second sacral vertebra with a double-sided tape (3M) and a hypoallergenic neoprene band for the acquisition of triaxial acceleration data of the center of body mass of the participant during the execution of the two conditions of the Stroop test in the upright posture. The sensor is an inertial measurement unit (IMU) (dimensions: 50 mm × 40 mm × 16 mm; weight: 36 g) formed by a triaxial accelerometer (MMA7341LT, range ± 3 g, Freescale, Austin, TX, USA), a triaxial gyroscope (ADXRS, range ±600 °/s, Analog Devices, Norwood, MA, USA), a battery (3.7 V, 595 mAh), a micro-SD card and a microcontroller. All acceleration data were recorded on this micro-SD card inside the UMI and later transferred to a computer for mathematical analysis.

Mathematical data analysis

The inertial sensor's raw three-dimensional linear acceleration data were processed through custom code in MATLAB, version 2016a (Mathworks, Natick, MA). Linear acceleration data was filtered using a 2nd-order Butterworth low-pass recursive digital filter with a cut-off frequency of 15 Hz[18]. The action of gravitational acceleration, defined as 9.81 m/s^2, was subtracted from the raw data to obtain the acceleration acquired by the inertial sensor in the X, Y, and Z axes. The linear velocity signal was then processed using a 1st-order digital recursive Butterworth filter with a cut-off frequency of 0.2 Hz for the anteroposterior (AP) and mediolateral (ML) components and a cut-off frequency of 0.5 Hz for the vertical (V) (first integration). Finally, the linear velocity was integrated to obtain the position (displacement) filtered with the high-pass filter[18-20]. The physiological complexity from the AP, ML, and V axes was calculated by the refined composite multiscale fuzzy entropy method (RCMFEμ)[21]. Then, the complexity index (CI) was computed[22]. The CI(15) plots the RCMFEμ entropy of each coarse-grained time series as a function of time scale and then calculates the area under the RCMFEμ curve. The higher the CI, the greater the multiscale irregularity of the signal[14].

Statistical analysis

Statistical analyzes were performed using the Statistical Package for the Social Science software (SPSS, IBM; v.22.0), adopting a significance level of 5%. We used t-tests to compare age, mass, height, and body mass index (BMI). Generalized Linear Mixed Models (GLMM) were used to test the effects of interaction (group vs. condition), group (faller and non-faller) and condition (MST and CST) for the Stroop test run time in sitting (conventional test) and in bipedal standing still posture, in the MST and CST conditions, as well as the complexity index of the body mass sway during the execution of both conditions of the Stroop test in the bipedal posture. Q-Q graphs were plotted to verify each model's adequacy (normality). Adjustments for univariate (main effects) and multivariate (interaction effect) comparisons of the estimated marginal means (MME) were made using the Bonferroni test. Comparisons between MME pairs were made based on the study's original scale of each dependent variable. The mean difference (MD) was adopted to measure effect size within and between factors.

RESULTS

No significant difference in demographic, anthropometric, and cognitive function characteristics between faller and non-faller participants was observed, as shown in Table 1. Participants in both groups performed worse in executive function (increased execution time) in the CST compared to the MST, both in the seated and upright positions. No significant interaction effect was observed for the complexity index of body mass center sway in the AP ($F = 0.189$; $p = 0.664$) and ML ($F = 0.000$; $p = 0.994$) direction. No significant group effects were observed for the complexity index of body mass center sway in the AP ($F = 1.237$; $p = 0.268$) and ML ($F = 1.766$; $p = 0.187$) direction. No condition effect for the complexity index of the center of mass sway in the AP ($F = 0.062$; $p = 0.804$) and ML ($F = 3.542$; $p = 0.063$) direction was evidenced in this study, as shown in Table 1.

DISCUSSION

This study analyzed whether selective attention affects postural control's complexity in once-only faller community-dwelling older adults. The first premise of this study was refuted since no significant difference in the physiological complexity of postural control during the bipedal upright standing posture in both Stroop test conditions (MST and CST) was observed between the two groups. No significant difference was observed between the groups in demographic, anthropometric, and cognitive function characteristics assessed by the Mini-Mental State Examination (MMSE) and the conventional Stroop test itself. Thus, the results regarding the maintenance of postural control during the demand for selective attention in both groups show that only one episode of fall suffered in 12 months, immediately before this study was carried out, was not enough to differentiate the physiology complexity involved in the maintenance of postural control of community-dwelling older adults classified as fallers compared to those without a history of falls.

In the literature, a faller is commonly defined as someone who has fallen at least once in a specified period, usually in the last six[3] or 12 months[4,5]. On the other hand, a recurrent faller has suffered two or more falls in the same period[3-6]. However, some evidence suggests that people who fell only once had functional characteristics such as stability, vision, proprioception, muscle strength, reaction time, gait variability, and somatosensory system, more similar to non-fallers than those who had two or more falls in a previous 12-month period[4-6.] Thus, it is believed that the fact that labeled faller participants experienced only one fall episode in the last year before the assessment may not have been sufficient to compromise the physiological complexity of postural control, especially under a cognitive demand for selective attention, such as assessed by the Stroop test in an upright bipedal position.

When considering the results of the conventional Stroop test (sitting), no significant difference between the groups was observed, both for the MST and CST. This result demonstrates that, although the groups were classified based on the self-report of only one fall in the last 12 months from the point of view of postural control and, specifically, cognitive performance, the participants of these groups were not physically and cognitively different from each other. On the other hand, a 48-month cohort study showed that older adults with a worse (lesser) physiological complexity of the anteroposterior excursion of the center of pressure under both single and dual tasks exhibited a higher rate of future falls. Additionally, the authors showed that participants in the lowest quintile of physiological complexity of the anteroposterior center of pressure sway during dual-task experienced 48% more falls during the four years of follow-up than those in the highest quintile. On the other hand, traditional postural sway metrics, as well as the performance of participants in the Short Physical Performance Battery (SPPB) were not associated with future falls. Compared to traditional metrics, the degree of multiscale complexity in the standing postural sway data, particularly during dual-task conditions, predicts better future falls in older adults. The divergence between the study mentioned above and our study can be explained by the fact that we evaluated a sample with a mean age of about 66 years, compared to the study by Zhou et al.[23], in which the participants had a mean age of 78 years.

The participants' functionality level in both groups can also explain our results. In our study, we evaluated a sample of community-dwelling older adults who had a usual gait speed equal to or greater than 1 m/s, a score ⩾ 52 points on the Berg balance scale, and good cognitive ability, demonstrated by 24 points or more obtained by the MMSE. Conversely, the study by Manor et al. (1985), showed that the physiological complexity of postural sway in pre-frail and frail older adults during bipedal quiet upright posture was lower in non-frail older adults[14]. This shows that the level of previously compromised physical and cognitive function may be one factor contributing to the reduction of physiological complexity throughout aging.

On the other hand, the second premise of this study was refuted as the participants of both groups (faller and non-faller) did not present a significant reduction (worsening) of the physiological complexity of postural control during the performance of the CST compared to the TSM. This result shows that, from the point of view of selective attention, the performance of the colored version of the Stroop test did not negatively influence the physiological complexity of postural control during the quiet upright standing bipedal posture. This result can be contextualized by the study's findings by Tsang et al. (2016), in which the association between postural control and cognitive performance was investigated in elderly individuals submitted to single and dual tasks, compared to young adults. Participants underwent the Stroop test while being evaluated using a force platform. The authors observed that the older adult group had significantly shorter reaction times, longer durations and higher error rates, and larger total oscillation areas with and without a concurrent cognitive task and that both groups had longer reaction times on the monotask, but only older adults had a significantly higher error rate. These results suggest that older adults tend to prioritize postural control over cognition when performing a dual task[8].

Another study, using a nonlinear analysis method (sample entropy) and a force platform, found that older people had a lower physiological complexity level than young people during cognitive tasks such as carrying out math equations and numerical sequences[24]. Therefore, we can infer that older adults, compared to young individuals, present significant differences in postural sway and reduction of physiological complexity in dual-task activities associated with cognitive activities regardless of the form of analysis (linear or nonlinear). In our study, the comparison of older adults (faller and non-faller) showed no significant difference between the groups since both comprised only older participants with similar physical and cognitive characteristics. Thus, it is seen that there is no decrease in physiological complexity in the colored version of the Stroop test. It is also worth noting that, when considering the results of the conventional version (sitting) of the Stroop test, no significant difference was observed for both the MST and CST.

The literature has shown that older adults have more difficulty in performing dual-task activities, as demonstrated by gait variability, such as time and rhythm, and in performing activities that require more attention, such as walking[6] or standing while performing other activities, such as talking, reasoning, reading[25,26] or even perform mathematical calculations and maintain postural balance demonstrated through measurements of postural sway[25]. Although the executive function of participants in both groups was worse in the CST (the increased execution time of this version of the test), no significant difference was observed in the postural control complexity index between the CST and MST conditions for both directions of postural sway (AP and ML). It is worth noting that we observed only a weak correlation between the TSM execution time and the complexity index in the AP ($r = 0.40$; $p = 0.002$) and ML ($r = 0.46$; $p < 0.001$) direction. There was no significant correlation between the complexity index and the CST. This result demonstrates that the Stroop test execution time and the complexity index quantify distinct and weakly correlated constructs. This result may explain a significant difference only between the execution time of both conventional versions of the Stroop test and not between the postural control complexity during the execution of both Stroop test versions. We infer, therefore, that this type of executive demand was not enough to differentiate the effects of the two conditions of the Stroop test on the quasi-static bipedal postural control. The results of this study are limited to older adults who self-reported only one episode of falls in the last 12 months, so we do not know what the physiological complexity of postural control in older adults who self-reported two or more falls would be. Furthermore, participants in this study lived independently in the community and did not have cognitive performance impairment. These limitations raise insights for future studies with older adults with cognitive impairment and some level of physical impairment to carry out their activities of daily living.

CONCLUSION

Selective attention demand does not affect the complexity of upright standing bipedal postural control in once-only faller community-dwelling older adults. Both faller and non-faller older adults showed no decrease in postural control physiological complexity while performing the color Stroop test compared to the monochromatic version.

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