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Effect of Cervical Kinesthetic Motor Imagery on Postural Control of Healthy Young Adults with Fear of Falling

Nélio Silva de Souza [1,*], Ana Carolina G. Martins [1], Caroline L. Ferreira [1], Yasmin S. Motizuki [1], Christiano B. Machado [1,2], Marco Orsini [3], Marco Antônio A. Leite [4] and Victor Hugo Bastos [5]

1 School of Physiotherapy, Serra dos Órgãos University Center (UNIFESO), Teresópolis, 25964-330 Rio de Janeiro, Brazil; acgfisio@gmail.com (A.C.G.M.); krolzinha.leal@hotmail.com (C.L.F.); yatizuki@gmail.com (Y.S.M.); cbmfisio@gmail.com (C.B.M.)
2 School of Estácio de Sá, Teresópolis, 25976-110 Rio de Janeiro, Brazil
3 Department of Rehabilitation Sciences, University Center Augusto Motta (UNISUAM), 21041-020 Rio de Janeiro, Brazil; orsinimarco@hotmail.com
4 Department of Neurology and Neuroscience, Federal Fluminense University/University Antônio Pedro Hospital (UFF/HUAP), Niterói, 24033-900 Rio de Janeiro, Brazil; marcoantonio.araujoleite@gmail.com
5 Department of Biomedical Sciences and Brain Mapping and Funcionality, Federal University of Piauí (UFPI), Parnaíba, 64202-020 Piauí, Brazil; bastosvh@gmail.com
* Correspondence: neliosds@gmail.com; Tel.: +55-0-15-21-99504-1558

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Abstract: Motor imagery (MI) is the act of coding the mental aspect of an intended task without executing it. Fear consists of an anxiogenic response to a previous event, which provides a state of alertness to the individual in the face of a threat. These two conditions (imagery and fear) may modulate orthostatic postural control, but their combined effect is still unknown. To investigate whether cervical kinesthetic motor imagery induces modulations in postural control and in the fear of falling (FoF) sensation in healthy young adults. Participants (n = 20) were placed on the Wii Balance Board® and oriented to perform and imagine three tasks for 60 s: (1) closed eyes; (2) cervical flexion; and (3) cervical inclination. The number of performed and imagined repetitions were recorded, and participants responded to a question at the end of each task regarding the FoF. There were four relevant effects: (1) there was no difference between the number of performed and imagined repetitions ($p > 0.05$) indicating similarities; (2) there was a greater sensation of FoF induced by kinesthetic MI tasks ($p < 0.001$); (3) there was a greater modulation of the center of pressure (mean velocity and amplitude) in the anteroposterior direction in phobic subjects ($p < 0.05$); and (4) there was no modulation between the non-phobic subjects in the anteroposterior direction ($p > 0.05$). The FoF during kinesthetic MI tasks may influence the orthostatic postural control, favoring the reduction in postural stability.

Keywords: motor imagery; fear of falling; postural control

1. Introduction

The imagination and the sensation of a movement are strictly related phenomena and have a voluntary control profile [1]. Motor imagery (MI) is defined as the act of mentally reproducing an action without executing it [2,3]. Basically, MI presents kinesthetic and visual strategies. The first simulation is based on sensory-motor information (proprioceptive) and the second is based on the sensory (visual) perception of the imagined movement [4]. Although there is a common neural substrate between these two strategies [2,5], distinct neural circuits are accessed in each one of them by imagining the same task [3,6]. Studies have shown that kinesthetic MI presents a greater modulation in orthostatic postural control compared to visual MI [7–9], and this effect has been related to the level of vividness of the imagined movement [10].

Another condition that also modulates the orthostatic postural control is the fear of falling (FoF), which represents a psychomotional (anxiogenic) response to a previous event, as in threatening (participant raised to different heights) [11–15] or functional (unipodal and bipodal supports) [16,17] situations. These inductions of FoF can immediately modulate the reflex activity of the neuromuscular spindle [18] influencing the anticipatory postural control in orthostatic position [19,20] due to activation of "neural networks" that process fear and anxiety (mainly lobules of the insula and amygdala) [21].

Evidence shows that both MI and FoF are able to modulate orthostatic postural control. Recently, we performed systematic reviews about the relation between postural control and FoF [22], and between postural control and MI [23]. It was observed that the group effects of MI and FoF on the orthostatic postural control are still unknown. Thus, the objective of the present study is to investigate whether cervical kinesthetic MI modifies postural control and/or FoF in healthy young adults.

2. Materials and Methods

A cross-sectional study was carried out with 20 healthy subjects (10 women and 10 men), all of them undergraduate students in Physiotherapy at Serra dos Órgãos University Center (UNIFESO). All volunteers signed a free and informed consent form for the research study, which was approved by the local ethics committee (CAAE: 54519816.1.0000.5247, 29 February, 2017). Exclusion criteria were: history of orthopedic diseases; visuomotor and/or neurological disease that compromised postural control; osteomioarticular impairments in the last month; restriction of active range of motion due to pain; weakness; vertigo; performance of physical activity; and, finally, the use of psychoactive substances and/or alcohol in a period less than 24 h before data collection.

2.1. Kinesthetic and Visual Imagery Questionnaire (KVIQ-10)

The ability of volunteers to perform MI was assessed from a 10-items version of the Kinesthetic and Visual Imagery Questionnaire (KVIQ-10). The questionnaire includes a scale containing five movements for each imagery strategy (visual and kinesthetic). This instrument measures subjectively the clarity (for the visual modality) and the intensity of the sensation (for the kinesthetic modality) in two ordinal scales of five points [24].

2.2. Wii Balance Board (WBB)®

The Wii Balance Board (WBB) was used as a posturography technique to study postural behavior as an indicator of stability [25], as well as a predictor of the risk of falling in elderly [26]. Comparative studies between the force platforms (stabilometry) and the WBB found no statistical difference between the measurements of center of pressure (CoP) coordinates [25,27,28], or in its accuracy [29]; as such, the WBB is considered a valid, reliable, and inexpensive instrument for research [25,30]. The WBB has four pressure transducers (piezoelectric balancing sensors), monitoring the forces in vertical (Z-axis) and horizontal—in the anteroposterior (AP, Y-axis) and mediolateral (ML, X-axis)—directions [29].

A WBB (Wii Balance Board™, Nintendo Co., Inc., Kyoto, Japan, serial number BC431808347, measuring 32 cm × 52 cm × 5.5 cm) with four balance sensors and four load cells supporting a maximum of 150 kg (330 lbs) was used for the measurement of CoP coordinates. The device was powered by four rechargeable batteries (size AA, 1.2 V and 2700 mAh) that allowed 60 h of use. The communication of the WBB with a notebook was made via Bluetooth, allowing a transmission of 60 signals from the CoP per second [31].

For the acquisition of this posturographic signal, a customized program (BrainBlox, available at: http://www.colorado.edu) and the analysis of the CoP signal (amplitude and velocity) in each horizontal direction (AP and ML) was performed in Matlab R2015a (MathWorks Inc., Natick, MA, USA). Basically, body balance occurs when the sum (Σ) of all forces (F) and moments of force (M) is equal to zero (Σ F = 0 and M = 0). In order to calculate the mean velocity (MV) of the CoP in the two directions (AP and ML), the following formula was used: MV= L/($n \times \Delta t$), where L is the total length of CoP (path length); N is the number of frames and Δt is the time interval. To calculate the amplitude (or standard deviation, SD) of CoP excursion, the following formula was used, where: X_{ap} and X_{ml} represent the CoP position in the AP and ML directions; $\overline{X}_{ap}$ and $\overline{X}_{ml}$ represent the adjustment of the zero mean of the center position in the AP and ML directions; and N = total points traveled in the oscillation length [32].

$$\begin{aligned} \mathrm{SD_{ML}} &= \left[\frac{\sum_{n=1}^{N}\left(x_{\mathrm{ML}(n)} - \overline{x}_{\mathrm{ML}}\right)^2}{N-1}\right]^{1/2} \\ \mathrm{SD_{AP}} &= \left[\frac{\sum_{n=1}^{N}\left(x_{\mathrm{AP}(n)} - \overline{x}_{\mathrm{AP}}\right)^2}{N-1}\right]^{1/2} \end{aligned} \quad (1)$$

2.3. Digital Goniometry

A digital goniometer iGAGING® (10 Digital Protractor/Goniometer-Enjoy Accuracy®, San Clemente, CA, USA, serial number 204781) was used in order to measure cervical range of motion (ROM). For the measurement of cervical flexion ROM, the goniometer axis was positioned at the level of the seventh cervical vertebra (spinous process) with the fixed arm parallel to the ground and the movable arm aligned to the ear at the end of the motion. For the measurement of cervical ROM in the right lateral inclination movement, the goniometer axis was positioned on the spinous process of C7, the fixed arm was placed perpendicular to the ground, and the movable arm was in the midline of the cervical spine [33]. In all measurements, the goniometer was positioned first in the mentioned anatomical points and then it was zeroed (calibration of the device). After its calibration, the ROM was measured three times for each movement.

2.4. Experimental Protocol

Volunteers were positioned on the WBB, barefoot, with the feet joined in the midline and the arms along the body. They were instructed not to move the arms or head during imaging tasks, and were observed by two examiners (one beside and another behind). Whenever movement was observed during the MI, the test was stopped. During MI, the participant was instructed to keep the plane of the face aligned without moving the chin or forehead. Initially, the participant remained for 60 s in two conditions: (1) standing with eyes opened (adaptation task) and (2) standing with eyes closed (control task). Then, the volunteer performed two blocks of tasks (the execution and the kinesthetic MI) of the following movements: (1) cervical flexion (instruction for the execution: “flex the cervical spine and return to the starting position, repeatedly”; instruction for the imaging: “imagine flexing the cervical spine and returning to the initial position, repeatedly. You must feel yourself accomplishing the movement”); (2) lateral inclination to the right (instruction for execution: “tilt the head to the right side by approaching the ear to your shoulder, repeatedly”; instruction for the imagery: “imagine yourself tilting your head to the right side by approaching the ear to the shoulder, repeatedly. You must feel yourself accomplishing the movement”). The executions of these tasks were performed with the eyes opened, and the kinesthetic MI with the eyes closed, during 60 s. A simple randomization of the tasks between the volunteers was carried out, keeping the same order for the execution and imaging blocks. During the task blocks, signals concerning the oscillations of the pressure center were acquired.

Each task (cervical flexion and inclination) was demonstrated by the experimenter, allowing the volunteer to execute it until he felt comfortable to perform it under the experimental conditions, that is, on the WBB. No instructions were given on the frequency and speed of the executed or imagined movements. In the execution block, the experimenter counted the number of repetitions, and during the imaging block, the participant was instructed to mentally count the number of repetitions in each task [7,10]. At the end of each task in both blocks (execution and imagination) a question was asked about the FoF: "from zero to 100, how much did you feel afraid of falling?" with zero corresponding to "no fear" and 100 corresponding to "a lot of fear" [34]. After the tasks of kinesthetic MI, the KVIQ-10 vividness scale was applied [24].

2.5. Data Analysis

Initially, the data distribution was verified through the Shapiro–Wilk test. For the comparative analysis of posture graphic parameters between kinesthetic MI conditions (cervical flexion and inclination) and the control condition (eyes closed), a nonparametric analysis of variance (Friedman's ANOVA) was used. The Wilcoxon test was used to compare the number of repetitions performed during the execution and the kinesthetic MI in each task. The Spearman correlation test was used to verify the degree of association between the variables of the CoP (amplitude and mean velocity) in each task. All analyzes were performed using the Statistical Package for the Social Sciences program (SPSS, version 20., Armonk, NY, USA), assuming an alpha significance level of $p \leq 0.05$.

3. Results

3.1. Subjects and Characteristics of the Group

The descriptive data related to the sample variables (n = 20) are described in Table 1. Regarding the history of falls in a year (see Table 1), the participants reported varied causes such as distraction during daily tasks or small accidents, such as stumbling on an obstacle in the street. The values related to the scoring obtained in the FoF scale after the tasks of MI are presented as mean (minimum–maximum), respectively: 20.4 ± 22.13 (0–75) for flexion and 18.2 ± 20. 2 (0–80) for cervical inclination.

Table 1. Descriptive data related to sample (n = 20).

Descriptive Data	Age (years)	BMI (kg/m^2)	Number of Falls in 1 Year	Subjective Scale of FoF (0 to 100)	FoF after MI of Cervical Flexion (0 to 100)	FoF after MI of Cervical Inclination (0 to 100)
Average ± SD	22.65 ± 4.09	25.20 ± 4.10	1 ± 1.48	12 ± 16.6	20.4 ± 22.13	18.2 ± 20.2
Minimum	19	18.81	0	0	0	0
Maximum	36	34.32	5	50	75	80

SD = standard deviation; BMI = Body mass index; FoF = fear of falling; MI = motor imagery.

3.2. Comparisons between Task Execution and Imagination

All participants presented a cervical ROM in flexion movements (mean of 57.3 cm) and inclination (mean of 30.9 cm) within the parameters of normality [33]. The comparison of the number of repetitions during the execution and the kinesthetic MI showed no differences in any of the tasks. The number of performed and imagined movements presented as mean (minimum–maximum) was: 18.5 (12–27) and 17.4 (4–32) for cervical flexion MI ($z = -0.56$; $p = 0.58$); 18.8 (10–27) and 17.7 (3–37) for MI of cervical inclination ($z = -0.85$, $p = 0.40$), respectively. Although dispersion values (minimum and maximum) in the MI tasks show a great dispersion, the central tendency (mean) is similar, without statistical difference. The fact that there is no statistical difference between the execution and imagination of the movements indicates that the participants actually imagined the proposed tasks, since there is a similarity between the execution and the imagination of each task (principle of isochronia). All participants presented high levels of vividness of the imagined movement (KVIQ-10) in the tasks of kinesthetic MI of cervical flexion (KVIQ mean of 3.3) and cervical inclination (mean KVIQ of 3.5). The score on the subjective sensation scale of the FoF presented statistical difference when comparing the execution and kinesthetic MI of the tasks, respectively: 8.1 (0–50) and 20.3 (0–75) for cervical flexion ($z = 3.52$, $p < 0.001$, Figure 1A); 9.25 (0–40) and 18.2 (0–80) for cervical inclination ($z = -1.99$, $p < 0.001$, Figure 1B).

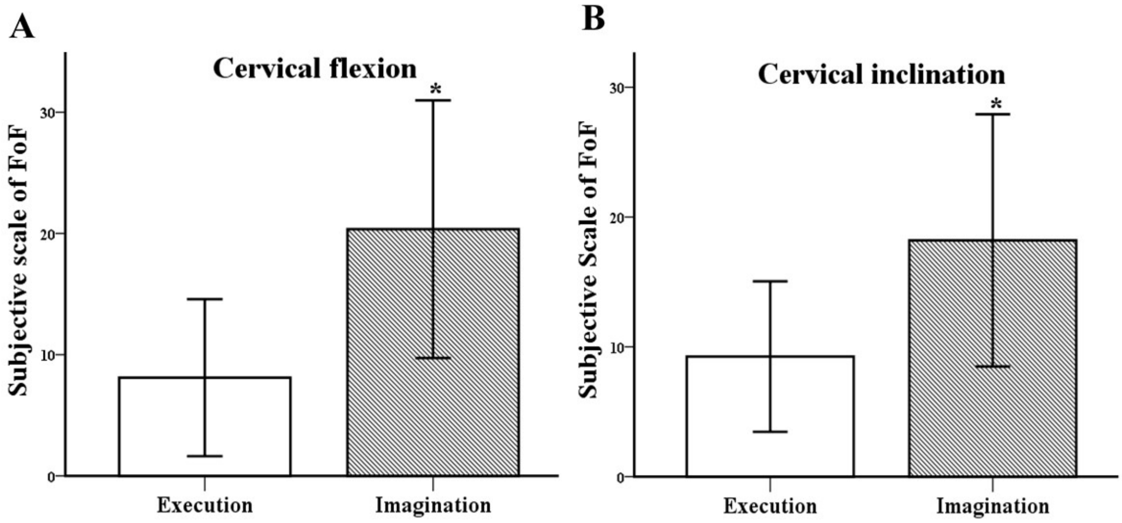

Figure 1. Fear of falling (FoF) scale comparing the execution and the imagination of the cervical movements of flexion (**A**) and inclination (**B**) (* $p < 0.001$).

3.3. Influence of Motor Imagery (MI) on Postural Control of Phobic and Non-Phobic Subjects

All measurements (mean ± standard error) of the posturographic parameters are presented in Figures 2 and 3. Participants were divided into phobic and non-phobic, according to their rating on the fear of falls scale (0 to 100) after MI tasks. Non-phobic subjects obtained scores between 0 and 10, whereas phobic subjects presented scores greater than 11. The phobic subjects ($n = 16$) presented higher amplitude (Friedman $\chi^2 = 10.77$, $p = 0.005$, Figure 2A) and mean velocity (Figure 2B, Friedman $\chi^2 = 6.53$, $p < 0.05$) of CoP oscillation in the AP direction in the task of MI of cervical inclination in comparison to the other tasks (control and MI of flexion). A strong relation between the amplitude (standard deviation) and the mean velocity of the CoP in the AP direction was evidenced, specifically in the task of MI of cervical inclination (rho = 0.70; $p = 0.002$). In order to graphically express this correlation force, a linear regression was applied ($R^2 = 0.744$, $p = 0.002$, Figure 3). In the ML axis, no differences were observed between the tasks (Friedman $\chi^2 > 4.00$, $p > 0.05$). The non-phobic subjects ($n = 4$) did not present statistical difference between the control and MI tasks (flexion and inclination), both in the standard deviation ($p > 0.05$; Figure 2C) and in the mean velocity ($p > 0.05$; Figure 2D) of oscillation of the CoP in the AP and ML directions (Friedman $\chi^2 > 4.00$; $p > 0.05$).

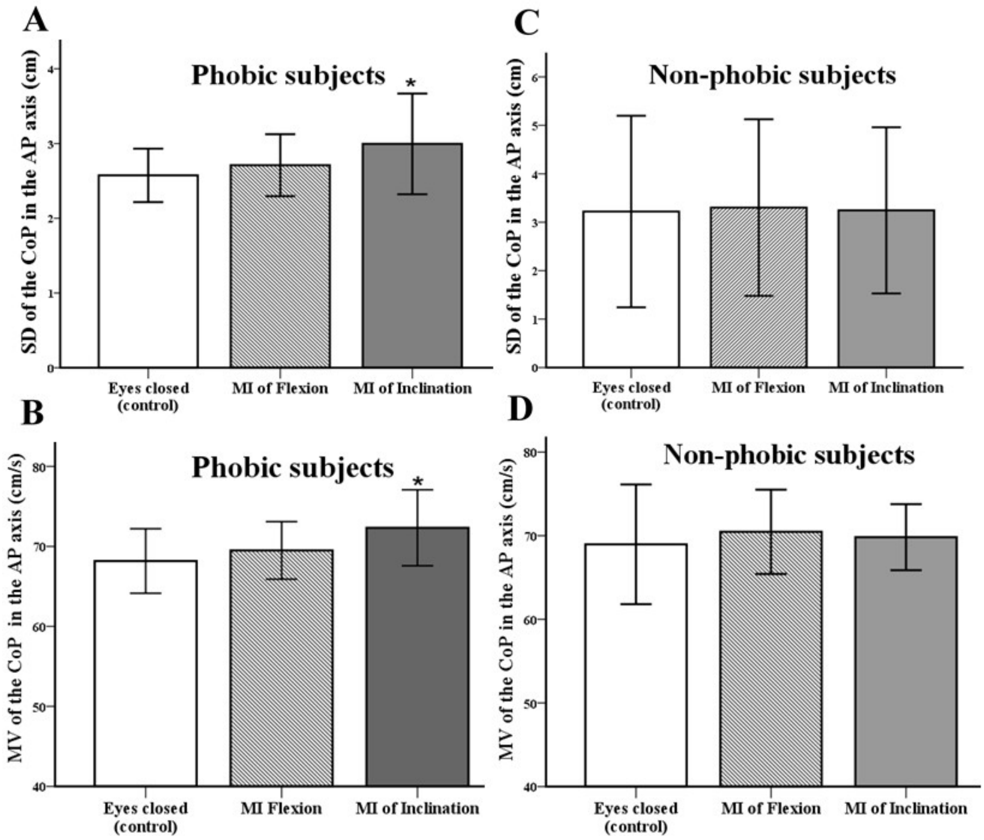

Figure 2. Standard deviation (SD) of the center of pressure (CoP) in the anteroposterior (AP) direction of the phobic (**A**) and non-phobic (**C**) subjects. Mean velocity (MV) of the CoP in the AP direction of the phobic (**B**) and non-phobic (**D**) subjects. The task of MI of cervical inclination showed greater CoP oscillation, both in SD and in MV, compared to the tasks of MI of cervical flexion and control (**A**,**B**; * $p < 0.05$). There was no statistical difference between the non-phobic subjects (**C**,**D**, $p > 0.05$). Note that even though there is no statistical difference, there is a greater modulation of the CoP in the task of MI of cervical flexion in the phobic subjects in comparison to the control task (**A**,**B**).

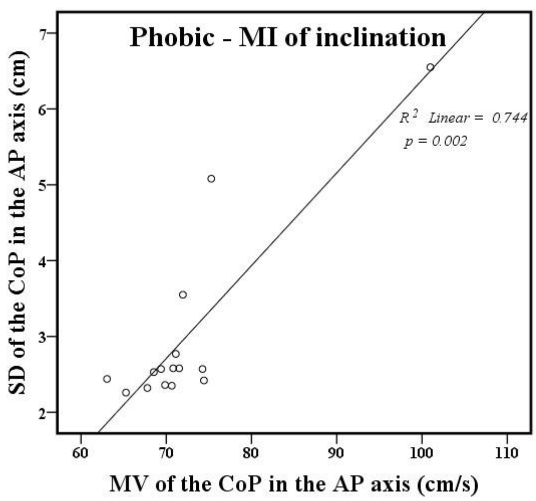

Figure 3. Linear regression graph showing a strong relationship between the amplitude (SD) and the mean velocity (MV) of the center of pressure (CoP) in the anteroposterior (AP) direction in the task of MI of cervical inclination in phobic subjects (rho = 0.70; $p = 0.002$).

3.4. Other Correlations

When comparing the parameters of CoP (SD and MV) in each task (eyes closed, MI of cervical flexion and cervical inclination) between the men ($n = 10$) and women ($n = 10$), no statistical difference was observed in the AP and ML axes (Friedman $\chi^2 > 4.00$, $p > 0.05$), indicating that the observed effects were not related to gender. By separating subjects ($n = 20$) according to the vividness associated with the imagined movement (KVIQ > 3 ($n = 14$) and KVIQ < 2 ($n = 6$)), no statistical difference was observed between CoP variables (Friedman $\chi^2 > 4.00$; $p > 0.05$), indicating that the observed effects were not related to the vividness of the sensation associated with the imagined movement (KVIQ). When comparing the subjective feelings of FoF (0 to 100) and the vividness of the imagined movement (KVIQ), there was no correlation (rho = 1.00, $p > 0.05$), indicating that there are no relationships between fear and vividness of imagined movement. Finally, when comparing the SD of the CoP in each direction (AP and ML) with the respective cervical ROM (flexion and inclination) there was no statistical difference (rho = 1.00; $p > 0.05$), indicating that cervical ROM did not influence the amplitude of the CoP (SD) in each direction (AP and ML).

4. Discussion

The aim of the present study was to investigate whether cervical kinesthetic MI induces modulations in postural control and FoF sensation in healthy young adults. In summary, the results showed four relevant effects: (1) there was no difference between the number of executed and imagined repetitions, indicating that the participants actually imagined the proposed tasks; (2) a greater sense of FoF was induced by kinesthetic MI (Figure 1); (3) there was a greater modulation of the CoP (SD and MV) variables in the AP direction in the phobic subjects (Figures 2A,B and 3); and (4) and there was no difference in the CoP variables between the non-phobic subjects (Figure 2C,D).

Some properties observed during the execution of movement are also present during MI [1,2,35,36], since there are similarities in the mental states between these conditions [37–39]. For example, when an individual performs and imagines walking at a fixed distance, the time spent is similar, with no statistical difference [40]. Similarly, the number of repetitions of the same executed and imagined task in a "fixed time window" also presents no statistical difference [7,9,10]. Although the sample ($n = 20$) also has shown similarity between the execution and imagination of the tasks (cervical flexion and inclination) when comparing the number of repetitions (principle of isochronia), this same similarity was not observed when comparing the sensation of FoF between execution and imagination, indicating that the MI induces a greater modulation in the sensation of FoF in relation to the execution of the same tasks (see Figure 1).

Recently, we performed two systematic reviews that expressed the relevance of the effects of MI [23] and FoF [22] on orthostatic postural control. Fear has shown influence on the ability to perform gait MI [41]. Studies have shown that kinesthetic MI presents a modulation effect on orthostatic postural control [7–9], depending on the vividness of the imagined movement [10], corroborating our results, since the participants also presented high levels of vividness (KVIQ). The present study also showed that the FoF during the tasks of kinesthetic MI (cervical flexion and inclination) is able to modulate the CoP variables, increasing their oscillation, which indicates greater postural imbalance (Figure 2A,B).

By definition, orthostatic postural balance is the ability to maintain the body mass center within the limits of the foot support base, exerting constant modulations in the centers of gravity and CoP [42]. Recently, a posturography study using the WBB showed that changes in CoP (increased SD and MV) may predict the risk of falls in the elderly [43]. The FoF consists of a psychoemotional response to a previous event, which can modulate the reflex activity of the neuromuscular spindle [18] and influence the anticipatory postural control [19,20] in threatening situations (elevating participants at different heights) [11–15,44] or functional (unipodal and bipodal supports) [16,17] situations. In this context, the present study showed a greater modulation in the CoP variables (SD and MV, see Figure 2A,B) with a linear relation between them (Figure 3), indicating a reduction in the postural stability of the phobic subjects.

The FoF consists of an anxiogenic response that can favor the actual event of falls [45,46]. The increase in the CoP mean velocity (as observed in the present study, Figure 2B) has been considered an important predictor of the risk of falls in the elderly [26,43]. In addition, high levels of anxiety can modulate oculomotor control [47] and influence orthostatic postural control in young adults [48] as in the elderly [49], partially explaining the results observed in the present study. This study presents a limitation in the form of the sample size (n = 20), which also provided a great difference in number between non-phobic (n = 4) and phobic (n = 16) group.

5. Conclusions

The FoF during tasks of kinesthetic MI showed an influence on orthostatic postural control, increasing the mean velocity and amplitude (SD) of CoP (for phobic subjects), favoring the reduction in postural stability at the time of mental simulation, which may indicate a greater risk of falls. Thus, more studies are needed to investigate and deepen the relationship between FoF during tasks of kinesthetic MI and its effects on postural balance in order to prevent falls in elderly and/or young adults.

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Author Contributions: Nélio Silva de Souza, Ana Carolina G. Martins, Caroline L. Ferreira, and Yasmin S. Motizuki participated in the acquisition of data. Nélio Silva de Souza and Christiano B. Machado participated in the analysis of data using Matlab. Nélio Silva de Souza, Christiano B. Machado, Marco Orsini, Marco Antônio A. Leite, and Victor Hugo Bastos guided the design and organization of the study. All authors participated in the revision of the manuscript and gave final approval for the version submitted for publication.

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