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# Three days of beam walking practice improves dynamic balance control regardless of the use of haptic anchors in older adults

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ABSTRACT

Balance deficits during walking increase the risk of falls in older adults. Providing haptic information through anchors improves dynamic balance control, but the benefits of practicing with anchors during walking need to be evaluated. We investigated the effect of practice with haptic anchors in the beam walking task in older adults. Twenty-five older adults participated in this study divided into 0% (G0, practice without the anchors) and 50% (G50, practice with the haptic anchors in 50% of the trials) groups. With the anchors, participants held in each hand a cable with a mass of 0.125 kg affixed to the end of the cable that contacted the ground. They walked and kept the anchors in contact with the ground such that they dragged them. Participants increased the distance walked on the beam and reduced the trunk angular acceleration after training, but this effect was independent of the anchors. The use of haptic anchors during beam walking training did not significantly affect older adults' performance and dynamic balance control. Both groups showed improvements in the post-test and 24-hr retention conditions, indicating that older adults can learn to adapt their gait to more challenging contexts.

## 1. Introduction

Balance deficits during walking increase the risk of falls in older adults [1]. Balance training can improve dynamic balance control in older adults and reduce the risk of falls by approximately 21% [2]. Therefore, there is room to increase the effectiveness of intervention programs by considering new strategies to promote dynamic balance control.

Haptic inputs obtained through light touch or anchors could improve balance control in younger and older adults during walking [3]. The haptic anchor consists of holding in each hand a flexible cable with a light mass (usually 0.125 kg) attached to one end of each cable [4]. The individuals should keep the mass in contact with the ground while pulling on the cable just enough to keep it taut such that during walking, they drag the anchors [5–8]. Changes in body sway alter the tension of these cables, resulting in stimulation of the tactile and muscular mechanoreceptors of the hand and forearm that provide the base of the haptic information incorporated by the postural control system to improve dynamical balance control [9]. The anchors supply haptic information about body orientation in relation to the support surface.

Older adults can retain or transfer the improvements obtained during the practice of postural and walking tasks [10–13]. One 30-minute session was sufficient to generate learning effects in balancing tasks [10]. Older adults exhibited learning effects in walking tasks after one or two days of practice [12,13]. In previous studies involving balancing tasks, the use of the anchors reduced postural sway in younger and older adults, and this improvement was retained after a short-term practice [11,14]. During walking, the anchors reduced trunk velocity and acceleration in the frontal plane in younger and older adults [5–8]; however, there was no short-term effect [6]. One hypothesis for this lack of after-effect during walking with the anchors would be the short intervention period (one session with nine walking trials) [6]. Therefore, we decided to have a multi-day intervention period to ensure enough practice for the older adults to exhibit improvements with the haptic anchors in the dynamic balance control.

In a previous study, practice with the anchors in 50% of the trials of a postural task was the only condition that resulted in learning effects for older adults [11], so we used the same practice regimen in the present

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study for the experimental group with anchors. It has been established in the literature that falls prevention exercises for older adults should be challenging enough to observe improvements in balance control; particularly activities that manipulate the base of support are recommended [2,15,16]. Therefore, we used the beam walking task as it reduces the base of support. Beam walking increases trunk acceleration and displacement in the frontal plane [7,17]. Changes in dynamic balance control during walking in older adults can be identified by increasing trunk acceleration [7,18,19], a predictor of falls in this population [19,20]. During beam walking, trunk acceleration is sensitive to detecting differences in dynamic balance due to age and anchors' use [5–7]. Besides trunk acceleration, we also assessed beam walking performance as the distance walked on the beam. This measure has been used in different studies and is sensitive to detect differences in performance due to beam width, age, clinical condition, expertise, and task demands [17,21,22].

We investigate the effect of multi-day practice with the anchors in older adults during beam walking. We expected that the benefits of using the anchors would transfer to the context without them. Thus, we hypothesized that both groups (experimental and control) would improve their beam walking performance and dynamic balance control after practice, but the group that used the anchors during practice would boost this effect.

## 2. Methods

### 2.1. Participants

Twenty-five healthy older adults participated in this study and were divided into two groups: 0% (G0) and 50% (G50). We estimated the sample size with a power analysis for an F test of repeated measures, within-between interaction with an effect size of 0.29 based on trunk acceleration [6] ($\beta = 0.8$, $\alpha = 0.05$, correlation among repeated measures = 0.5, G*Power Version 3.1.9.2), which resulted in a minimum sample size of 9 individuals per group. The local ethics committee approved this study, and participants signed a consent form before data collection. We included individuals who could understand the verbal instructions, stand and walk without any aid device. Exclusion criteria were cognitive impairment, stroke, severe neuromuscular, musculoskeletal, or cardiovascular problems, visual problems not corrected by glasses or lens, and vestibular or somatosensory deficits.

We assessed the level of physical activity with the self-reported Modified Baecke Questionnaire [23], the cognitive conditions through the Mini-Mental State Exam [24], and the executive function using the Trail Making Test – Parts A and B [25].

### 2.2. Groups randomization

Participants were allocated to each group through a blind randomization process. A collaborator blinded to the study procedures prepared manila envelopes numbered sequentially. Half the envelopes contained the information "G0" and the other half had "G50" inside it. Envelopes were sealed, numbered, and stored in a safe place. The opening order of the envelopes was randomized using the website https://www.randomizer.org/. Randomization was performed after applying the inclusion and exclusion criteria.

### 2.3. Procedures

Participants walked barefoot on a balance beam to avoid the potential influence of footwear on body stability, as rigid soles improve stability during beam walking [26]. We instructed the participants to walk at their preferred speed and step in the middle of the beam. The beam was made of aluminum with the following dimensions: 0.02 m high, 0.06 m wide, and 4 m long. Since beam width was smaller than foot width, the base of support was reduced. Beam edges were slightly rounded to prevent foot pain. None of the participants complained about foot pain during beam walking. Retroreflective markers were placed bilaterally on the 5th metatarsal, lateral malleolus, calcaneus, acromion, anterior and posterior iliac spine, as well as markers on the 7th cervical vertebra (C7), 10th thoracic vertebra (T10), xiphoid process of the sternum (XP), and incisura jugularis (IJ). Ten cameras of the Vicon motion capture system (Oxford, UK) tracked the displacement of these markers with a sampling frequency of 100 Hz.

We organized the experiment in four phases: pre-test (Pre), practice, post-practice (Post), and retention (Ret, Fig. 1). In the pre-test, all participants walked on the beam without the anchors. They performed two trials for familiarization purposes and then completed a block of five trials with a 30-s rest between trials. Five minutes after the pre-test, participants performed six blocks of practice, with five trials per block (practice phase). The practice phase extended for three consecutive days (30 trials per day), totaling 90 practice trials. Participants had a 30-s break between trials and a 1-minute break between blocks. The G0 performed all the practice trials without the anchors, whereas the G50 performed the practice with the anchors in 50% of the trials (Table 1). The distribution of trials with and without the anchors was based on the faded feedback frequency protocol [11]. In this protocol, the feedback frequency is higher in the first trials and gradually decreases throughout the practice session. At the end of the third day of practice, participants performed the post-practice test. In this test, participants of both groups performed a block of five trials without the anchors. The post-practice test occurred fifteen minutes after the last trial of the practice phase. The retention test was performed on the fourth day of the experiment and started 24-hour after the last trial of the practice phase on day 3. Both groups performed two blocks (Ret1 and Ret2) of five trials without the anchors. Participants rest 30-s between trials and 1-minute between blocks. We placed the retroreflective markers only in the Pre, Post, and Ret trials.

An experimenter, blind to the groups in all phases, assessed the participants in the pre-test, post-practice, and retention. The participants of both groups did not use the anchors, and the evaluation conditions were the same for both groups. This experimenter was not the same experimenter responsible for conducting the practice sessions.

For the G50, each anchor consisted of a cable with a mass of 0.125 kg attached to one end of the cable inside a small cloth bag. Participants were instructed to hold one anchor in each hand while the mass contacted the ground (Fig. 2A). Participants kept the anchors in contact with the ground during the beam walking task such that they dragged them. In this way, the anchor cables were taut. The participant perceived changes in the cable traction, which provided haptic information about the body's position in relation to the support surface.

### 2.4. Data analysis

Body marker coordinates were filtered with a fourth-order, low-pass digital Butterworth filter with a cut-off frequency of 6 Hz. Foot contacts on the beam were obtained by visual inspection of the foot stick figure formed by the markers positioned on each foot. In the trials where the participants stepped off the beam before completing the 4-m distance, beam walking distance was calculated as the sum of successive step lengths successfully performed over the beam (i.e., the valid steps were the ones until the last foot contacted the beam). Step length was calculated as the difference between the anteroposterior (AP) coordinates of the calcaneus markers of the successive foot contacts on the beam. In the trials where the participants walked the entire beam, the walked distance corresponded to 4 m. For each block of five trials, we summed the distance walked on the beam over the trials and divided it by 20 m (i.e., maximum possible walked distance) to normalize the distance walked. Step speed was calculated by dividing step length by step duration. Step duration corresponded to the temporal difference between successive foot contacts on the beam.

Markers on the trunk (C7, T10, XP, and IJ) were used to define the

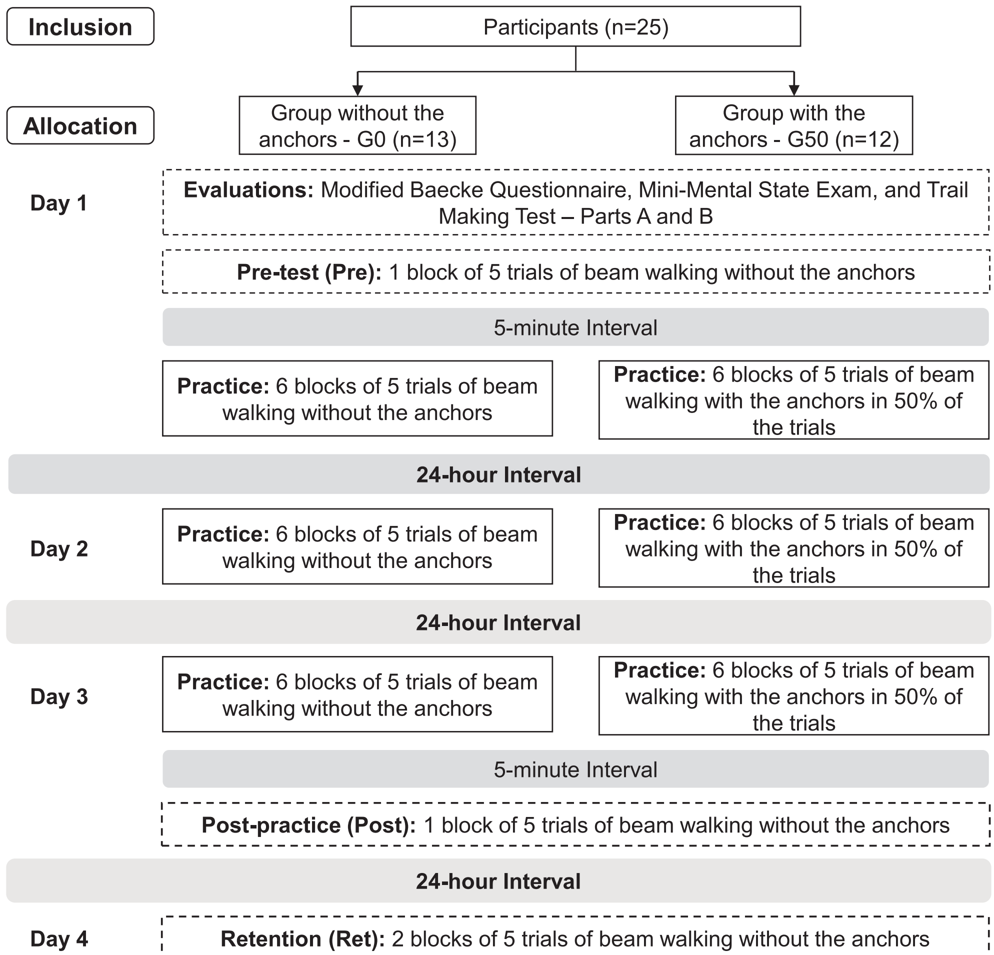


**Fig. 1.** Diagram illustrating the experimental groups, conditions, and assessments.

trunk segment following the International Society of Biomechanics recommendation [27]. We used the Visual3D software (C-Motion, Inc.) to build the trunk model and compute the trunk angle. The anterior-posterior axis (AP, Y coordinate) of the laboratory coordinate system was aligned with the beam length and the medial–lateral axis (ML, X coordinate) was perpendicular to the beam, the vertical axis (Vertical, Z coordinate) was the cross-product of X by Y (Fig. 2B). The tridimensional Euler angles of the trunk were calculated relative to the laboratory coordinate system (rotation sequence XYZ): flexion/extension (X-axis), lateral tilt (Y-axis), and rotation (Z-axis). The trunk lateral tilt angle displacement was derived twice to obtain the trunk angular acceleration in the frontal plane. We calculated the root mean square (RMS) for each 1-s window of the trunk angular acceleration and then averaged the values of these windows [6,7]. The reduction in the trunk acceleration RMS indicates fewer adjustments to keep dynamic balance.

### 2.5. Statistical analysis

The mean values across trials for each phase (Pre, Post, Ret1, and Ret2) were used in the statistical analysis, except for the distance walked on the beam, as it sums the values of the five trials. Since the data were not normally distributed, we transformed them using the natural logarithm. We ran two-way (2 groups × 4 phases) analyses of variance (ANOVA), with repeated measures in the second factor. When the assumption of sphericity was violated, we corrected the degrees of freedom using the Greenhouse-Geisser method. We carried out post-hoc analyses with Bonferroni adjustment. The distance walked was not normally distributed after transformation and we ran non-parametric tests. First, we carried out Mann-Whitney tests to assess the group effect in each phase. Then, we ran Friedman tests to determine the effect of phases and used the Wilcoxon Signed Rank as post-hoc tests. For each significant pairwise comparison, we computed Cohen's d. The significance level was set at 0.05.

## 3.

### 3.1. Sample characterization.

Table 2 shows the data of participants' anthropometric, cognitive, and physical activity level parameters from both groups. Except for body mass, smaller for G50 than G0, no other parameter differed between groups. These results allow us to identify that randomization generated homogeneous groups.

### 3.2. Distance walked on the beam

Participants performed 5.6 steps (±2.3) in trials in which they did not walk the entire beam and 8.4 steps (±1.5) in trials in which they walked the whole beam.

The Mann-Whitney test did not identify any effect of group in any of the phases (Pre: $p = 0.57$; Post: $p = 0.21$; Ret1: $p = 0.13$; Ret2: $p = 0.80$). Thus, the groups did not differ from each other before and after the practice protocol. Since groups did not differ, we carried out the Friedman tests combining the data of both groups. The Friedman test showed a main effect of phase across groups ($p \leq 0.0001$). The post-hoc

**Table 1**
Description of practice blocks and trials, with and without anchors, for the 50% group (G50) for each day of practice. The exact sequence of anchor conditions was repeated in all three days of practice.

| Block | Trial | Anchor |
|---|---|---|
| 1 | 1 | With |
| 1 | 2 | With |
| 1 | 3 | With |
| 1 | 4 | With |
| 1 | 5 | With |
| 2 | 6 | With |
| 2 | 7 | With |
| 2 | 8 | Without |
| 2 | 9 | Without |
| 2 | 10 | Without |
| 3 | 11 | Without |
| 3 | 12 | Without |
| 3 | 13 | With |
| 3 | 14 | With |
| 3 | 15 | With |
| 4 | 16 | With |
| 4 | 17 | Without |
| 4 | 18 | Without |
| 4 | 19 | Without |
| 4 | 20 | Without |
| 5 | 21 | Without |
| 5 | 22 | With |
| 5 | 23 | With |
| 5 | 24 | Without |
| 5 | 25 | Without |
| 6 | 26 | Without |
| 6 | 27 | Without |
| 6 | 28 | Without |
| 6 | 29 | With |
| 6 | 30 | With |

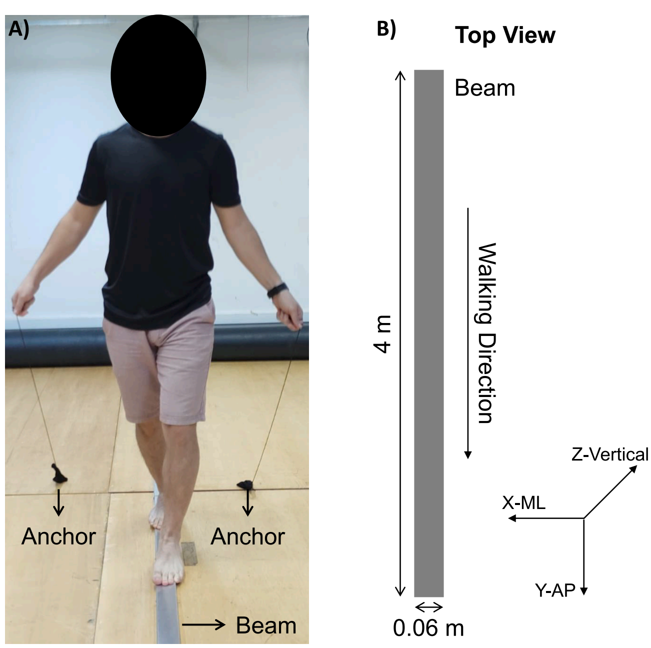


**Fig. 2.** (A) Photo illustrating the task of walking on the beam using the haptic anchors. Note that the photo was taken with a young adult for illustrative purposes only. (B) Top view of the beam with the dimensions and the orientation of the coordination system (Y-AP: anterior-posterior direction; X-ML: medial-lateral direction; Z-Vertical: vertical direction).

analysis indicated that both groups increased the distance walked on the beam from Pre to Post ($p = 0.002$; $d = 0.54$), Ret1 ($p = 0.01$; $d = 0.39$) and Ret2 ($p \leq 0.0001$; $d = 0.75$, Fig. 3A). Furthermore, the distance walked in Ret2 increased compared to Ret1 ($p = 0.02$; $d = 0.36$, Fig. 3A).

**Table 2**
Mean and standard deviation (±) of anthropometric, cognitive, and physical activity parameters of participants in groups G0 (no anchor) and G50 (with anchors).

| Parameters | G0 (n = 13) | G50 (n = 12) | p-value |
|---|---|---|---|
| Age (years) | 70.3 ± 6.4 | 70.4 ± 5.8 | 0.965 |
| Height (m) | 1.65 ± 0.07 | 1.59 ± 0.09 | 0.097 |
| Body mass (kg) | 79.6 ± 16.0 | 67.7 ± 10.8 | **0.039*** |
| Body mass index (kg/m$^2$) | 29.4 ± 6.0 | 26.6 ± 3.2 | 0.158 |
| Mini-mental state exam (points)[A] | 27.5 ± 2.6 | 28.1 ± 2.7 | 0.463 |
| Trail Making Test – Part A (s)[B] | 46.6 ± 24.6 | 39.7 ± 17.5 | 0.728 |
| Trail Making Test – Part B (s)[B] | 132.0 ± 99.9 | 102.7 ± 43.4 | 0.829 |
| Physical activity level (points)[C] | 8.3 ± 10.7 | 5.7 ± 5.9 | 0.683 |

* $p < 0.05$.
[A] Scores close to 30 points (maximum score) indicate the absence of cognitive deficit.
[B] Cut-off scores: Trail Making Test – Part A > 78 s; Trail Making Test – Part B > 273 s.
[C] Scores close to zero indicate a low level of physical activity, as measured by the Modified Baecke Questionnaire for Older Adults. The following cut-off points can be used to classify the level of physical activity [23]: low level < 7.9, moderate level < 14.9, high level > 15.7.

Relative to Pre, there was an increase in beam walking distance of 17.4% for Post, 13% for Ret1, and 23.2% for Ret2. There was also an increase of 9% in the distance walked on the beam between Ret1 and Ret2.

### 3.3. *Step speed*

The ANOVA did not exhibit any main effect of group ($F_{1,23} = 0.14$, $p = 0.708$) or phase ($F_{1.8,41.2} = 1.18$, $p = 0.313$). The group-by-phase interaction was also not significant ($F_{1.8,41.2} = 0.51$, $p = 0.586$). The mean step speed across groups and phases was 0.6 ± 0.2 m/s (mean ± standard deviation).

### 3.4. *Trunk angular acceleration RMS*

The ANOVA did not identify either a main effect of group ($F_{1,23} = 0.001$, $p = 0.979$) nor an interaction between group and phase ($F_{2.2,49.8} = 1.59$, $p = 0.213$), but there was a main effect of phase ($F_{2.2,49.8} = 5.39$, $p = 0.006$). The post-hoc analysis showed that trunk angular acceleration RMS reduced from Pre to Post ($p = 0.013$, $d = 0.59$) and Ret2 ($p = 0.035$, $d = 0.56$, Fig. 3B). In Post and Ret2, there was a reduction of 23.2% and 22.3%, respectively, in the trunk angular acceleration RMS. The other pairwise comparisons were not statistically significant.

## 4. Discussion

We investigated the effect of multi-day practice with the anchors during beam walking in older adults. Practicing with the anchors did not reveal any advantage as G0 and G50 did not differ from each other for any of the variables evaluated, contradicting one of our hypotheses. Our data, however, confirmed the hypothesis that both groups would improve beam walking performance and dynamic balance control after practice.

Our randomization effectively created two homogeneous groups, as there were no group differences for sample characterization and walking parameters in the pre-test. The exception was a difference between groups for body mass. Despite this difference, the body mass index did not differ between groups, and there is no evidence that an increase in body mass influences beam walking [21]. In addition, the results of the sample characterization data indicate that the older adults included in this study were healthy.

The increased distance walked on the beam after training occurred in both groups, characterizing a performance improvement not yet reported in the literature. Existing studies on beam walking focused on the acute effects of this task and not on the adaptations that may arise due to

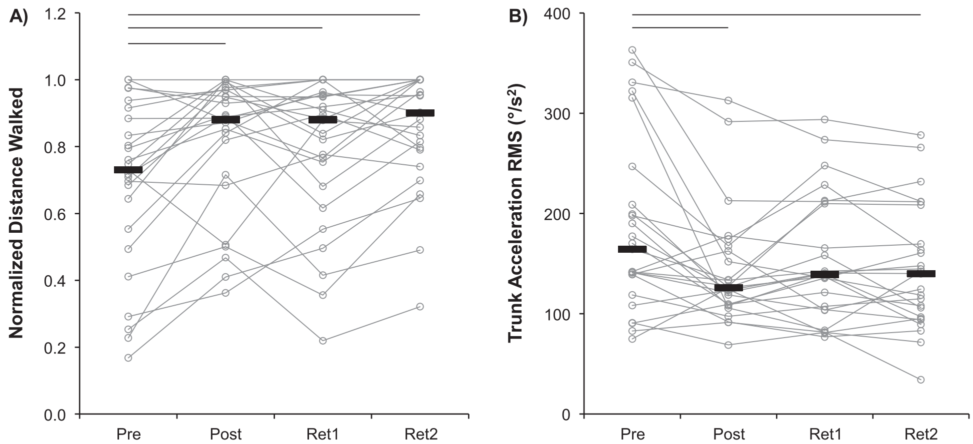


**Fig. 3.** Normalized distance walked on the beam (A) and trunk angular acceleration root mean square (RMS) (B) at four-time points. The thick horizontal black lines indicate medians across participants. The thin black lines on the top of each graph indicate statistical significance (see text for exact p-values). Each circle indicates individual data (n = 25).

practice [5,7,17,21,22]. The improvement in the distance walked occurred in post-practice and during the 24-hr retention conditions, indicating a robust effect maintained even one day after the training. The distance walked increased 9% from RET1 to RET2, suggesting that short-term effects in the retention tests are present as a reminiscence of the previous days of practice [28]. This performance improvement demonstrates that older adults learned to walk better on the beam after three days of practice, indicating they maintain the ability to learn to adapt gait according to environmental demands [29].

After the training period, the trunk angular acceleration reduced, indicating that older adults in both groups improved their dynamic balance control [7,18,19]. It shows that lesser trunk adjustments were needed to walk on the beam after the training period. This improvement in dynamic balance control occurred both in the post-test and 24-hr retention condition. This result reinforces that older adults can improve balance control through training, particularly in challenging contexts such as beam walking, where the base of support is substantially reduced. This gait adaptability and balance control improvement can be clinically decisive in avoiding falls in older adults during dynamic contexts [30].

Despite these improvements, the effect of training with the haptic anchors did not contribute to a more accentuated improvement in both performance and dynamic balance control. In previous studies with younger and older adults, individuals who trained with the anchors performed better on retention tests than individuals who did not use the anchors in training [11,14]. An essential difference between those studies and the present work is the task performed. Participants completed a balancing task in those two studies, which is quite different from the beam walking task used in the present study. Thus, one possibility to eventually observe anchor effects on beam walking would be to include an even longer training period since beam walking is much more complex than standing. However, the fact that both groups have improved performance and dynamic balance control in the beam walking task after three practice sessions do not suggest that more practice would be needed to verify any effect of the anchors.

Haptic anchors improve dynamic balance control during walking in younger [8] and older adults [5–7]. Although previous studies have shown a transfer effect of the haptic anchor training to the context without the anchors during balancing tasks in younger and older adults [11,14], this transfer does not seem to occur in a more dynamic task as beam walking. In a previous study in which the older adults performed a single training session, we also did not observe the transfer benefits of the anchors to the situation without the anchors while walking with a reduced base of support [6]. In that study, two hypotheses were formulated. First, walking with a reduced base of support on the ground was not challenging enough, as the effects of haptic anchors seem to be more effective in more difficult tasks [9]. However, the level of difficulty of the locomotor task did not affect the effect of the haptic anchors on dynamic balance control in a subsequent study conducted by our group [7]. Second, more training time with the anchors would be needed to observe any transfer effect. The present findings refute this second hypothesis. The older adults had substantial practice with the anchors, but this was insufficient to generate a greater effect for this group.

One possibility is that the acquisition of haptic information through anchors is different from standing still to walking, which would justify the absence of transfer effect in walking. However, Coelho et al. [31] showed that individuals with chronic dizziness of peripheral vestibular origin performed better in dynamic balance tests after completing a six-week intervention program using anchors than a group that performed the same training protocol without the anchors. This training protocol involved locomotor tasks performed with different levels of difficulty. The group that used the anchors managed to maintain the effects of training until three months after the end of the intervention program. Thus, individuals who have more pronounced deficits in dynamic balance control seem to benefit from training with anchors and can transfer the effects of this training to other dynamic tasks. As the participants in this study were healthy older adults, the contribution of anchors to improve performance and balance control in beam walking may have been limited, not enough to generate any transfer effect to the post-test and retention. Thus, one hypothesis is that individuals with greater deficits in dynamic balance control (e.g., older people with a history of falls) could benefit more from the anchors and transfer these effects to the condition without them. Future studies may investigate the effect of training with the anchors on participants at risk or with a history of falls.

One could also argue that the interval between the end of the intervention and the retention test (24-h) was short for consolidating the anchor benefits. However, a recent *meta*-analysis showed the 24-h interval is sufficient to observe motor memory consolidation [32]. In addition, the comparison of retention tests performed immediately after the intervention and one or two weeks later do not yield any strong tendency [33]. Therefore, it is unlikely that a longer interval would necessarily benefit motor memory consolidation.

Although beam walking is an interesting paradigm to challenge dynamic balance, regular walking occurs with a broad base of support where foot placement is a crucial strategy for balance control [34]. Foot placement and ankle control strategies are limited during beam walking, and trunk control becomes an essential strategy [34]. Therefore, it is unclear whether beam walking training effects would transfer to regular walking. It is known that frontal plane trunk position and acceleration affect step width during regular walking in younger and older adults

[35]. Then, the reduction in trunk acceleration observed in the present study could potentially be transferred to regular walking contributing to the step width control, a relevant strategy for ensuring gait stability during regular walking [34]. Future studies should address this possibility.

The present study was not conducted without some limitations. As we recruited healthy older adults, it is not possible to generalize our findings to all older adults. Older adults at risk for falls may benefit differently from using anchors while walking. Although the variables we used were sensitive enough to identify important changes in gait, other variables that more directly measure dynamic stability (e.g., the margin of stability or local dynamic stability) may be more sensitive to detect possible effects of practicing with the haptic anchors on gait balance control. However, previous studies showed that trunk acceleration in the frontal plane was sufficient to observe the benefits of the anchors during gait [5–7]. Future studies may test these aspects.

## 5. Conclusions

Practicing with the haptic anchors during beam walking training did not significantly affect older adults' performance and dynamic balance control. Both groups showed improvements in the post-test and 24-hr retention conditions, indicating that older adults can learn to adapt their gait to more challenging contexts after three days of training.

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*CRediT authorship contribution statement*

**Geovana Milani:** Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Visualization, Writing – original draft. **Andréia A.S. Costa:** Conceptualization, Methodology, Investigation, Data curation, Writing – review & editing. **Eduardo B. Junqueira:** Investigation, Data curation, Writing – review & editing. **Eduardo G. Campoi:** Investigation, Data curation, Writing – review & editing. **Henrique G. Campoi:** Investigation, Data curation, Writing – review & editing. **Paulo R.P. Santiago:** Software, Resources, Writing – review & editing. **Renato Moraes:** Conceptualization, Methodology, Software, Writing – review & editing, Supervision, Funding acquisition.

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