UNIVERSIDADE DE SÃO PAULO
ESCOLA DE EDUCAÇÃO FÍSICA E ESPORTE

Treinamento de equilíbrio unipodal: revisão sistemática da literatura e efeitos em indivíduos idosos

Alexandre Jehan Marcori

São Paulo
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Single leg balance training: systematic review of the literature and effects in older individuals

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ALEXANDRE JEHAN MARCORI

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Tese apresentada à Escola de Educação Física e Esporte da Universidade de São Paulo, como requisito parcial para a obtenção do título de Doutor em Ciências

Área de Concentração: Estudos Socioculturais e Comportamentais da Educação Física e Esporte

Orientador: Prof. Dr. Luis Augusto Teixeira

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“Escrevo algumas palavras ainda me recuperando do impacto que me causou a leitura”

O idiota, ***Fiodor Dostoiévski***

RESUMO

MARCORI, AJ. **Treinamento de equilíbrio unipodal: revisão sistemática da literatura e efeitos em indivíduos idosos.** 2022. 96 f. Tese (Doutorado em Ciências) – Escola de Educação Física e Esporte, Universidade de São Paulo, São Paulo. 2022.

A literatura disponível sobre treinamento de equilíbrio unipodal em idosos é escassa. Apesar da grande relevância deste tema, poucas investigações analisaram os efeitos de treinar equilíbrio corporal apoiado apenas sobre uma perna em pessoas idosas. Dada a maior demanda de equilíbrio e complexidade neuromotora envolvida em se manter nesta postura de base reduzida, o treinamento de equilíbrio unipodal tem potencial para desencadear efeitos positivos no controle do equilíbrio de idosos. Para tanto, conduzimos uma revisão sistematizada da literatura com o objetivo de compilar os resultados, descrever os métodos utilizados, e avançar o conhecimento relacionado a esta forma de treinamento. Os achados desta revisão mostraram que intervenções que acumulam de 10 a 390 min. em postura unipodal são capazes de promover ganhos significativos no controle do equilíbrio. Porém, nenhum estudo revisado apresentou um controle positivo, ou seja, um grupo de treinamento de equilíbrio que realizasse exercícios equivalentes, porém com menor demanda de equilíbrio. O estudo experimental desenvolvido na presente tese preenche esta lacuna, ao comparar os efeitos do treinamento de equilíbrio dinâmico unipodal vs. bipodal em idosos saudáveis. Para isso, 66 idosos (60 a 80 anos) foram selecionados e divididos em três grupos: treino unipodal (n = 22, 4 homens); treino bipodal (n = 22; 5 homens) e grupo controle sem treinamento (n = 22; 6 homens). Os participantes foram avaliados antes e após 12 semanas de intervenção nas seguintes tarefas: a) equilíbrio dinâmico e reativo, por meio de deslocamento cíclico/contínuo e único/inesperado da base de suporte (plataforma de força), respectivamente; b) cognição, por meio do teste *trail-making* para atenção e *Rey auditory verbal learning* para memória; e c) força de membros inferiores, por meio do teste de sentar e levantar por 30 s. Os resultados mostraram que, tanto nos testes de equilíbrio dinâmico e reativo quanto nos testes cognitivos os três grupos melhoraram do pré- para o pós-teste de maneira equivalente. É possível que a simples exposição às perturbações causadas pela movimentação da base de suporte no pré-teste seja capaz de induzir adaptações persistentes no controle do equilíbrio, equivalentes àquelas desencadeadas pelo treinamento. Os ganhos de força foram observados apenas nos grupos de treinamento, porém de maneira semelhante entre eles. Estes resultados sugerem que treinar equilíbrio de maneira unipodal ou bipodal produz desfechos semelhantes no controle do equilíbrio, força e cognição de idosos, conforme avaliado nos testes descritos. Este achado tem grande relevância para a prescrição do treinamento de equilíbrio em idosos, de maneira que, desde que as atividades sejam realizadas de forma dinâmica e desafiadora conforme a capacidade do indivíduo, treinar de maneira uni- ou bipodal tem o potencial de promover resultados equivalentes.

Palavras-chave: equilíbrio unipodal; quedas; idosos; treinamento.

ABSTRACT

MARCORI, AJ. **Single leg balance training: systematic review of the literature and effects in older individuals.** 2022. 96 f. Doctoral dissertation (PhD in Science) – School of Physical Education and Sport, University of São Paulo, São Paulo. 2022.

The available literature regarding single leg balance training in older adults is scarce. Despite the relevance of this topic, few investigations have analyzed the outcomes of training body balance while supported on a single leg. Given the increased balance demand and neuromotor complexity required to sustain balance on this reduced support base, single leg balance training has the potential to promote positive effects in older adults' balance control. We conducted a systematic review of the literature aiming to compile the results, describe the methods, and advance on the knowledge related to this form of training. The findings from this review showed that interventions with 10 to 390 min. of accumulated single leg balance were capable of promoting significant improvements of balance control. However, none of the analyzed studies had a positive control, i.e., a group that performed balance training with equivalent exercises, but reduced balance demand. The experimental protocol proposed in this dissertation aimed to fill this gap in the literature by comparing the effects of single vs. bipedal balance training program in healthy older adults. Sixty-six older individuals (age range 60 to 80 years) were selected and randomly divided into three groups: single leg balance (n = 22; 4 men), bipedal balance (n = 22; 5 men), and untrained control group (n =22, 6 men). The participants were evaluated before and after a 12-week balance training intervention in the following tasks: a) dynamic and reactive balance, assessed by cyclic/continuous and single/unexpected movement of the force plate support base, respectively; b) cognition, assessed by the trail-making test, for attention evaluation, and Rey auditory verbal learning, for memory evaluation; and c) lower limbs' strength, assessed through the 30-s sit-to-stand test. Results revealed equivalent gains from the pre- to the post-test across the three groups in balance control, for both dynamic and reactive tasks, and in the cognitive tests. It is possible that the simple exposure to the perturbations of the support base during pre-testing can have induced persistent gains in balance control, equivalent to those caused by the training program. Strength gains were observed only in the training groups. Overall, these results suggest that training balance either on a single leg or in bipedal stance can induce equivalent outcomes in balance control, cognition, and leg strength, as assessed by the employed tasks. These findings are relevant for balance training prescription for older individuals, as training with a more or less challenging (single vs. double leg support) protocol has the potential to promote equivalent results, given that dynamic and complex tasks are applied within the individuals' capacity to execute them.

Keywords: single leg balance; falls; older adults; training.

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LIST OF ABBREVIATIONS

CNS	Central nervous system
CP	Center of pressure
PEDro	Physiotherapy evidence database scale quality assessment
SBT	Single leg balance training
BBT	Bipedal balance training
CG	Control group
MMSE	Mini mental state examination
AP	Anteroposterior axis
ML	Mediolateral axis
TMT	Trail-making test
RAVLT	Rey auditory verbal learning test
SPSS	Statistical package for the social sciences
RMS	Root mean square
SE	Standard error
SRM	Standardized residual measure
SD	Standard deviation

SUMMARY

CHAPTER I
INTRODUCTION AND GOALS

1 INTRODUCTION

Human balance control relies on the dynamic and continuous integration of visual, vestibular, proprioceptive, and somatosensory systems (MAHBOOBIN et al., 2005; PAILLARD, 2017). Information from these sensory sources is constantly processed, integrated, and used by the central nervous system (CNS) to determine motor responses and achieve balance stability in a variety of tasks (HORAK, 2006; MAHBOOBIN et al., 2005; PAILLARD, 2017). Of relevance, reactive responses are required when an individual is exposed to an unexpected perturbation (MOCHIZUKI et al., 2008, 2010; RINALDIN et al., 2020), or to adjust balance after moving their own body through space (KARIM et al., 2012). In both cases, motor responses aim to stabilize center of mass over the support base (PAILLARD, 2017), thus being necessary for balance maintenance in dynamic and reactive situations (e.g., walking in a crowded place, public transportation-induced perturbations, unexpected trips, or slips). Therefore, the ability to control balance in different contexts is crucial, especially for older populations, in which a decreased balance capacity might lead to health- and even life-threatening situations (TAKESHIMA et al., 2014).

With a decreased capacity to control balance, the ability to properly respond to an unexpected postural perturbation is also reduced. These perturbations may be both intrinsic, caused by self-produced movements, or extrinsic, caused by external factors (BLAKE et al., 1988; ROBINOVITCH et al., 2013). Independent of the cause, the individual must use compensatory movement responses to regain balance (DE SOUZA et al., 2019). Recent investigations have analyzed older adults in situations of balance perturbations, verifying that repeated exposure to challenging conditions of perturbation can lead to an increased capacity to maintain and restore balance (KURZ et al., 2016; OSTI; DE SOUZA; TEIXEIRA, 2017; PAI; BHATT, 2007). These adaptations are related to fine-tuning of dynamic balance control, which requires both anticipatory postural adjustments (movements performed before the determined change of posture to assure that balance is maintained in the new body position and segmental organization; KANEKAR; ARUIN, 2015) and automatic postural responses (neuromuscular strategies performed without superior levels of processing in the CNS, aimed at balance maintenance; COELHO; TEIXEIRA, 2018). Within this context, different forms of balance training, especially in dynamic conditions, have been proposed to improve these aspects of balance control in older adults.

Dynamic balance characteristics, such as weight shifting from one leg to the other and high levels of control in slow movement speeds have been found in Tai-chi Chu'an training (HACKNEY; WOLF, 2014). With this form of exercise, improved anticipatory postural adjustments (GHANDALI et al., 2017) and shorter latency in muscle activation following an external perturbation (XU; LI; HONG, 2005) have been observed. On the other hand, perturbation training via displacement of the support base can promote other adaptations. In previous research in older adults it has been verified that repeated displacements of the support base led to reduced muscle activity in distal leg muscles and increased stability of center of pressure (CP) control (COELHO et al., 2018). Also in older adults, slip training on a treadmill while walking promoted faster stepping in responses to regain balance following a slip (KURZ et al., 2016). Taken together, these results suggest that training with different methods can all lead to some form of improvement in balance control, as reducing muscle activation of agonists represent a less stiff joint and a more efficient postural response to a perturbation (NAGAI et al., 2011), while the stepping response is commonly used in daily activities to regain balance in the case of a perturbation (MELZER et al., 2009). Hence, training with voluntary and reactive movements can improve dynamic balance control and the capacity to respond to a perturbation.

Other investigations and training approaches have revealed pertinent findings in younger adults. After interventions with single leg balance training, reductions in muscle coactivation at the hip and ankle joints were verified during balance perturbations (FREYLER et al., 2016), as well as faster muscle activation onset in posterior leg muscles with reduced angular velocity of the hip and ankle joints (KRAUSE et al., 2018). These neuromuscular adaptions represent improved balance control in dynamic conditions following single leg training. Considering that major losses of balance can happen during single leg support (BLAKE et al., 1988; CHOMIAK; VIEIRA; HU, 2015), the mentioned adaptations are particularly relevant as improved neuromuscular control related to using hip joint strategies is able to maintain the center of mass within the support base during single leg stance (FREYLER et al., 2015). Improvement of single leg stance seems fundamental for a balance training intervention that aims to promote better balance control in older adults. Given the relevance of single leg balance control in the older population (ARAUJO et al., 2022), training in a single leg posture has the potential to increase quality of life and functional capacity. However, in older adults, there is reduced evidence regarding balance interventions exploring tasks with challenging postural characteristics, such as single leg balance.

Challenging postures are under the control of high order structures of the CNS, such as the cerebral cortex (TAUBE et al., 2006). The activation of cortical regions related to the performance of a motor task, when performed repeatedly due to training, can promote positive structural adaptations (DRAGANSKI et al., 2004). In balance training, this phenomenon was observed by verifying increased thickness in the motor cortex after a single session of training a dynamic balance task (TAUBERT et al., 2016). Chronically, after six weeks of dynamic balance training, gray matter density increments were observed in different regions of the frontal and parietal cortices (TAUBERT et al., 2010). In line with these findings, previous research using electroencephalography verified a complex and diffuse neural network responsible for controlling perturbed balance, comprising coordinated activation of the frontal, central, and parietal regions (VARGHESE; STAINES; MCILROY, 2019). Considering cortical activation represents an essential stimulus to induce neuroplastic adaptations in the CNS (LÖVDÉN et al., 2010), training balance in dynamic and challenging postures have an increased potential to promote neuromotor adaptations. Indeed, in a review regarding neural plasticity and motor skills, Carey, Bhatt and Nagpal (2005) suggested that the level of cognitive effort applied during the performance of a complex motor task is responsible for inducing the outcomes of adaptation as a consequence of learning. These authors also presented evidence comparing the execution of repetitive and more simple tasks in contrast to more challenging motor tasks, concluding the complexity level of the motor task is a key factor in promoting neural adaptations. From these findings, it seems that the high demand of cortical activity generated by the performance of a challenging dynamic balance task leads to neural and behavioral outcomes following training.

Training interventions aimed at improving balance control in older adults should require challenging and complex task performance. As such, previous reviews on this topic suggest that multimodal programs, i.e., those encompassing different aspects of movement control and stimulating distinct motor capacities, are more likely to improve balance control in older adults (HACKNEY; WOLF, 2014; LELARD; AHMAIDI, 2015; PAILLARD, 2017). However, it is worth mentioning that previous reviews about balance training have not focused on programs of exclusively single leg balance. Given that task complexity plays a relevant role in promoting training adaptations, and that reducing the support base to single leg stance is a known strategy to increase balance difficulty and complexity (MUEHLBAUER et al., 2012), reviewing the literature available for this type of training (i.e., single leg balance) is invaluable to expand the knowledge in the topic. Indeed, it is expected that a training program exploring different movement possibilities, with more challenging tasks, and stimulating different sensorial systems related to balance control (somatossensorial, vestibular, and neuromuscular) can promote optimal outcomes, as sensorial and neuromuscular losses observed with aging affect balance control (WIESMEIER; DALIN; MAURER, 2015). However, previous research with balance training in older adults, besides not applying more complex and challenging tasks in the intervention, also lacked a more global evaluation of the physical and cognitive capacities related to balance control, as proposed in the following sections. Based on the raised evidence, reviewing the literature of single leg balance training, and promoting a single leg balance training intervention for older adults, accompanied by a complete evaluation protocol of distinct balance tasks and other physical and cognitive capacities, comprise the original points approached in the present dissertation.

2 GOALS

The main goal of this work is to investigate the effects of single leg balance training in older adults. For such, a systematic review of single leg balance training literature was conducted, followed by an experimental research that promoted a 12-week intervention of single leg balance training in older adults. The specific goals of each experiment (i.e., systematic review and intervention) are presented below, in their respective chapters (II and III).

CHAPTER II

SINGLE LEG BALANCE TRAINING: A SYSTEMATIC REVIEW

Abstract

Single leg balance training promotes significant increments in balance control, but previous reviews on balance control have not analyzed this form of balance training. Accordingly, we aimed to review the single leg balance training literature to better understand the effects of applying this training to healthy individuals. We searched five databases - PubMed, EMBASE, Scopus, Lilacs, and Scielo - with the following inclusion criteria: (a) peer-reviewed articles published in English; (b) analysis of adult participants who had no musculoskeletal injuries or diseases that might impair balance control; and (c) use of methods containing at least a pre-test, exclusive single leg balance training, and a post-test assessment. We included 13 articles meeting these criteria and found that single leg balance training protocols were effective in inducing balance control gains in either single- or multiple-session training and with or without progression of difficulty. Balance control gains were achieved with different amounts of training, ranging from a single short session of 10 minutes to multiple sessions totaling as much as 390 minutes of unipedal balance time. Generalization of balance gains to untrained tasks and cross-education between legs from single leg balance training were consistent across studies. We concluded that single leg balance training can be used in various contexts to improve balance performance in healthy individuals. These results extend knowledge of expected outcomes from this form of training and aid single leg balance exercise prescription regarding volume, frequency, and potential progressions.

This review was published in Perceptual & Motor Skills, volume 129, issue 2, 2022, under the same title as the current chapter.

It can be permanently found in the link: https://doi.org/10.1177/00315125211070104

First page of the published article is in the Attachment (A), page 68.

1 INTRODUCTION

Published literature reviews have concluded that athletes (BRACHMAN et al., 2017), healthy adults (PAILLARD, 2017), stroke patients (VEERBEEK et al., 2014), and older adults (LESINSKI et al., 2015; LOW; WALSH; ARKESTEIJN, 2017) benefit from balance training. Key outcomes have included reduced injury risks (HÜBSCHER et al., 2010) and incidence of falls (HORAK, 2006). Lesinski and colleagues (2015) proposed that, for balance training to be effective for increasing balance stability, a relevant training component is the challenge/difficulty imposed by the task. A potential strategy for increasing balance difficulty in training tasks is using a single leg stance to reduce the base of support, as this reduction challenges the neuromotor system to maintain body balance (MUEHLBAUER et al., 2012). Thus, there is evidence that single leg stance can be employed in balance training to impose a high balance demand, and several balance training programs have relied exclusively on single leg balance tasks throughout the training sessions (KAMIKURA; SAKURABA; MIURA, 2018; VERNADAKIS et al., 2012).

Previous research has investigated adaptation mechanisms associated with balance training through single leg stance. After a single trial in young adults' unipedal balance training on an unstable platform, a research verified that the neuromotor system quickly adapted to this challenge by reducing thigh and hip muscle activation, in association with decreased amplitude of center of mass oscillation (VAN DIEËN; VAN LEEUWEN; FABER, 2015). Similarly, others have found impressive gains in balance performance through single session (MARCORI et al., 2020; YASUDA; SAICHI; IWATA, 2018) or multiple session (LAUFER, 2008) training. Given its potential to improve balance stability to high levels, single leg balance training seems to be an alternative approach to more traditional balance training programs that have used bipedal exercises. Another interesting aspect of single leg balance training is its potential for cross-education (PAILLARD, 2017). Balance training on one leg can lead to performance gains of the contralateral leg (ZHOU, 2000). Evidence from a limited number of studies to date that have investigated this phenomenon suggests that, after single leg balance training, performance gains of the contralateral leg are very similar to those observed in the trained leg (LAUFER, 2008; MARCORI et al., 2020).

The total time spent on single leg stance training throughout an intervention can be fundamental to interpreting the distinct results of previous studies. Even though previous literature reviews have analyzed the dose-response relationship of general interventions for balance training (GEBEL et al., 2018; LACROIX et al., 2017; LESINSKI et al., 2015), none of these reviews specifically evaluated training programs that applied exclusive single leg balance training. To the best of our knowledge, this is the first review to compile evidence of this method of balance training. Our aim in this systematic review was to analyze experimental research reporting the effects of single leg balance training applied to healthy individuals. In selecting studies for this review, we sought investigations that included at least a pre- and post-test assessment after an exclusive single leg balance intervention period. Our specific goals were to describe from these studies (a) the equipment, evaluation methods and main outcomes of training; (b) training duration, frequency, and practice time; (c) task difficulty increments (progression) across training; and (d) balance control gains achieved.

2 METHODS

We followed the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) recommendations (MOHER et al., 2009) as closely as possible to conduct this review, and we indexed this review in the Prospective Register of Systematic Reviews (PROSPERO) database (CRD42020212939).

2.1 Inclusion Criteria

For this systematic review, we included results from research that aimed primarily to analyze the outcomes of single leg balance training in healthy younger and older adults. Additionally, our inclusion criteria were that (a) articles be peer-reviewed and published in English; (b) methods contained at least a pre-test, exclusive single leg balance training, and a post-test; and (c) participants were without musculoskeletal injuries or diseases that might impair balance control. Eligible articles had to present complete information regarding the training protocol, either in the main text or as supplementary material, and their methodological procedures had to lead to a sound conclusion.

2.2 Search Strategy

In our first step, our systematic search was for all articles published up to January 13th, 2021. Our search terms were: (“single leg” [text word] OR "monopedal" [text word] OR "unipedal" [text word] OR “one leg” [text word]) AND ("balance training" [text word] OR “equilibrium training” [text word]). After performing the search, we applied filters for article language (English only) and type of content (articles only). Moreover, to not rely solely on review filters in the search engine, which can lead to overlooking interesting articles, we undertook a further manual search of the reference lists of selected articles to complete the article selection process. Next, two researchers independently analyzed all the retrieved articles to determine whether they met our inclusion criteria. Initially, articles were screened by reading their titles and abstracts. If the article was considered within our scope, it was read in full to confirm its eligibility for inclusion. In cases of divergence between the two authors performing these independent determinations, a third researcher was consulted to assist a consensus.

2.3 Eligibility, Assessment Quality and Risk of Bias

We rated selected articles using the Physiotherapy Evidence Database (PEDro) scale. We selected this instrument for to its capacity to optimally measure the methodological quality of exercise interventions (DE MORTON, 2009). For these ratings, two researchers independently rated the manuscripts using the PEDro scale. We calculated the Kappa coefficient to verify the level of agreement between these raters. We did not use the PEDro scale score as an eligibility criterion, but rather, as a critical descriptive critical tool for judging the quality of the research interventions. Figure 1 presents the flowchart of the selection process.

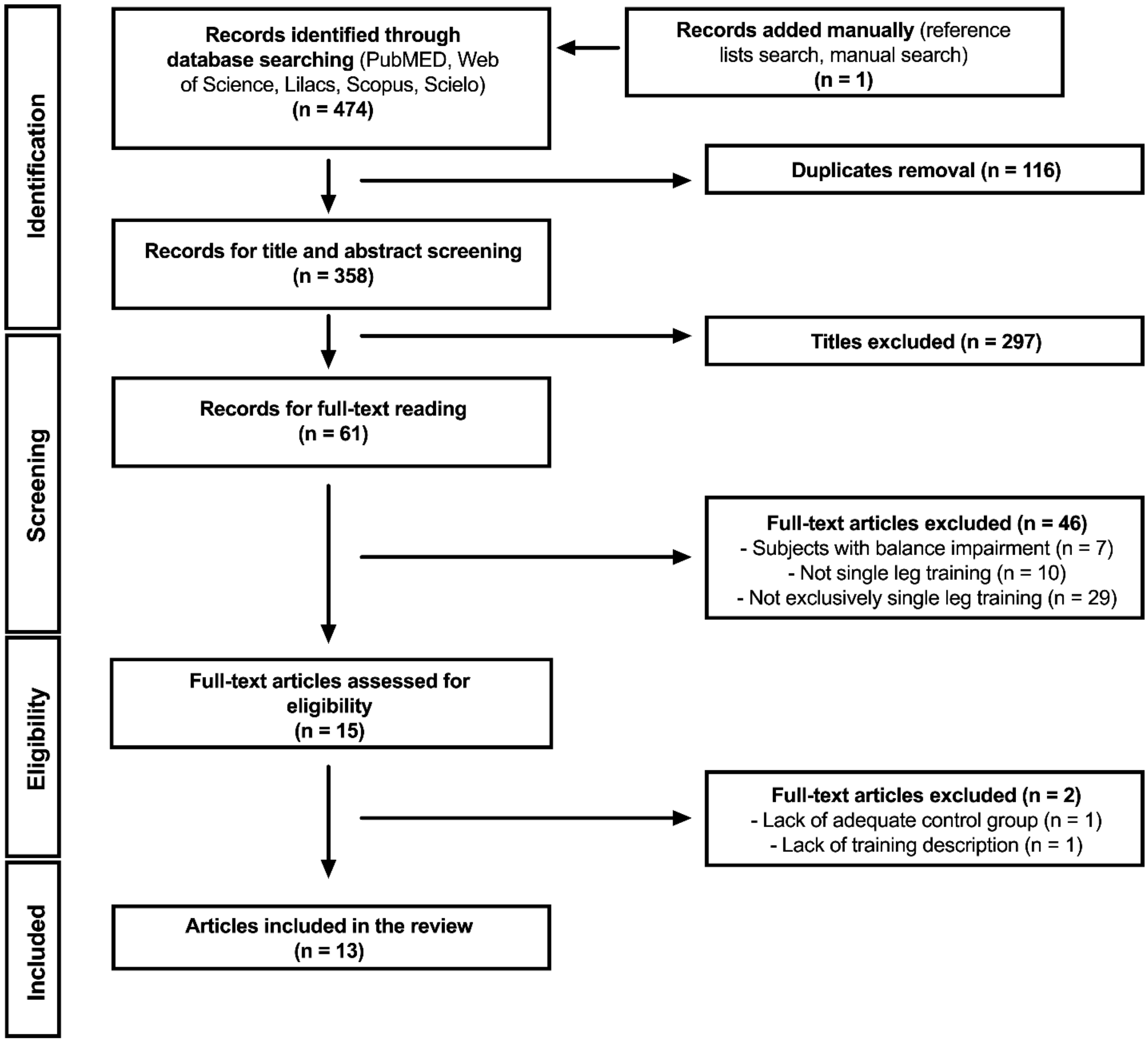

Figure 1. Systematic review flowchart.

We undertook data extraction and summary according to the author, publication year, sample size, age, sex, training intervention characteristics, methodological protocols, outcome measurements, and main results. We extracted other information regarding calculations of training volume based on the methods section of each article whenever possible. The difference in percentage change from the baseline of the main variable of each study was calculated by the following equation: $\frac{post*100}{pre} - 100$ (HIGGINS; LI; DEEKS, 2021). This analysis provided the average percentage gain of each intervention, assuming the pre-test performance as 100% and calculating the difference between this score and the value obtained in the post-test. Some data was multiplied by -1 to change the score sign, so positive values indicate positive results following training. Because the standard deviation of the percentage change from baseline was not available, confidence intervals for this information could not be calculated. All extracted data were entered into a Microsoft Excel spreadsheet for later description. As methodological heterogeneity between selected studies prevented a meta-analysis, we reported our findings descriptively mainly in tables.

3 RESULTS

We included 13 articles in the present review (GIBOIN; GRUBER; KRAMER, 2018; KAMIKURA; SAKURABA; MIURA, 2018; LAUFER, 2008; LI et al., 2016; MARCORI et al., 2020; OLIVEIRA et al., 2013; ROTHERMEL et al., 2004; SCHLENSTEDT et al., 2017; SILVA et al., 2018a, 2018b; VAN DIEËN; VAN LEEUWEN; FABER, 2015; VERNADAKIS et al., 2012; YASUDA; SAICHI; IWATA, 2018).

Among selected articles, the median PEDro score was 5 (range: 4 - 6), indicating experiments of moderate quality within these articles (CASHIN; MCAULEY, 2020). We considered this level of methodological quality sufficient for interpretations of most findings. Specific PEDro scores for each experiment are presented below (see Figure 2). One included article had a single-group experimental design and was not rated with the scale (VAN DIEËN; VAN LEEUWEN; FABER, 2015). Cohen's Kappa coefficient revealed a raters' agreement score of 0.89 ($p < 0.001$), indicating excellent interrater agreement. The most common methodological weakness in these studies was a lack of blind assessors, participants, and therapists (trainers, in this case) when assessing outcomes. An improvement in this methodological aspect of future studies would reduce risk of bias, especially in research designs with more than one group.

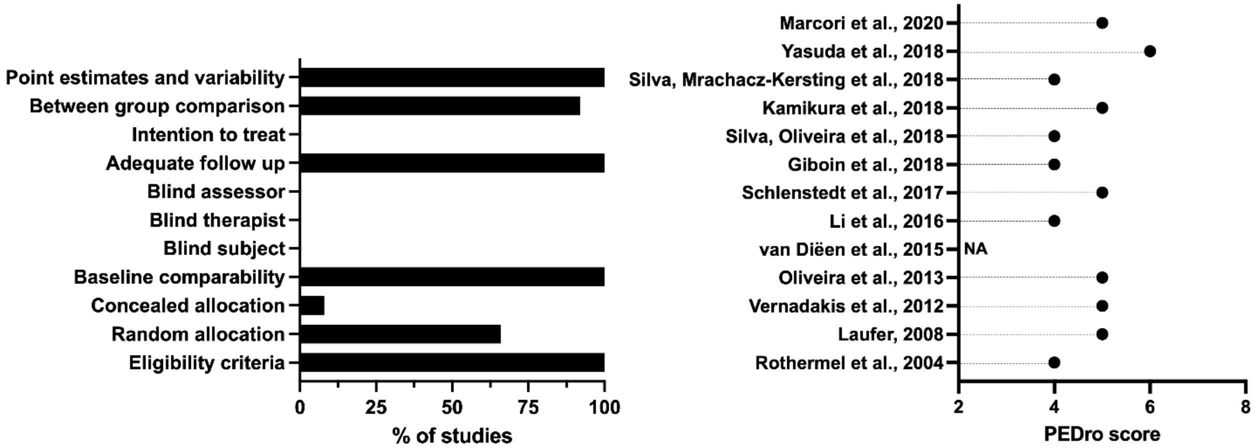

Figure 2. Outcomes from Physiotherapy Evidence Database Scale Quality Assessment. NA = information not available

The main characteristics and findings from articles included in this review are presented in Table 1. Single session interventions varied from 30 to 50 minutes' duration for both younger (MARCORI et al., 2020; VAN DIEËN; VAN LEEUWEN; FABER, 2015) and older (YASUDA; SAICHI; IWATA, 2018) adults. Multi-session interventions varied from two (KAMIKURA; SAKURABA; MIURA, 2018) to 14 weeks of separate sessions (LI et al., 2016), with four weeks being the most common (ROTHERMEL et al., 2004; SCHLENSTEDT et al., 2017; SILVA et al., 2018a, 2018b). Training frequency range was 2-5 sessions/week, with three times per week being the most usual frequency. Training sessions usually lasted around 30 minutes, with an average of 10 minutes spent with warm-up and cool down exercises.

Based on the information provided in the methods section of each study, we estimated the amount of time that participants actually spent in unipedal stance and found that, for single-session experiments, 10-15 minutes was sufficient to induce adaptations in balance control, such as increments in balance time on a tilt platform (MARCORI et al., 2020; VAN DIEËN; VAN LEEUWEN; FABER, 2015). In multi-session interventions lasting over two weeks, estimated session times spent in single leg stance ranged from 40-390 minutes (see Table 1). Based on these results, it seems that a minimum of 40 minutes of unipedal stance accumulated throughout an intervention was sufficient to improve balance performance. However, a dose-response relationship could not be properly calculated, due to differences across studies in training, measurements, and experimental settings. Thus, it is not possible to estimate how much extra time spent training in multi-session programs affected incremental balance gains.

To suggest a minimal training volume that might elicit positive outcomes, we individually analyzed each experimental protocol and its results. The studies that provided at least 25 minutes per week of single leg balance over a minimum of four weeks yielded robust and persistent balance gains that were also transferred to different tasks (GADRE et al., 2019; OLIVEIRA et al., 2013; SCHLENSTEDT et al., 2017; SILVA et al., 2018a, 2018b). Hence, this volume of single leg balance training may be the minimal amount required to produce significant improvements in balance, and it represents our recommendation for future studies.

Table 1. Characteristics and main results of the single leg balance training interventions included in the review

	Participants	Main goal	Training	Surface	Progression	ETSLS	Results
Rothermel et al., 2004	n = 45, 27M 20.9 ± 2.4 y University students	Analyze the effect of active foot positioning in single leg balance training	4 weeks 12 sessions 10 min/session Trained one leg	Ground, foam pad	Arms and contralateral leg movements, vision, and surface	40 min.	Single leg + Active positioning 0
Laufer, 2008	n = 64, 17M 24 ± 31.1 y University students	Compare single leg training with dual cognitive task of high vs. low demand	3 days 3 sessions 15 min/session Trained one leg	Foam pad	NA	15 min.	HCD ++ LCD +
Vernadakis et al., 2012	n = 32, 18M 20.6 ± 0.6 y University students	Compare single leg training vs. balance training with Nintendo Wii	8 weeks 16 sessions 24 min/session Trained both legs	BOSU vs. Wii balance board	Arms and contralateral leg movements, and surface	144 min. (each leg)	Single leg + Wii +
Oliveira et al., 2013	n = 23, 23M 26.7 ± 3.6 y NA	Analyze the effect of unipedal training on cross-education	6 weeks 24 sessions 25 min/session Trained one leg	Ground, foam pad, unstable platform	Arms, contralateral leg, head, and trunk movements, vision, and surface	390 min.	Trained side ++ Non-trained side +
Van Diëen et al., 2015	n = 14, 5M 22.8 ± 2.2 y NA	Investigate the motor and sensory changes underlying learning of a single leg balance task	Single session 30 min. Trained one leg	Unstable platform	NA	15 min.	Adaptations: Muscular activity ++ Coordination ++ Sensorial +
Li et al., 2016	n = 80, 44M 68.8 ± 5.8 y Physically independent	Compare single leg training with vs. without association of biofeedback	14 weeks 30 sessions 5 min/session Trained both legs	Ground	NA	30 min. (each leg)	Single leg + Biofeedback ++
Schlenstedt et al., 2017	n = 51; 25M 55 a 70 y Physically independent	Analyze the effect of unipedal training on cross-education	4 weeks 16 sessions 15 min/session Trained one leg	Ground, foam pad, unstable platform	Arms, contralateral leg and head movements, and surface	144 min.	Trained side ++ Non-trained side +

Table 1. Continuation.

Giboin et al., 2018	n = 69; 47M 24 ± 4.3 y University students	Analyze the effect of practicing an additional balance task intra- or inter-session	3 weeks 6-9 sessions 20-30 min/session Trained one leg	Unstable platform, slackline	NA	Intra: 30 min. Inter: 60 min.	Intra: + Inter: +
Silva, Oliveira et al., 2018	n = 24; 24M 18 to 25 y University athletes	Analyze the effect of single leg training on landing mechanics after lateral jump	4 weeks 12 sessions 30 min/session Trained one leg	Unstable platform	Arms, contralateral leg and head movements, surface, and vision	180 min.	Adaptations: Muscular activity + Coordination ++
Kamikura et al., 2018	n = 33; 33M 20.8 ± 0.6 y Amateur athletes	Analyze the effect of single leg forward reaching training in athletic movements	2 weeks 10 sessions 20 reps/session Trained both legs	Ground	NA	25 min. (each leg)	Frontal landing 0 Lateral landing 0 Side turns 0
Silva, Mrachacz-Kersting et al., 2018	n = 24, 24M 25.3 ± 2.3 y Physically active	Analyze the effects of wobble board training on movement strategies to maintain single leg balance	4 weeks 12 sessions 30 min/session Trained one leg	Unstable platform	Arms, contralateral leg and head movements, vision, and surface	180 min.	Adaptations: Balance + Muscular activity + Coordination +
Yasuda et al., 2018	n = 20, 10M 71.9 ± 2.9 y Physically independent	Compare single leg training with vs. without biofeedback	Single session 30 min. Trained one leg	Ground	NA	12 min.	Single leg + Biofeedback ++
Marcori et al., 2020	n = 30, 16M 21.4 ± 1.5 y University students	Analyze asymmetries of cross-education (right leg vs. left leg training)	Single session 50 min. Trained one leg	Unstable platform	NA	10 min.	Right leg training ++ Left leg training +

Note. M = number of male participants; y = years; NA = not available/applicable; ETSLS = estimated time of single leg stance, throughout the entire intervention, calculated with the information available in the methods sections of each experiment; HCD/LCD = high/low cognitive demand; "+" indicates significant results for that group, from pre- to post-test; "++" indicates that the results of this group were significantly better than the results of the other group; "0" indicates lack of significant results for that group, from pre- to post-test.

Overall results of the main outcome of each experiment are presented in Figure 3. Twelve of the thirteen studies indicated a significant difference from pre- to post-test for the single leg training group (see Table 1 for more details). As shown in the detailed methodological characteristics of the reviewed experiments in Table 2, significant gains in balance performance were observed in different variables, like CP length, CP velocity, balance time on a tilt board, stability index, and muscular activity. While a meta-analysis could not be performed due to high heterogeneity between experiments, these results point toward a shared positive outcome for balance training in distinct analysis, variables, and training settings.

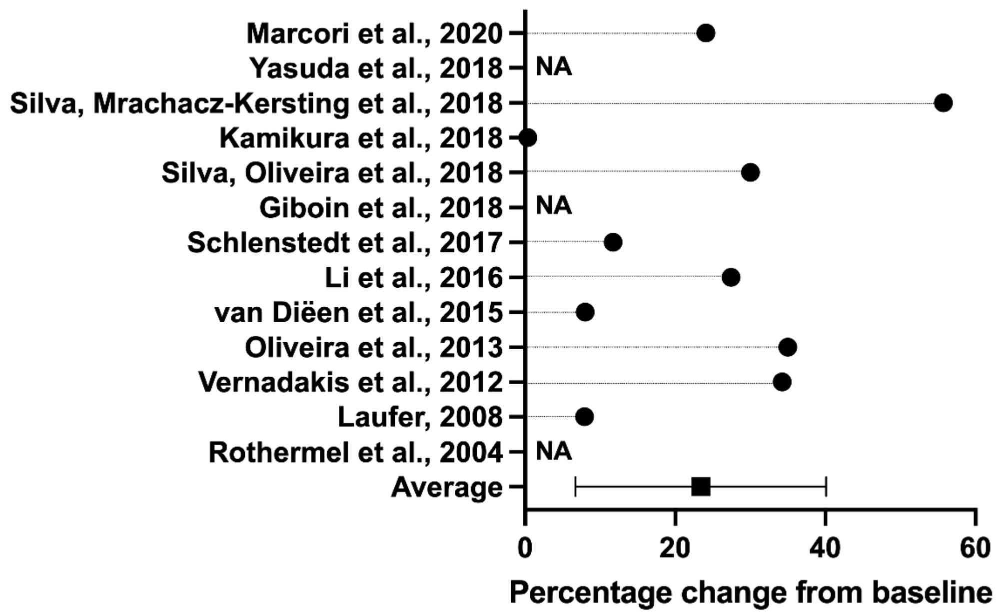

Figure 3. Difference in percentage change from baseline for the main outcome of each experiment. The black square and horizontal bars represent the average and standard deviation across experiments, respectively; NA = information not available.

Most investigations used a force plate or equivalent device to evaluate balance stability, based on CP displacement amplitude or velocity (LAUFER, 2008; LI et al., 2016; OLIVEIRA et al., 2013; ROTHERMEL et al., 2004; SCHLENSTEDT et al., 2017;

SILVA et al., 2018b; VERNADAKIS et al., 2012; YASUDA; SAICHI; IWATA, 2018). The other studies analyzed effects of unipedal balance training through ground reaction forces with a specific device (KAMIKURA; SAKURABA; MIURA, 2018), movement patterns and coordination through kinematic analysis (GIBOIN; GRUBER; KRAMER, 2018; VAN DIEËN; VAN LEEUWEN; FABER, 2015), total balance time measured with a custom platform or reflective markers (MARCORI et al., 2020; SILVA et al., 2018b), and muscle activation pattern through electromyography (SILVA et al., 2018a).

The experimental tasks used for evaluation varied in time, length and support surface. Evaluation time length was 10-60 seconds, with most quiet standing protocols lasting about 30 seconds. The support surface for evaluation was either stable, like the surface of a force plate, or unstable like a tilt platform or a wobble board. A single experiment assessed perturbed posture by applying unpredictable translations of the support base while participants stood on a unipedal stance (OLIVEIRA et al., 2013). Other experiments used tasks closer to the sporting context, such as lateral jumping (SILVA et al., 2018a) and a sequence of athletic movements such as turning, landing and jumping (KAMIKURA; SAKURABA; MIURA, 2018). Only a few of the included studies employed more than one type of equipment in their evaluation protocol, sometimes combining force plate with EMG (OLIVEIRA et al., 2013; SILVA et al., 2018b) or kinematic analysis (SILVA et al., 2018a).

Table 2. Methodological aspects of the single leg balance training interventions

	Probing task	Main equipment	Main variable	Training type	Probing task equal to training	Retention test analyzed
Rothermel et al., 2004	15s single leg stance on stable surface	Force plate	CP velocity (cm/s)	Dynamic	No	No
Laufer, 2008	20s single leg stance on stable surface with dual cognitive task	Force plate	CP velocity (cm/s)	Static	Yes	Yes / 2 days
Vernadakis et al., 2012	20s single leg stance on unstable platform	Biodex Stability System	Stability Index	Dynamic	No	No
Oliveira et al., 2013	Forward perturbations on a moveable platform in single leg stance	Force plate	CP velocity (m/s)	Dynamic	No	No
Van Diëen et al., 2015	16s single leg stance on unstable platform	Optotrak	Joint coordination and COM control	Dynamic	Yes	No
Li et al., 2016	30s bipedal stance on stable surface	Balance-A device	CP length (cm)	Static	No	No
Schlenstedt et al., 2017	30s single leg stance on stable platform	Force plate	CP velocity (mm/s)	Dynamic	No	Yes / 4 weeks

Table 2. Continuation

Giboin et al., 2018	20s single leg stance on unstable platform	Vicon Nexus	Balance time on tilt board (s)	Dynamic	Yes	No
Silva, Oliveira et al., 2018	Single leg landing from a maximal lateral jump	Electromyography	Modular organization of muscle activity (coordination)	Dynamic	No	No
Kamikura et al., 2018	Take-off jump, frontal and lateral landing, and turning	Ground reaction force meter	Ground reaction force (N)	Dynamic	No	No
Silva, Mrachacz-Kersting et al., 2018	Up to 60s single leg stance on unstable platform	Force plate	Balance time on wobble board (s)	Dynamic	Yes	No
Yasuda et al., 2018	30s single leg stance on stable surface	Wii balance board	CP velocity (mm/s)	Static	Yes	Yes / 5 days
Marcori et al., 2020	10s single leg stance on unstable platform	Custom unstable platform	Balance time on tilt board (s)	Dynamic	Yes	Yes / 1 week

Note. CP = Center of pressure; COM = center of mass.

4 DISCUSSION

In the present review, we aimed to analyze experimental research that investigated the outcomes of single leg balance training in healthy younger and older adults. Moreover, we sought to describe the training protocols, progression, structure, main outcomes, and potential implications of these studies. Thus, we will discuss our findings in the context of recent literature regarding balance control, emphasizing the effects of single leg balance training and offering suggestions for future research.

4.1 Training protocols, progression, and structure

To promote improvements in balance control, most studies we reviewed employed structured training progressions. Arm, contralateral leg, and trunk movements were sometimes added throughout the training sessions to increase the participants' challenge during the intervention period (KAMIKURA; SAKURABA; MIURA, 2018; OLIVEIRA et al., 2013; ROTHERMEL et al., 2004; SCHLENSTEDT et al., 2017; SILVA et al., 2018a, 2018b; VERNADAKIS et al., 2012). Another strategy used to promote training progression was increasing surface instability (OLIVEIRA et al., 2013; ROTHERMEL et al., 2004; SCHLENSTEDT et al., 2017; SILVA et al., 2018a, 2018b; VERNADAKIS et al., 2012). Some increased task difficulty over training sessions through segmental movements (KAMIKURA; SAKURABA; MIURA, 2018; OLIVEIRA et al., 2013; ROTHERMEL et al., 2004; SCHLENSTEDT et al., 2017; SILVA et al., 2018a, 2018b; VERNADAKIS et al., 2012) starting by requiring participants to keep a quiet stance, and progressively adding arm, trunk, and free leg movements (e.g., shoulder flexion-extension, hip flexion-extension, reach out movement with trunk flexion, and combination of arm and leg movements). More complex tasks involved using the upper limbs, like for catching and throwing a ball, and bouncing a ball on the floor (SILVA et al., 2018b; VERNADAKIS et al., 2012). Head tilts, sideways and back and forth, were also applied to increase balance difficulty (SILVA et al., 2018a). Each experiment provided their own unique progression structure, while the common point across investigations was complexity, incrementally increasing requirements for coordinative movements with moving limbs. For instance, simple arm movements (such as shoulder flexion) might be performed first, with catching and throwing a ball coming later in the training program.

Participants progressed throughout the training sessions, or within a session, based on the criterion of being able to perform a set of required movements. Once those movements could be performed with minor imbalances, progressions were made toward more challenging tasks.

These manipulations of complex multi-limb movements may be optimal for single leg training, as recent evidence has shown that the upper limbs, trunk, and the contralateral leg are consistently used to compensate for balance perturbations (DE SOUZA et al., 2019). These segments have been shown to play a role in maintenance (TEIXEIRA; COUTINHO; COELHO, 2018) and recovery (LOWREY; NASHED; SCOTT, 2017) of dynamic balance control, suggesting that balance control involves whole-body movements. Hence, training multi-limb movements in single leg stance could tackle this precise adaptation of balance control, offering the opportunity to fine-tune this complex motor strategy for maintaining body balance.

Progressions through manipulations of support base malleability were made by using equipment like foam pad, malleable semi-circle, and wobble board (OLIVEIRA et al., 2013; ROTHERMEL et al., 2004; SCHLENSTEDT et al., 2017; SILVA et al., 2018a, 2018b; VERNADAKIS et al., 2012). The most common means of applying this progression was to change from a stable (ground) to unstable surfaces once participants were able to perform the required set of movements selected for that phase of the training program. Studies in which training progression was implemented through surface instability were the same studies that employed progressions through multi-limb movements (OLIVEIRA et al., 2013; ROTHERMEL et al., 2004; SCHLENSTEDT et al., 2017; SILVA et al., 2018a, 2018b; VERNADAKIS et al., 2012). Due to this overlap, it was not possible to separate the contributions of surface instability and multi-limb movements as paths to dynamic balance stability gains. It is worth mentioning, however, that a previous systematic review of balance training in healthy adults suggested that challenging the neuromotor system by either requiring stabilization on unstable surfaces or making other complex body movements might produce equivalent effects (DISTEFANO; CLARK; PADUA, 2009). The question as to which form of progression promotes better outcomes in single leg balance training is still to be answered. Additionally, no investigation directly compared whether adding progressions would produce better results in balance performance. Thus, the question remains open as to whether different types of progressive training (with more challenging progressions vs. protocols with a single exercise) differentially affect balance performance outcomes.

We identified a study that applied multi-limb movements in single leg stance for older adults (SCHLENSTEDT et al., 2017). This study found significant improvements in CP stability during quiet single leg stance after four weeks of training in which there were progressive increments in balance difficulty through the addition of increasingly complex movements with the free leg, arms, and head. However, the control group in this study was sedentary, leaving unanswered the question of whether training with a less challenging protocol, such as bipedal exercises usually prescribed to older adults, would produce different results. The other studies in this review that assessed older adults applied static single leg balance training without training progression, and these investigators also showed balance performance gains among their participants (LI et al., 2016; YASUDA; SAICHI; IWATA, 2018) (see Table 1). Since training (duration, frequency) and evaluation (experimental task, equipment) protocols differed between these investigations, direct comparisons of these studies' findings are not possible. We should mention, however, that even with a short intervention time of two minutes per day of single leg stance and without any type of progression in challenge, these researchers observed increased balance stability when participants were evaluated in quiet bipedal stance (LI et al., 2016). Similarly, they observed better balance control, as indicated by decreased CP velocity, after a single session of single leg balance training for older adults (YASUDA; SAICHI; IWATA, 2018). Results from these two older adult experiments (LI et al., 2016; YASUDA; SAICHI; IWATA, 2018) reveal the efficacy of single leg balance training when used to promote positive adaptations even without difficulty progression in this population.

4.2 Training outcomes

We observed different adaptations among participants in these studies, mainly due to the different measurement protocols, experimental tasks and equipment used across the experiments. The most common finding among these studies was a reduction in CP displacement (LAUFER, 2008; ROTHERMEL et al., 2004; VAN DIEËN; VAN LEEUWEN; FABER, 2015; VERNADAKIS et al., 2012) and velocity (OLIVEIRA et al., 2013) after training. Older adults also showed reduced CP displacement and velocity following single leg balance interventions (LI et al., 2016; SCHLENSTEDT et al., 2017; YASUDA; SAICHI; IWATA, 2018). These CP-related adaptations are postulated as a positive aspect of postural control (WINTER, 1995), as they reflect the neuromotor system's capacity to integrate afferent and efferent inputs to maintain balance (HORAK, 2006). Moreover, recent evidence has suggested that reduced CP displacement assessed in quiet stance can be interpreted as an attempt to minimize sway amplitude to promote safety and a more stable postural position (BORZUCKA et al., 2020) – an adaptation observed in both younger and older adults (CARPENTER et al., 2006). Thus, an important improvement in postural control was provided by single leg balance training.

Two other relevant adaptation features following single leg balance training were (a) reduced lower limb muscle activation (OLIVEIRA et al., 2013; SILVA et al., 2018a, 2018b; VAN DIEËN; VAN LEEUWEN; FABER, 2015), and (b) refined whole-body dynamic coordination in using the arms, contralateral leg, and trunk to maintain balance (SILVA et al., 2018b; VAN DIEËN; VAN LEEUWEN; FABER, 2015). These two adaptations suggest an initial suboptimal strategy in which participants focused on increasing muscular activity and co-contraction levels of the ankle and shank muscles to reduce joint oscillations. With training, this strategy was gradually replaced by a more effective and integrated whole-body dynamic control, enhancing balance performance. Even though one of the main strategies used to maintain balance in challenging postures is the hip strategy (FREYLER et al., 2015), recent evidence has shown active participation of the contralateral leg, trunk, and arms to maintain balance in perturbed conditions (DE SOUZA et al., 2019). Thus, single leg balance training with multi-limb movements can promote specific adaptations, leading, in turn, to increased dynamic balance stability.

Balance assessment using a tilting or unstable platform revealed increased balance time after training (GIBOIN; GRUBER; KRAMER, 2018; MARCORI et al., 2020; SILVA et al., 2018b). In this scenario, balance gains might be explained by an attenuation of reflex excitability (KELLER et al., 2012) and increased cortical control (MCILROY et al., 2003). Keller and colleagues (2012) suggested that stability gains after balance training are a consequence of suppressed Ia-afferent excitation to the alpha-motoneurons, causing an inhibition of exaggerated reflex responses provoking exaggerated joints' oscillation and balance instability. This is especially relevant for training using tilt platforms, in which a perturbation in one direction might cause an exaggerated muscular response leading to a perturbation in the opposite direction. Thus, fine-tuning muscle activation is essential to maintain balance in these unstable conditions. As such, reduced muscle activation in the lower limbs found after single leg training on a tilting platform (SILVA et al., 2018b) is in line with this notion. Parallel to this peripheral adaptation, enhanced cortical processing of sensory afference also occurs with balance training (MCILROY et al., 2003). Since the ability to maintain balance depends on processing and integrating different sensory inputs (HORAK, 2006), the accumulated evidence suggests that single leg balance training can induce more efficient processing in the somatosensory cortex due to repeated exposure to challenging balance conditions. This central adaptation, then, suggests the possibility of improving balance performance in tasks that are not specifically trained.

The issue of specificity in balance adaptation has been previously reviewed by Paillard (2017) who suggested that balance training usually does not promote gains in different tasks from those that were trained, except in cases of individuals with low levels of balance performance, like older adults. In our review, balance evaluation tasks were different from the training task in seven of the 13 experiments (KAMIKURA; SAKURABA; MIURA, 2018; LI et al., 2016; OLIVEIRA et al., 2013; ROTHERMEL et al., 2004; SCHLENSTEDT et al., 2017; SILVA et al., 2018a; VERNADAKIS et al., 2012). Except in one research (KAMIKURA; SAKURABA; MIURA, 2018), all revealed a transfer of balance gains. Generalization occurred in distinct situations: (a) from static training to static evaluation (LI et al., 2016), (b) from dynamic training to static evaluation (ROTHERMEL et al., 2004; SCHLENSTEDT et al., 2017), and (c) from dynamic training to dynamic evaluation (OLIVEIRA et al., 2013; SILVA et al., 2018a; VERNADAKIS et al., 2012). In dynamic training to dynamic evaluation, participants underwent a training program that had a high demand for dynamic balance, by performing single leg stance on unstable surfaces associated with multi-limb movements (see “Training progression” and Table 1 for more details). This leads to the notion that the level of challenge to maintain balance imposed by the tasks applied in training may play a role in the transfer of learning.

Among amateur athletes, both task complexity and training volume seem to mediate generalization of gains. A single exercise without progressions and a total exercise volume of 25 minutes over two weeks showed no transfer of learning to sporting tasks (KAMIKURA; SAKURABA; MIURA, 2018). On the other hand, training programs with progressive balance difficulty and high volume (>45 minutes of single leg stance per week) showed increments in balance performance on tasks not directly trained (GADRE et al., 2019; SILVA et al., 2018a). Our review points towards the idea that higher training volumes associated with adequate progression of training difficulty and increasing the balance demand throughout the intervention were able to promote gains that were transferred to untrained tasks (ROTHERMEL et al., 2004; VERNADAKIS et al., 2012), including the challenging sporting context (GADRE et al., 2019; SILVA et al., 2018a).

We found through this review that, among older adults, two experiments used a probe task that was distinct from the training task, and both showed generalization of balance gains (LI et al., 2016; SCHLENSTEDT et al., 2017). In these interventions, training conditions involved single leg balance, while the evaluation was made in the bipedal stance – again, showing a transfer of gains from a complex to a simpler task. Aside from the issue of task complexity, previous evidence has already suggested an increased possibility of balance gain generalization for older adults due to their initially low levels of balance stability (PAILLARD, 2017). Thus, findings of generalization agree with both these notions, i.e., increased task complexity during training and initial lower levels of balance may enhance the transfer of balance gains to untrained tasks.

Another form of generalization of gains is cross-education, observed when performance increases with a limb due to contralateral training. This phenomenon was observed in the studies we reviewed that tested balance gains in the non-trained leg (KAMIKURA; SAKURABA; MIURA, 2018; LAUFER, 2008; MARCORI et al., 2020; OLIVEIRA et al., 2013; ROTHERMEL et al., 2004; SCHLENSTEDT et al., 2017). Three studies specifically addressed the issue of cross-education, with results documenting improvement in balance stability achieved with the trained leg transferred to the contralateral untrained leg following a single training session (MARCORI et al., 2020), and following training programs lasting four weeks (SCHLENSTEDT et al., 2017) and six weeks (OLIVEIRA et al., 2013) (see Table 1). Moreover, transfer of learning occurred either with training progression (OLIVEIRA et al., 2013; SCHLENSTEDT et al., 2017) or with constant training difficulty (MARCORI et al., 2020), suggesting that inter-lateral transfer of learning can occur independently of increasing balance difficulty during training. This idea seems to apply equally to different forms of evaluation. Cross-education was observed in quiet (SCHLENSTEDT et al., 2017), perturbed (OLIVEIRA et al., 2013), and dynamic (MARCORI et al., 2020) balance training (for more details, see Table 2). Therefore, the reviewed results support the notion that cross-education is a consistent effect in single leg balance training.

4.3 Limitations and directions for further research

A main limitation of this review was that no article we reviewed directly compared single leg to bipedal balance training. Moreover, there was a lack of consistency across studies in terms of training settings and measurement of balance gains. Another common gap in these studies was the absence of neural/cortical measures that might explain cortical activity associated with balance gains from unipedal training. Finally, while not within the scope of this review, it is important to note that we did not analyze balance training in individuals with any form of balance impairment, meaning that generalization to those populations should be made with caution. These are all appropriate directions for further research.

5 CONCLUSIONS

In the present review, we identified that single leg balance training protocols are effective for promoting balance gains in healthy adults. From the evidence we reviewed, single- or multiple-session training, with or without difficulty progression in the training, induced persistent increments in balance control among both younger and older healthy adults. Additionally, these studies showed generalization of balance gains to untrained tasks and cross-education between legs with single leg balance training. These conclusions from past research may aid trainers, coaches, and practitioners in applying single leg balance in their training routines, and they provide useful information to support science-based exercise prescription.

CHAPTER III

SINGLE LEG VS. BIPEDAL BALANCE TRAINING IN OLDER ADULTS

Abstract

Body balance training literature lack investigations comparing different demands of balance control. We aimed to evaluate the effects of a single leg balance training (SBT) program compared to a less demanding bipedal balance training (BBT) program in older adults. Sixty-six community dwelling older adults (age range 60 to 80 years) were recruited and randomized into three groups: SBT (n = 22; 4 men), BBT (n = 22; 6 men), and untrained control group (CG; n = 22, 5 men). Participants received a 12-week intervention of a challenging dynamic balance training program, while the CG participated only in the pre- and post-test evaluation. Dynamic and reactive balance were assessed in a force plate by means of cyclic oscillation and single unexpected displacement of the support base, respectively. Cognition was assessed through the trail-making and Rey auditory verbal learning tests. Legs' strength was measured through the 30-s sit-to-stand test. Results showed equivalent improvements across the three groups from the pre- to the post-test in balance control, given by reduced center of pressure displacement, and also in the cognitive tests. Strength gains was observed in the intervention groups only. These results lead to the conclusion that both SBT and BBT have similar potential to promote balance, cognitive, and strength gains in older adults.

1 INTRODUCTION

The ability to maintain balance is invaluable to older adults. The risk of falling at least once a year, in individuals aged 65 years or more, is around 30-40% (CUMMING et al., 2008). According to the 2021 World Health Organization report, falls are the second leading cause of accidental/non-intentional deaths worldwide, affecting more prominently older adults from underdeveloped countries (WHO, 2021). While not all falling-related accidents are fatal, recent evidence has pointed that around 10% of falls lead to injuries and hospitalization needs (MORELAND; KAKARA; HENRY, 2020). These hospitalizations periods tend to be accompanied by immobilization due to fractures (NORDELL et al., 2000; SPANIOLAS et al., 2010), which, in turn, can lead to severe loss of functional capacity, as older adults are more susceptible to deleterious effects of muscle disuse (HVID et al., 2010). This loss of function can dangerously leave the individual either within a frailty threshold, a persistent motor deficit, or unable to perform daily living activities (CARSON, 2015; ROH et al., 2017). To prevent this scenario, behavioral interventions have been proposed, among which balance training is the most recommended to improve balance control in this population (LELARD; AHMAIDI, 2015; SHERRINGTON et al., 2011).

Despite the relevance of balance training, research on this topic has been heterogeneous considering the exercises applied (LESINSKI et al., 2015). Previous training interventions in older adults varied from using on-water exercises (OSTI; DE SOUZA; TEIXEIRA, 2017), treadmill slip induction (KURZ et al., 2016), slackline (DONATH et al., 2016), public park machines (LEIROS-RODRÍGUEZ; GARCÍA-SOIDAN, 2014), and simple bodyweight exercises (NAGAI et al., 2012). While results from all of these interventions showed some form of improvement in balance control, they diverge in the level of balance demand regarding the applied exercises. As highlighted in the two previous chapters of the present dissertation, task complexity and high levels of motor challenge can be an important mediator in the outcomes of training (CAREY; BHATT; NAGPAL, 2005; MARCORI et al., 2022). The current literature, though, leaves unsolved the issue of which level of balance demand (higher vs. lower) is the optimal to improve balance control in older adults. Hence, comparing the effects of an intervention between groups with different levels of balance demand can advance the knowledge in the field.

Constraining the support base to single leg stance is a stablished strategy to increase the balance demand of balance tasks (MUEHLBAUER et al., 2012). Single leg balance training has shown persistent and consistent results in younger adults, with improvements in single leg balance time (GIBOIN; GRUBER; KRAMER, 2018; MARCORI et al., 2020), joint coordination and center of mass control (VAN DIEËN; VAN LEEUWEN; FABER, 2015), coordination of muscle activity (SILVA et al., 2018a), and CP control (LAUFER, 2008; ROTHERMEL et al., 2004) – assessed in different tasks and contexts. However, outcomes of single leg balance training in older adults are limited to increased CP control during static bipedal (LI et al., 2016) and unipedal balance on a stable surface (SCHLENSTEDT et al., 2017; YASUDA; SAICHI; IWATA, 2018). Detailed evaluation of balance capacities after single leg training was not performed in previous investigations with older adults (cf. Chapter II, Table 2). Considering that balance is a complex motor ability, evaluation of training outcomes should comprise the distinct manifestations of balance control (dynamic and reactive), lower limbs' strength, and executive cognitive functions – as these are all related to balance performance (DEMNITZ et al., 2017; HORAK, 2006). Of increased relevance are the capacity to respond to an unexpected perturbation and maintain balance in dynamic conditions, as these represent common scenarios related to balance loss in older adults (O'CONNOR et al., 2017; ROBINOVITCH et al., 2013).

The capacity to properly select a muscular strategy and respond to an unexpected balance perturbation depends on the sensorimotor integration to generate an efficient postural response (TING, 2007). By training balance in dynamic conditions, the individual is exposed to constant imbalances, which can prime the neuromotor system to learn predicting bodily position in space during self-produced movements. This adaptation is interpreted as a refinement of internal models, defined as an internal neural representation of the body formed by the integration of continuous information processing from the vestibular and somatossensorial systems (PAILLARD, 2017). From this perspective, an adequate training protocol of challenging dynamic balance conditions can refine internal models, increasing individuals' capacity to predict the consequences of their voluntary movements (and involuntary, in case of perturbations) and maintain the center of mass within the support base, thus improving balance control. Research showing positive adaptations in postural responses via feedforward mechanisms after perturbed balance training in older adults agree with this notion (COELHO et al., 2018; PAI; BHATT, 2007). Indeed, with a challenging balance training program, the CNS processes the sensorial information gathered in the first trials of a given movement to improve subsequent motor responses, shifting from a reactive control based on feedback, towards a proactive control based in feedforward mechanisms (BHATT; PAI, 2005). Considering the evidence suggesting losses of balance occur mostly due to incorrect voluntary movements – such as weight shifts and turning (O'CONNOR et al., 2017; ROBINOVITCH et al., 2013), the capacity to predict (i.e., feedforward) the consequences of body movements in space is crucial to older adults. Therefore, the coordinative demand created by complex single leg movements can be a promising training approach in this context, with increased potential to improve reactive and dynamic balance control in older adults.

Evidence from single leg balance training programs in older adults come from a reduced number of investigations and protocols. Previous studies either lacked movement complexity and variation, training only quiet single leg stance (LI et al., 2016; YASUDA; SAICHI; IWATA, 2018), or applied complex tasks but focused on static and not reactive/dynamic balance responses after training (SCHLENSTEDT et al., 2017). As noted in the systematic review (Chapter II), no previous investigation has compared a unipedal vs. bipedal balance training program in older adults, and assessment of intervention outcomes were limited to static balance. Although both of these topics have theoretical relevance for understanding manifestation of balance control adaptations after training and potential practical application for exercise prescription for older individuals, these issues have been left untouched in previous research. In the current investigation, we aimed to evaluate the global effects (balance, strength, and cognition) of a single leg balance training program compared to a bipedal balance training program in older adults. Based on previous research with younger adults showing consistent improvements in single leg training programs (MARCORI et al., 2020; SILVA et al., 2018a; VAN DIEËN; VAN LEEUWEN; FABER, 2015), and associated evidence for the role of motor complexity in neuromotor adaptations (CAREY; BHATT; NAGPAL, 2005; HODGES; LOHSE, 2020), we hypothesized superior gains in balance control, executive cognitive functions, and strength for the single leg training group.

2 METHODS

2.1 Participants

Sample size was calculated a priori with G*Power 3.1 (Franz Faul, Germany), for a two-way analysis of variance 3 (group) x 2 (evaluation: pre- and post-test) with repeated measures on the second factor. We considered a moderate effect size ($f = 0.3$), significance at $\alpha = 0.05$ and a power of $(1-\beta) = 0.95$, according to recommendations (FAUL et al., 2007). Based on these parameters, this calculation indicated a minimum of 48 participants.

Participants were recruited from the local community around University of São Paulo, via advertising in the University's website and social media. After advertising in the community, a total of 120 participants were screened for eligibility. Inclusion criteria were the following: age between 60 and 80 years old, no musculoskeletal, sensorial or neurological diseases that could impair training participation, no continuous usage of balance-affecting medication, no involvement in systematic balance training in the previous year, and a Mini Mental State Examination (FOLSTEIN; FOLSTEIN; MCHUGH, 1975) score above 23. Each participant was individually contacted via personal phone and an interview was scheduled. After conducting the individual interviews, 66 participants were selected. They were randomized intro three groups: single leg balance training (SBT; n = 22, 4 men); bipedal balance training (BBT; n = 22, 6 men); and untrained control group (CG; n = 22, 5 men). Prior to research initiation, all individuals provided informed consent (Appendix A, page 73) and clearance to exercise from a cardiologist. All procedures were approved by the ethical committee of the University of São Paulo (CAAE 20284919.2.0000.5391, Process N° 3.681.879; Attachment B, page 69). General characteristics of the three groups are presented in Table 3.

Table 3. General characteristics of the participants (mean and standard deviation)

	Single-leg balance training (n = 22)	Bipedal balance training (n = 22)	Control group (n = 22)
Age (years)	69.91 ± 4.91	69.52 ± 4.76	69.95 ± 5.42
Height (m)	1.61 ± 0.10	1.63 ± 0.12	1.60 ± 0.08
Weight (Kg)	69.67 ± 15.87	68.67 ± 14.54	66.71 ± 12.14
MMSE (score)	29 ± 1	28 ± 1	28 ± 1

Note. MMSE = Mini Mental State Examination.

2.2 Experimental protocol

This research was conducted in four steps: 1) enrollment and assessment for eligibility; 2) randomization, group allocation and pre-test; 3) 12 weeks of training intervention; and 4) post-test assessment for analysis. Pre-test was applied before intervention began, and post-test was applied after the last training session with a minimum of 48 h rest. The training sessions, conducted in the University sports facility, were 60 min. long (10 min. warm up, 40 min. main balance exercises, 10 min. cool down and stretching) and administered twice per week, totaling 24 sessions. Participants in the training groups were sub-divided into two groups of about 11 individuals for training administration, and Physical Education professionals supervised the sessions to ensure safe and consistent exercise performance. To control for potential circadian cycle effects, half of the participants in each group trained in the morning (10 to 11 AM), and the other half in the afternoon (4 to 5 PM). The training groups were blind to the research manipulation, i.e., unaware that other participants were receiving a different training program. Participants were excluded from the analysis if unable to participate in more than 75% of the training sessions due to any reasons (i.e., 18 sessions or more). The flow diagram of the experimental protocol is illustrated in Figure 4.

2.3 Balance training

The SBT group received challenging, dynamic postures while in single leg stance. During training, participants performed coordinated movements with the upper limbs, the non-supporting leg, and trunk. As suggested by previous reviews on the topic (LESINSKI et al., 2015; MARCORI et al., 2022), training progressions were applied to promote increasing challenge and to induce the expected adaptations. Progressions were organized according to training difficulty by manipulating movement complexity (from single- to multi-joint, and single- to multi-directional movements), speed (from slow to fast), and contextual interference (from low to high). A list of movements and progressions is provided in the Appendix B (page 77). The entire program was structured in four training blocks of 3 weeks each: 1st block, single- and multi-joint movements in the same direction, using arms and leg; 2nd block, addition of movements to different directions for each limb and more complex coordination patterns, including head movements; 3rd block, addition of objects to manipulate, and multi-directional movements with the arms, leg, and trunk; and 4th block, combination of head movements, visual restriction, and increased time supported in each movement. The 40-min. main part was composed of 4 to 5 exercises, performed in 3-4 sets of 8-12 repetitions each leg, followed by a complete sequence combining all movement patterns of the previous exercises in 2-3 sets of 10 repetitions, and a final 10-min group activity in which participants interacted with each other maintaining single leg balance and manipulating objects (e.g., passing balls of different sizes and weights). Average single leg balance time was 12 min/leg/session, totaling 288 min. for each leg, or 576 min. total, at the end of the intervention. Our training volume is in agreement with the most recent systematic review on single leg balance training, which suggested at least 25 min/week of single leg stance for interventions longer than 4 weeks (MARCORI et al., 2022).

The BBT group practiced dynamic postures supported on bipedal stance. During training, participants performed coordinative movements with the arms, legs, trunk, and head. The bipedal stance guarantees an ample support base, favoring body balance stability, and reducing balance demand as compared to the SBT group. Training principles, progressions, session structure, and administration protocols were equivalent to those applied in the SBT. The main purpose of this group was to provide a dynamic balance training program with reduced demand, but similar coordinative (between the arms) and strength requirements as those in the SBT. Training tasks applied to this group were as similar as possible to those applied to the SBT group, adapted for bipedal stance.

The CG group received no intervention. Participants were instructed to not enroll in any formal exercise program and continue their daily activities as usual. The main purpose of this group was to analyze the testing effect of the evaluation (i.e., if repeated assessment induces gains in performance). These participants were offered the opportunity to enroll in the training program as soon as the research ended.

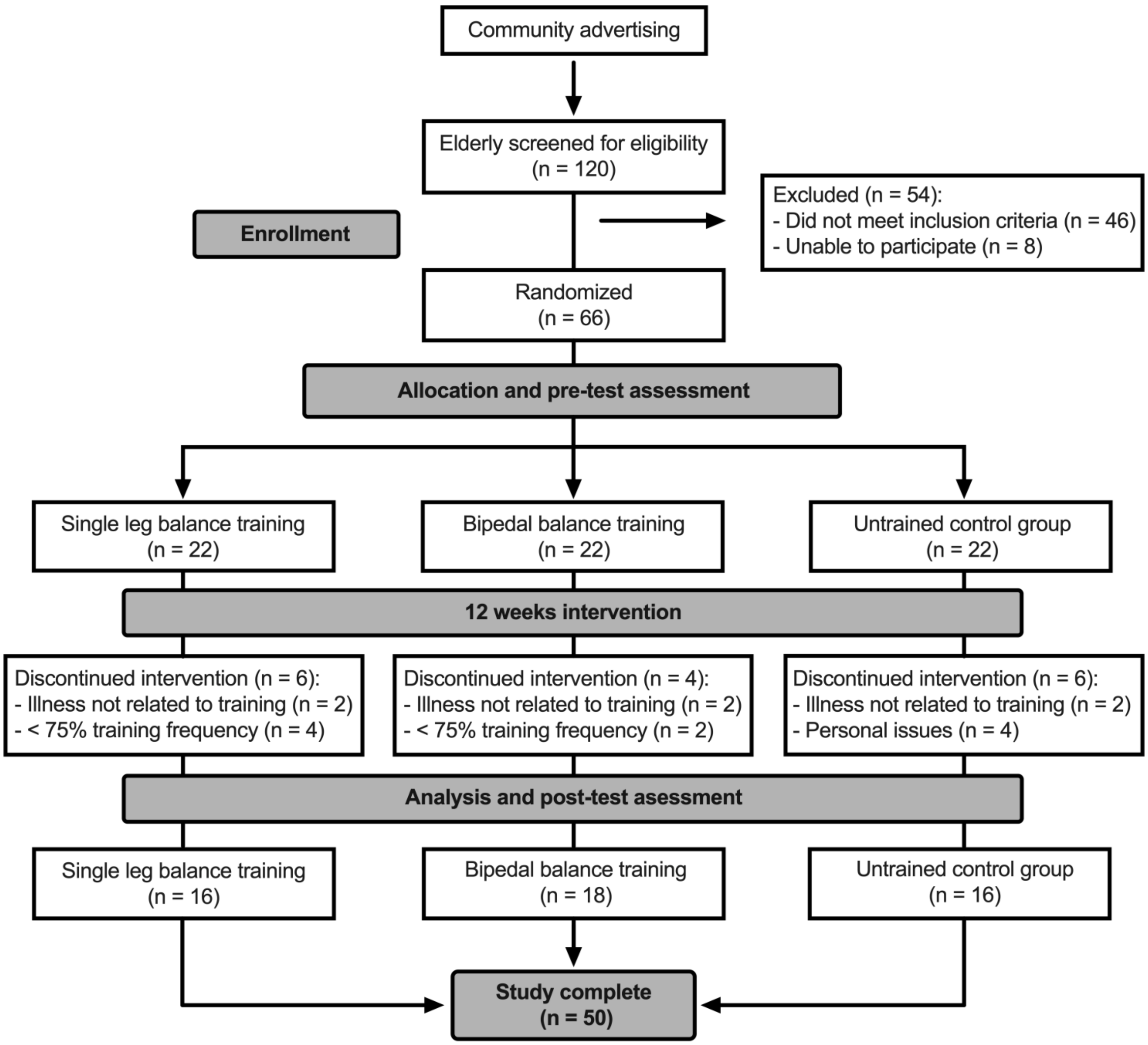

Figure 4. Flow diagram of the study.

2.4 Tasks, equipment, and variables

The pre- and post-test assessments were multifactorial, having as the primary goal to evaluate balance performance of different tasks in both mediolateral (ML) and anteroposterior (AP) axes, and as secondary goals to measure performance of executive cognitive functions and lower limbs' strength. As previous evidence has suggested high specificity of balance gains (PAILLARD, 2017), we selected for the assessment balance tasks that were not directly trained in neither group. Order of balance tasks was randomized across participants. Complete evaluation session lasted approximately 50 min. per participant.

2.4.1 Dynamic balance

The dynamic balance evaluation consisted of keeping dynamic equilibrium on a moveable support base generating sinusoidal horizontal translations in a single axis (either AP or ML). Participant's aim was to maintain upright posture through feet-in-place responses during 30 s trials. Frequency of platform oscillation was 0.8 Hz, and the amplitude of displacement was set at 10 cm. The moveable platform was custom built, having a force plate (AMTI, model OR6) as the support base. Platform displacement was controlled via software developed in LabVIEW (National Instruments). For each axis, participants had one familiarization trial followed by three probing trials in the same axis for data acquisition. No cueing was provided about platform displacement onset time, with trials randomly starting 2–5 s after verbal prompt. With these procedures, we prevented pre-planning of the ensuing movement or anticipation of platform movement onset (TEIXEIRA; COUTINHO; COELHO, 2018).

Participants received the following instructions: a) keep feet hip-width apart; b) keep both arms relaxed along the trunk, hands slightly touching the upper thigh; c) following platform translation, feet were to be kept in place, while arms and trunk could be used to recover balance; d) maintain visual focus on a spot placed 1 m away, at the eyes height; and e) refrain from trying to anticipate platform translation onset. Trials were repeated if a step was taken to recover balance. To prevent falls and injury risks, participants wore a safety harness attached to the ceiling, and a researcher always stood near the participant to aid in case of major losses of balance.

Center of pressure displacement data from the force plate, sampled at 200 Hz, was acquired through the Nexus software (Vicon Motion Systems, UK). In this evaluation, CP data was processed with a personalized routine in RStudio (RStudio, Inc., v.1.2.5001), following preliminary visual inspection of individual trial signals. Data was filtered (4th order, 10 Hz low-pass, Butterworth filter) before extracting the following variables: root mean square (RMS) of CP displacement in each axis. Average values of the three trials in each axis were computed for analysis.

2.4.2 Reactive balance

The reactive balance evaluation consisted of recovering stable body balance following a sudden translation of the supporting platform, keeping the feet in place. Balance was perturbed through 7-cm long platform translations, with peak velocity of 40 cm/s. The full trial of platform translation lasted 6 sec. after a random onset (displacement, slow return to center). The same custom-built platform, software, and equipment described in the previous topic were used. For each axis (AP and ML), participants had two familiarization trials, followed by ten probing trials in the same axis for data acquisition. Probing trials were performed five in each direction, i.e., backward or forward in the AP evaluation, and left or right in the ML evaluation. To assure direction unpredictability in the probing trials, sequence of perturbation direction was pseudorandomized (the same across participants). Participants received the same instructions as in the dynamic balance task, with the additional information of trying to not anticipate platform displacement direction. With this setup, our protocol required pure reactive responses based on different sources of on-line feedback (COELHO; TEIXEIRA, 2018). Trials were repeated in cases of stepping to recover balance.

CP data was collected and processed with the same routine as described in the dynamic balance task. The following variables were extracted: amplitude of CP displacement in each axis (higher minus lower value). The first displacement in each direction was discarded due to initial trials effect (CAMPBELL et al., 2013; LIU et al., 2017), and average values of the eight trials in each axis were computed for analysis.

2.4.3 Dual motor-cognitive task

The dual motor-cognitive task evaluation consisted of performing the same balance task as described for the dynamic balance task, only in the AP axis, performing simultaneously arithmetic subtractions. Participants were asked to continuously subtract 3 from a given number as fast as possible, speaking aloud. This task had three probing trials, each starting with a different number (e.g., 125; 209; 217), unknown to the participant until verbal prompt of trial onset. Participants were instructed to keep subtracting 3 from their previous answer, even if a mistake was made and noticed.

Center of pressure data was processed with the same routine as described in the dynamic balance task. In this evaluation, the following additional variable was measured: number of corrected answers in the subtraction task. The average of the three trials was computed for analysis.

2.4.4 Executive cognitive functions

To evaluate short- and long-term memory, the Rey Auditory Verbal Learning Test (RAVLT) was applied (REY, 1958). Standard procedures of application of this test were followed according to previous recommendation (STRAUSS; SHERMAN; SPREEN, 2006). In this test, the participant listened to the evaluator reading aloud a list of 15 nouns. After listening, the participant tried to recall, in any order, as many nouns as possible. This procedure was performed five times in a row, accounting for the short-term memory evaluation. Afterwards, the evaluator read a novel list of 15 nouns, followed by the participant's attempt to recall this novel list. Finally, after the novel list, the participant tried to recall, two times in a row, the first list, but without the evaluator reading it again – accounting for the long-term memory evaluation. The number of words recalled was computed for analysis. For the short-term, the sum of the first five trials was computed for analysis, and for the long-term memory, the sum of the last two trials was computed for analysis.

The Trail Making Test (TMT) was applied (REITAN, 1955) to evaluate attention capacity, processing speed, and mental flexibility. Standard procedures of application were followed according to previous recommendation (STRAUSS; SHERMAN; SPREEN, 2006). This test is divided into two parts. In part A (TMT-A), in a sheet of paper, the participant was instructed to trace a line connecting randomly distributed numbers in ascending order (1 to 25), as fast as possible. In part B (TMT-B), the participant had the same goal, however, numbers and letters are randomly distributed in the sheet of paper, and the connecting line should follow a numeric-alpha ascending order (e.g., 1-A-2-B-3-C-4-D, and so forth). TMT-B also have 25 items to be connected. The time spent to complete the task was computed for analysis.

2.4.5 Lower limbs' strength

Considering that balance training programs may lead to increments in strength, in a complementary analysis we evaluated strength of the lower limbs. For this purpose, the 30-s sit-to-stand test was applied (JONES; RIKLI; BEAM, 1999). Participants' goal was to sit and stand as many times as possible during three 30-s trials. Instructions were: a) arms crossed over the chest, to prevent momentum gain from swinging; b) feet hip-width apart; c) full knee and hip extension movement to validate the repetition; and d) feet always in contact with the floor. A 2-min. resting period between trials was provided, and the average number of completed repetitions was computed for analysis.

2.4.6 Single-leg reciprocal tapping task

As a measure of progress, participants were evaluated at pre-test, every 3 weeks at the beginning of the training session throughout the intervention, and at post-test with this evaluation. This task consisted of balancing on the self-declared preferred leg, and alternately touching two targets with the contralateral leg, positioned on the floor. Targets were 20 cm apart from each other, with the one target positioned in the medial line of the supporting foot, and the other target in front of the first, thus requiring AP swinging of the leg. Targets were determined by red tape with 15x7 cm dimensions. Participants' goal was to touch each target 10 times in an alternated fashion, as fast as possible. This task was employed under the assumption that good dynamic balance would lead to faster swing leg movements. It was repeated three times with the same leg in each evaluation, and the average time to complete the task was computed for analysis.

2.4.7 Difficulty and feeling scales

To control for training intensity between groups, participants of the intervention groups were asked to answer the Borg CR10 perceived exertion/difficulty scale (BORG,

1982) after each training session, according to previous recommendations (WILLIAMS, 2017). For affective responses, the Feeling Scale (HARDY; REJESKI, 1989) was utilized, composed of a 11-point rating scale ranging from +5 (I feel very good) to –5 (I feel very bad), crossing zero (neutral). In both scales, scores of each session were computed for analysis.

2.5 Statistical analysis

After processing CP data in RStudio, average values of each participant were computed in SPSS for analysis (IBM Statistics, v.24, USA). Prior to any statistical procedure, the final data sheet was sent to an independent researcher, who assigned random numbers (1 to 3) to each experimental group (SBT, BBT, CG). After, the data sheet was sent for another researcher to run the analysis, containing only the groups' numbers, but no indication of the number assigned to each group. Only after processing all outputs, the groups' numbers were revealed. With this procedure, statistical analysis was blind.

For inferential analysis, we fitted a generalized linear mixed-effects models to compare the training outcomes. A linear distribution with identity link function was used for all variables. To analyze the 3 (group) x 2 (pre- and post-test) design, we employed "group", "test", and "group by test" interaction as fixed effects. Given the repeated measure in the test factor (pre- and post-test), participant's ID was employed as random effect. The same analysis was applied to compare the single-leg reciprocal tapping task, with a design of 2 (training group) x 4 (week: 3, 6, 9 and 12). Whenever necessary, pairwise comparisons were made with the Bonferroni method, and effect sizes of significant effects were calculated with Cohen's *d* and interpreted as follows: trivial (≤ 0.19), small (0.20 to 0.49) medium (0.50 to 0.79), and large (≥ 0.8) (COHEN, 1988). Data are presented as mean ± standard error, and significance was set at 5%.

To compare the outcomes of the Borg CR10 and Feeling scales, a chi-square test was applied to analyze if the frequency of response in each category was different between groups in each training session. In case of significance, standardized residual measures were calculated to identify in which cell the observed was different from the expected frequency, being interpreted as follows: values > 2 indicate significantly more participants with a given answer than the other group, while values < - 2 indicate significantly less participants with a given answer than the other group (HABERMAN, 1973). Because 24 sessions were compared, to avoid type-I error *p* value was divided by 24 and set at $p < 0.002$.

3 RESULTS

Abbreviations in the results section were made according to the following pattern: axis of balance perturbation – axis of CP analysis. Hence, AP-AP means anteroposterior displacement of the support base (in both dynamic and reactive tasks) and CP analysis in the AP axis.

3.1 Dynamic balance

Representative curves of the CP behavior, for each platform displacement direction and axis of analysis, from a single participant of the SBT group are presented in Figure 5. Analysis of RMS of CP displacement in the AP-AP axis indicated a significant main effect of test (F[1, 94] = 17.875; $p < 0.001$), but no main effect of group (F[2, 94] = 0.714; $p = 0.492$) or interaction (F[2, 94] = 1.808; $p = 0.170$) were found (Figure 6, panel A). Pairwise comparisons for the test effect indicated significantly lower values in the post-test (M = 31.723 ± 1.738 mm) as compared to the pre-test (M = 41.441 ± 2.580; d = 0.625; Contrast Estimate = 9.718; SE = 2.299; t = 4.228; $p < 0.001$). Analysis of RMS of CP displacement in the AP-ML axis indicated no main effects of test (F[1, 94] = 0.022; p = 0.881), group (F[2, 94] = 0.645; p = 0.527) or interaction (F[2, 94] = 1.017; p = 0.366) (Figure 6, panel B).

Analysis of RMS of CP displacement in the ML-ML axis indicated a significant main effect of test (F[1, 91] = 33.118; $p < 0.001$), but no main effect of group (F[2, 91] = 0.918; $p = 0.403$) or interaction (F[2, 91] = 1.998; $p = 0.141$) were found (Figure 6, panel C). Pairwise comparisons for the test effect indicated significantly lower values in the post-test (M = 36.796 ± 1.039 mm) as compared to the pre-test (M = 42.995 ± 1.477 mm; d = 0.686; Contrast Estimate = 6.199; SE = 1.077; t = 5.755; $p < 0.001$). Analysis of RMS of CP displacement in the ML-AP axis indicated no main effects of test (F[1, 92] = 2.140; p = 0.147), group (F[2, 92] = 1.547; p = 0.218) or interaction (F[2, 92] = 0.730; p = 0.485) (Figure 6, panel D).

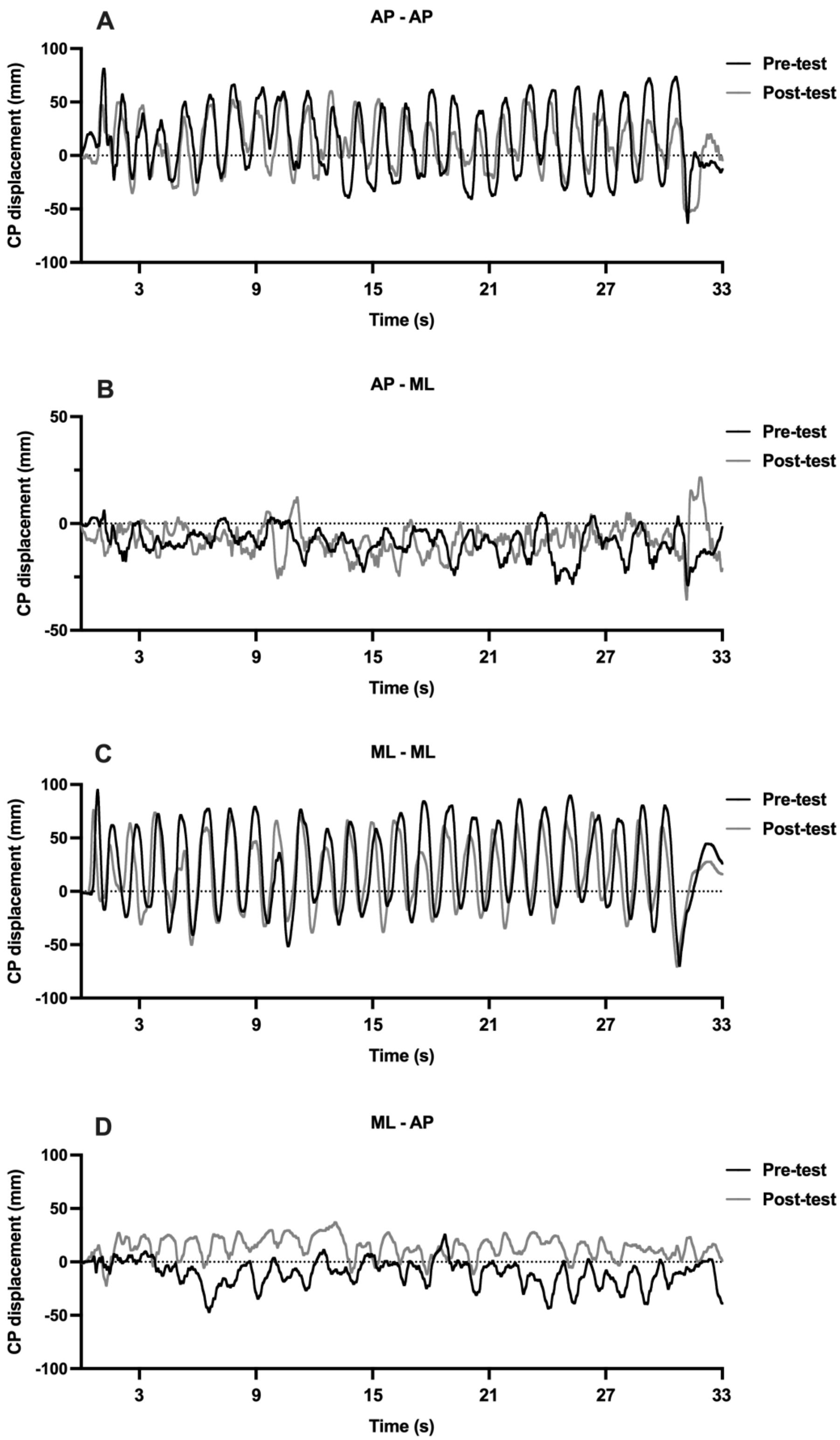

Figure 5. Center of pressure (CP) displacement in the dynamic balance task of a single participant, as a function of platform oscillation direction (AP/ML, left sided legend) and analyzed direction (AP/ML, right sided legend).

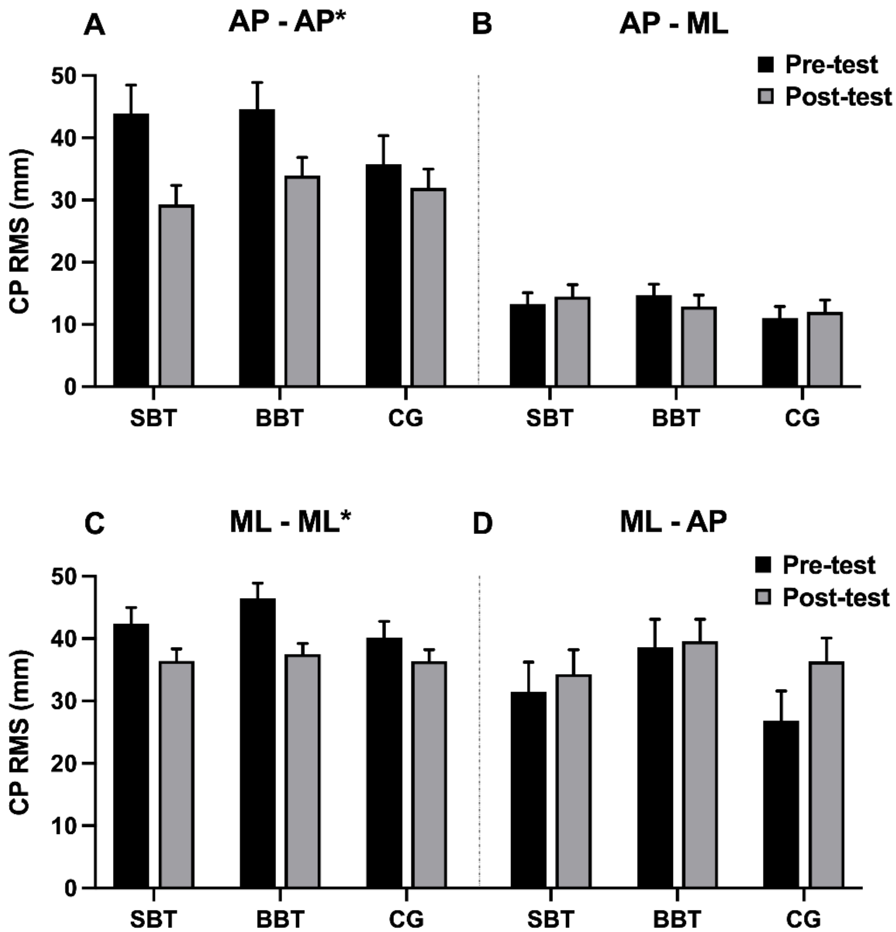

Figure 6. Root mean square (RMS) of center of pressure (CP) displacement in the dynamic balance task, comparing the groups (SBT: single leg balance training, BBT: bipedal balance training, CG: control group) between the pre- and post-tests, as a function of platform oscillation direction (AP/ML, left sided legend) and analyzed direction (AP/ML, right sided legend). * indicates significant main effect of test.

3.2 Reactive balance

Representative curves of the CP behavior, for each platform displacement direction and axis of analysis, from a single participant of the SBT group are presented in Figure 7. Analysis of amplitude of CP displacement in the AP-AP axis indicated a significant main effect of test (F[1, 90] = 4.073; p = 0.047), but no main effect of group (F[2, 90] = 0.856; p = 0.428) or interaction (F[2, 90] = 1.934; p = 0.151) were found (Figure 8, panel A). Pairwise comparisons for the test effect indicated significantly lower values in the post-test (M = 114.414 ± 2.287 mm) as compared to the pre-test (M =

118.925 ± 2.443 mm; *d* = 0.269; Contrast Estimate = 4.511; *SE* = 2.235; *t* = 2.018; *p* = 0.047). Analysis of amplitude of CP displacement in the AP-ML axis indicated a significant main effect of test (*F*[1, 90] = 9.238; *p* = 0.003), but no main effect of group (*F*[2, 90] = 0.624; *p* = 0.538) or interaction (*F*[2, 90] = 0.502; *p* = 0.607) were found (Figure 8, panel B). Pairwise comparisons for the test effect indicated significantly lower values in the post-test (M = 53.020 ± 3.436 mm) as compared to pre-test (M = 66.954 ± 5.316 mm; *d* = 0.440; Contrast Estimate = 13.935; *SE* = 4.585; *t* = 3.039; *p* = 0.003).

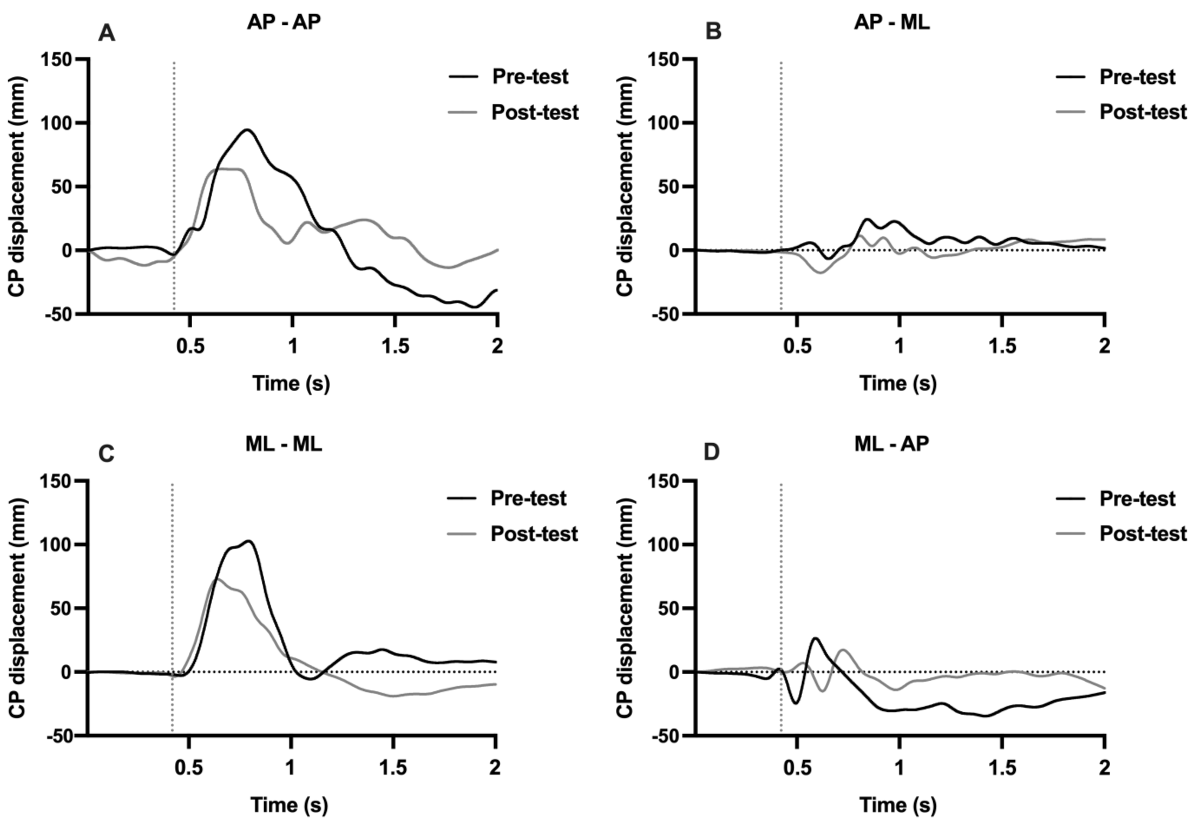

Figure 7. Center of pressure (CP) displacement in the reactive balance task of a single participant, as a function of platform oscillation direction (AP/ML, left sided legend) and analyzed direction (AP/ML, right sided legend). Vertical dashed lines represent time of perturbation onset.

Analysis of amplitude of CP displacement in the ML-ML axis indicated no main effects of test (*F*[1, 89] = 1.466; *p* = 0.229), group (*F*[2, 89] = 1.210; *p* = 0.303) or interaction (*F*[2, 89] = 1.299; *p* = 0.278) (Figure 8, panel C). Analysis of amplitude of CP displacement in the ML-AP axis indicated significant main effects of test ($F[1, 89] = 79.601$; $p < 0.001$) and group ($F[2, 89] = 3.275$; $p = 0.042$), but no interaction ($F[2, 89] = 2.391$; $p = 0.097$) was found (Figure 8, panel D). Pairwise comparisons for the test effect indicated significantly lower values in the post-test (M = 30.589 ± 2.785 mm) as compared to the pre-test (M = 48.600 ± 3.074 mm; $d = 0.868$; Contrast Estimate = 18.011; $SE = 2.019$; $t = 8.922$; $p < 0.001$). Pairwise comparisons indicated no significant differences between groups ($p > 0.050$).

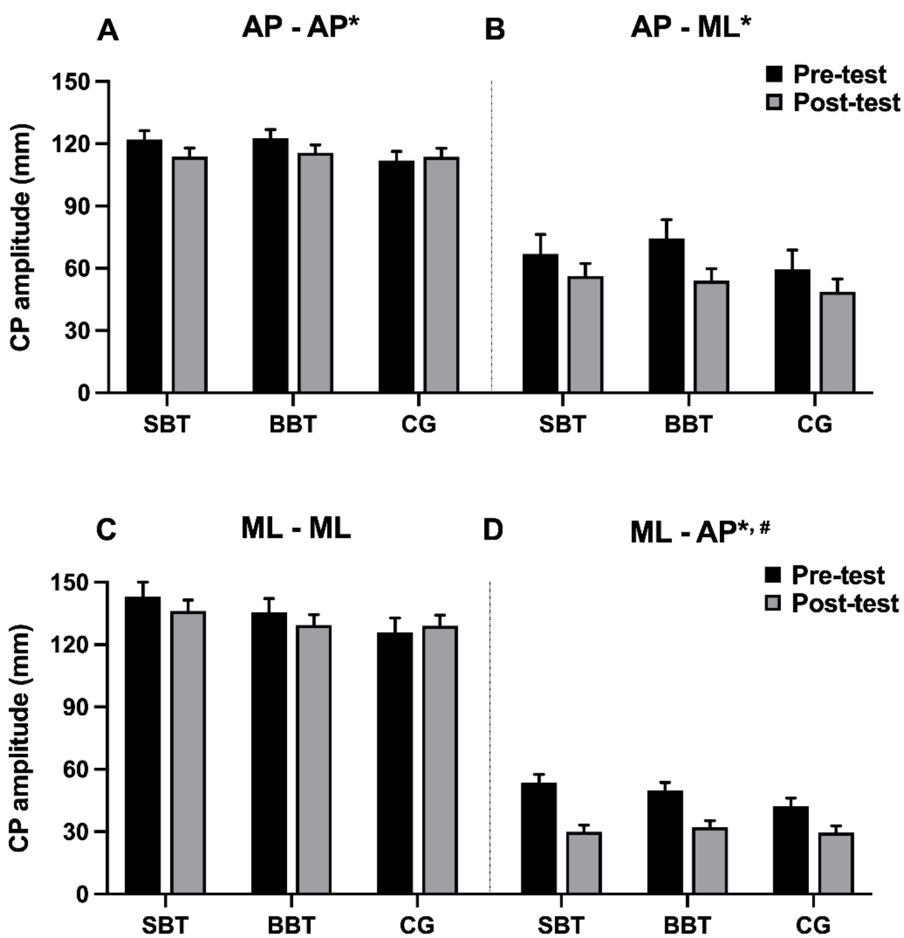

Figure 8. Amplitude of center of pressure (CP) displacement in the reactive balance task, comparing the groups (SBT: single leg balance training, BBT: bipedal balance training, CG: control group) between the pre- and post-tests, as a function of platform oscillation direction (AP/ML, left sided legend) and analyzed direction (AP/ML, right sided legend). * indicates significant main effect of test; # indicated significant main effect of group.

3.3 Dual motor-cognitive task

Analysis of RMS of CP displacement in the AP-AP axis during the dual-task indicated a significant main effect of test ($F[1, 86] = 11.935$; $p = 0.001$), but no main effect of group ($F[2, 86] = 0.843$; $p = 0.434$) or interaction ($F[2, 86] = 1.403$; $p = 0.251$) were found (Figure 9, panel A). Pairwise comparisons for the test effect indicated significantly lower values in the post-test (M = 34.403 ± 1.944 mm) as compared to the pre-test (42.595 ± 2.284 mm; $d = 0.546$; Contrast Estimate = 8.192; $SE = 2.371$; $t = 3.455$; $p = 0.001$). Analysis RMS of CP displacement in the AP-ML axis during the dual-task indicated no main effects of test ($F[1, 86] = 0.009$; $p = 0.925$), group ($F[2, 86] = 0.0015$; $p = 0.985$) or interaction ($F[2, 86] = 0.101$; $p = 0.904$) (Figure 9, panel B).

Analysis of the number of correct subtractions performed during the dual-task condition indicated a significant main effect of test ($F[1, 90] = 12.825$; $p = 0.001$), but no main effect of group ($F[2, 90] = 1.562$; $p = 0.215$) or interaction ($F[2,90] = 0.988$; $p = 0.376$) were found (Figure 9, panel C). Pairwise comparisons for the test effect indicated significantly higher values in the post-test (11.606 ± 0.637 n) as compared to the pre-test (10.488 ± 0.632 n; $d = 0.249$; Contrast Estimate = -1.118; $SE = 0.312$; $t = -3.581$; $p = 0.001$).

3.4 Cognitive executive functions

Analysis of short-term memory through the RAVLT test indicated a significant main effect of test ($F[1, 94] = 8.318$; $p = 0.005$), but no main effect of group ($F[2, 94] = 1.654$; $p = 0.197$) or interaction ($F[2, 94] = 1.258$; $p = 0.289$) were found (Table 4). Pairwise comparisons for the test effect indicated significantly higher values in the post-test (50.664 ± 1.278 words) as compared to the pre-test (47.666 ± 1.355 words; $d = -0.322$; Contrast Estimate = -3.000; $SE = 1.040$; $t = -2.884$; $p = 0.005$). Analysis of long-term memory indicated significant main effects of test ($F[1, 94] = 9.295$; $p = 0.003$) and group ($F[2, 94] = 3.449$; $p = 0.036$), but no interaction ($F[2, 94] = 0.889$; $p = 0.415$) was found (Table 4). Pairwise comparisons for the test effect indicated significantly higher values in the post-test (19.961 ± 0.702 words) as compared to the pre-test (17.841 ± 0.819; $d = -0.393$; Contrast Estimate = -2.120; $SE = 0.695$; $t = -3.049$; $p = 0.003$). Pairwise comparisons for the group effect indicated the SBT remembered more words (21.036 ± 1.205) when compared to the BBT group (16.698 ± 1.135; $d = -0.524$; Contrast Estimate

= 4.338; *SE* = 1.655; *t* = 2.621; *p* = 0.031), and no other significant comparison between groups (*p* > 0.050).

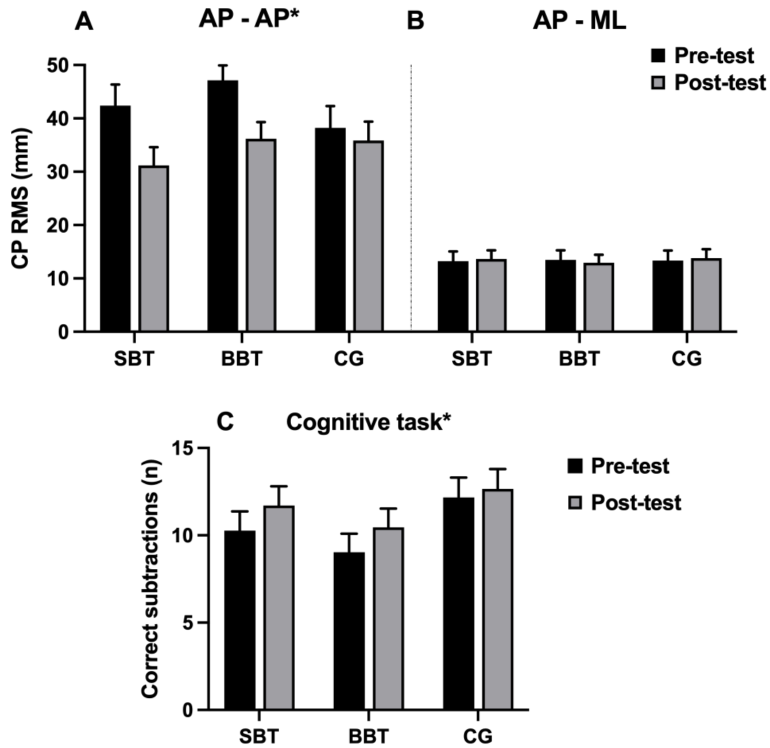

Figure 9. Root mean square (RMS) of center of pressure (CP) displacement (A and B) and cognitive performance (C) in the dual-task, comparing the groups (SBT: single leg balance training, BBT: bipedal balance training, CG: control group) between the pre- and post-tests, as a function of platform oscillation direction (AP) and analyzed direction (AP/ML, right sided legend). * indicates significant main effect of test.

Analysis of attentional capacity and mental flexibility with the TMT-A test indicated a significant main effect of test (*F*[1, 90] = 9.332; *p* = 0.003), but no main effect of group (*F*[2, 90] = 0.984; *p* = 0.378) or interaction (*F*[2, 90] = 0.245; *p* = 0.783) were found (Table 4). Pairwise comparisons for the test effect indicated significantly lower values in the post-test (35.542 ± 1.732 s) as compared to the pre-test (41.973 ± 2.627 s; *d* = 0.408; Contrast Estimate = 6.431; *SE* = 2.105; *t* = 3.055; *p* = 0.003). Analysis of the second part of the test, TMT-B, indicated no main effects of test (*F*[1, 90] = 3.638; *p* = 0.060), group (*F*[2, 90] = 2.548; *p* = 0.084) or interaction (*F*[2, 90] = 3.036; *p* = 0.053) (Table 4).

Table 4. Cognitive executive functions for each group and moment of analysis.

	SBT		BBT		CG	
	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
Short-term memory (n)*	49.0 ± 2.4	52.0 ± 2.3	43.6 ± 2.3	48.6 ± 2.1	50.3 ± 2.4	51.3 ± 2.3
Long-term memory (n)*#	19.3 ± 1.4	22.7 ± 1.2	15.9 ± 1.4	17.5 ± 1.2	18.3 ± 1.4	19.6 ± 1.2
TMT-A (s)*	39.1 ± 4.6	30.7 ± 3.0	44.4 ± 4.6	38.4 ± 3.1	42.4 ± 4.4	37.5 ± 3.0
TMT-B (s)	72.4 ± 13.7	78.1 ± 13.3	121.5 ± 13.6	111.1 ± 13.3	99.6 ± 13.6	80.6 ± 12.3

Note. SBT = single leg balance training; BBT = bipedal balance training; CG = control group; RAVLT = Rey auditory verbal learning task; TMT = trail-making test; n = number; * indicates overall test effect ($p < 0.05$ vs. pre-test), # indicates group effect ($p < 0.05$ SBT vs. BBT), ± indicates standard error.

3.5 Lower limbs' strength

Analysis of number of repetitions in the 30-s sit-to-stand test indicated a significant main effect of test (F[1, 92] = 53.751; $p < 0.001$) and interaction (F[2, 92] = 9.046; $p < 0.001$), but no main effect of group (F[2, 92] = 0.079; $p = 0.924$) was found (Figure 10). Pairwise comparisons for the interaction indicated a significant improvement from pre- to post-test for the SBT (Contrast Estimate = -3.823; *SE* = 0.585; $t = -6.539$; $p < 0.001$) and BBT (Contrast Estimate = -2.834; *SE* = 0.534; $t = -5.309$; $p < 0.001$), but not for the CG (Contrast Estimate = -0.479; *SE* = 0.566; $t = -0.846$; $p = 0.400$). Effect sizes for these comparisons of pre- vs. post-test were medium for both training groups (SBT, $d = 0.689$; BBT, $d = 0.526$), and trivial for the CG ($d = 0.095$).

3.6 Single-leg reciprocal tapping task

Analysis of time to complete the single-leg reciprocal tapping task indicated a significant main effect of test (F[1, 94] = 101.301; $p < 0.001$) and interaction (F[2, 94] = 21.797; $p < 0.001$), but no effect of group (F[2, 94] = 0.934; $p = 0.397$) was found (Figure 11). Pairwise comparisons for the interaction indicated significant improvement from pre- to post-test for the SBT (Contrast Estimate = 7.174; *SE* = 0.768; $t = 9.341$; $p < 0.001$) and BBT (Contrast Estimate = 5.611; *SE* = 0.724; $t = 7.749$; $p < 0.001$), but not for the CG

(Contrast Estimate = 0.354; *SE* = 0.768; *t* = 0.461; *p* = 0.646). Effect sizes for these comparisons of pre- vs. post-test were large for both training groups (SBT, *d* = -2.534; BBT, *d* = -1.950), and trivial for the CG (*d* = -0.123).

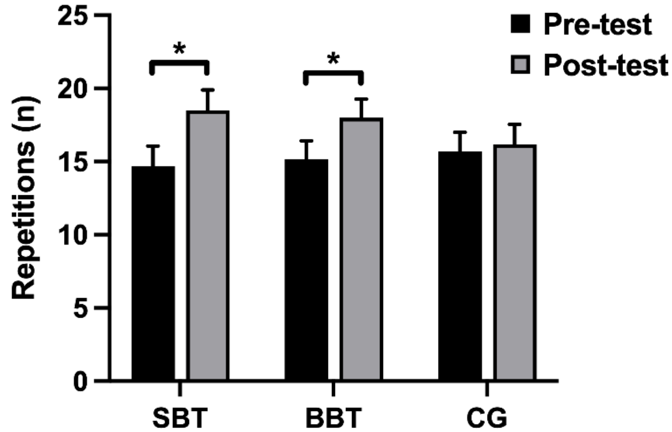

Figure 10. Repetitions (n) for the 30-s sit-to-stand test for each group (SBT: single leg balance training, BBT: bipedal balance training, CG: control group), comparing the pre- and post-tests. * indicates $p < 0.05$ vs. pre-test of the same group.

Analysis of time to complete the same task throughout the weeks between the two training groups (e.g., week 3, 6, 9 and 12) indicated a significant main effect of week (F[3, 113] = 32.668; $p < 0.001$) and interaction (F[3, 113] = 2.692; $p = 0.050$), but no group effect (F[1, 113] = 3.591; $p = 0.061$) was found (Figure 11). For the week effect, pairwise comparisons indicated time to complete the task improved significantly up to week 12 (i.e., week 3 > 6 > 9 > 12; all $p < 0.035$). For the group by week interaction, pairwise comparisons indicated the SBT performed significantly better than the BBT at week 6, with a large effect size (*d* = -0.845; Contrast Estimate = -1.402; *SE* = 0.568; *t* = -2.469; *p* = 0.015)

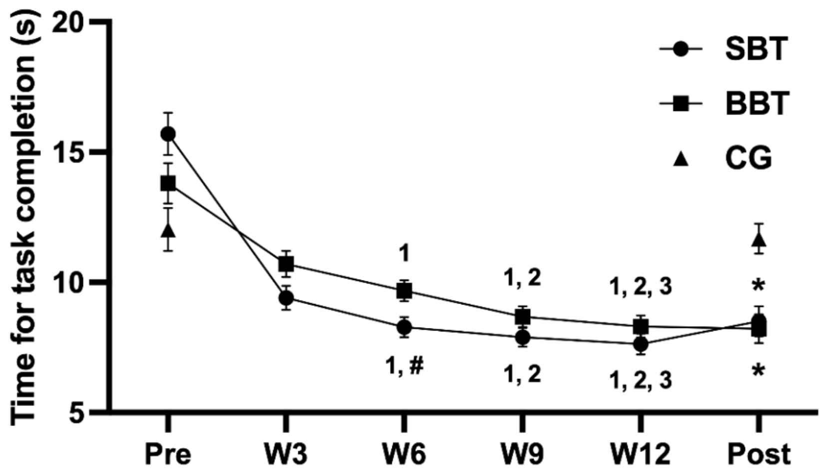

Figure 11. Time for task completion of the single-leg reciprocal tapping task, comparing the groups (SBT: single leg balance training, BBT: bipedal balance training, CG: control group) between pre-test, weeks of training, and post-test. W = week; * = $p < 0.05$ vs. pre-test of the same group; 1 = $p < 0.05$ vs. week 3; 2 = $p < 0.05$ vs. week 6; 3 = $p < 0.05$ vs. week 9; # = $p < 0.05$ vs. BBT in the same week.

3.7 Difficulty and feeling scales

Chi-square analysis of the Borg CR10 scale revealed no significant differences between groups when comparing individual training sessions (*df* = 2; $\chi^2 < 13.792$; $p > 0.032$). However, an overall difference in frequency of difficulty response was indicated when comparing all sessions between groups (*df* = 8; $\chi^2 = 71.954$; $p < 0.001$). Standardized residual measures revealed a higher frequency of participants in the SBT rating the training sessions as of higher difficulty (i.e., positive SRM values in "6" and "9" categories, and negative SRM values in "3" and "4" categories). Similar outcomes were observed for the Feeling scale. Chi-square analysis revealed no differences between groups when comparing individual training sessions (*df* = 2; $\chi^2 < 6.875$; $p > 0.032$), but indicated significant differences in frequency of affective response when comparing all sessions between groups (*df* = 3; $\chi^2 = 14.830$; $p = 0.002$). Standardized residual measures revealed a higher frequency of participants in the SBT rating the training sessions as less pleasant (i.e., positive SRM value in the "3" category). These results are presented in Table 5.

Table 5. Summarized responses from all training sessions for Borg and Feeling scales.

		SBT			BBT		
		n	%	SRM	n	%	SRM
Borg CR10:	**2**	0	(0%)	-1.4	4	(1%)	1.3
	3	3	(1%)	-2.3*	19	(5%)	2.1*
	4	10	(3%)	-4.1*	63	(17%)	3.8*
	5	51	(16%)	1.1	78	(21%)	1.1
	6	115	(35%)	2.6*	79	(21%)	-2.5*
	7	75	(23%)	0.8	73	(19%)	-0.7
	8	41	(12%)	0.1	49	(13%)	0.1
	9	26	(8%)	2.1*	11	(3%)	-2.0*
	10	6	(2%)	1.2	2	(0%)	-1.1
Feeling scale:	**2**	3	(1%)	1.4	0	(0%)	-1.3
	3	11	(3%)	2.3*	1	(0%)	-2.1*
	4	66	(20%)	0.5	68	(18%)	-0.5
	5	246	(76%)	-0.7	310	(82%)	0.6

Note. Comparison of absolute and relative frequency of responses between groups (SBT: single leg balance training, BBT: bipedal balance training, CG: control group) for each category; SRM: standardized residual measure. * indicates the cell count is significantly different than expected.

4 DISCUSSION

In this experiment, we aimed to assess the effects of unipedal versus bipedal stance during training on dynamic and reactive balance, cognitive executive functions, and strength in a sample of older adults. Based on previous results of single leg balance training in younger adults (MARCORI et al., 2020; SILVA et al., 2018a; VAN DIEËN; VAN LEEUWEN; FABER, 2015) and the most recent literature review on this topic showing robust balance gains following training (MARCORI et al., 2022), we hypothesized superior balance, cognitive, and strength gains for the SBT. Different from the expected, analysis of dynamic and reactive balance after training showed equivalent gains of balance control – as assessed by CP behavior – for both SBT and BBT, as well as for the CG. For cognitive executive functions, we found similar outcomes, with all three groups improving equivalently from the pre- to the post-test. Strength gains in the lower limbs, and a clinical test of dynamic balance, however, showed different results. Assessment after training showed that only the intervention groups (SBT and BBT) improved from the pre- to the post-test in these evaluations, without differences between them.

The oscillatory platform in the dynamic balance evaluation provides externally generated movement of the support base, requiring individuals to regulate balance control according to the cyclic pattern of the imposed task (TEIXEIRA; COUTINHO; COELHO, 2018). This control requirement differs from the exercises implemented during the training sessions, in which individuals had to deal with imbalances imposed by self-generated movements (such as coordinating arms and head while balancing). In this direction, balance control has been posed as task specific (HARPER et al., 2021; KISS; SCHEDLER; MUEHLBAUER, 2018; PAILLARD, 2017). Accordingly, previous interventions with a high-demand dynamic balance training failed to show generalization of balance control to tasks different from those specifically trained (DIJKSTRA et al., 2015; KÖNIG et al., 2019; SERRIEN et al., 2017). In line with these findings, previous investigations have highlighted the unrelatedness of balance performance in quiet and dynamic balance (LEME et al., 2022; RIZZATO et al., 2021), quiet and reactive balance (OWINGS et al., 2000), and dynamic and reactive balance (Appendix C, page 78). Taken together, these findings support the notion that improving in a given task does not guarantee equivalent improvements in other contexts requiring balance control. It is possible that learning how to control balance during self-imposed balance losses, as performed in the provided training, do not generalize to the ability to control balance during externally-imposed movements of the support base. From this evidence, and considering that all three groups (SBT, BBT, and CG) displayed similar improvements from pre- to post-test, we believe this effect is due to repeated testing and the ability to learn from this short experience, and not necessarily due to training. Independent of group, increased performance in the post-test in the dynamic balance task represent an intact adaptative capacity of older adults to improve balance control. This finding may be explained by the ability of the CNS to fine-tune movement control with temporal regularities of the support oscillation base, stabilizing the center of mass via reductions in trunk and head oscillation (VAN OOTEGHEM; FRANK; HORAK, 2009). Furthermore, because platform oscillation was constant and cyclic in our evaluation, feedback information gathered from each cycle could enhance postural adjustments within the sensorimotor system for the next cycle (MIERAU; HÜLSDÜNKER; STRÜDER, 2015). Indeed, repeated perturbations may lead to the formation of a sensorimotor set, controlling movement in a feedforward manner to predict and adjust motor response parameters for the next perturbations (COELHO et al., 2018), thus leading to a more stable balance control and reduced CP sway.

The evaluation of reactive balance produced equivalent findings, i.e., similar improvements from pre- to post-test for all three groups. Previous research showing long-term retention to short periods of exposure to external balance perturbations aids interpreting these findings. König and colleagues (2019) provided a 25-min single session of slip training in the treadmill for a sample of older adults. The increments in balance control on the slip task observed after the training session was retained after 14 weeks. Similarly, Pai and colleagues (2014) verified that rate of falls in an unexpected slip-like perturbation is reduced from 42% (1st trial) to 0% after only 24 trials. In their investigation, older adults returned to the laboratory to be evaluated in the same task after six months and showed a retained 0% rate of falls (PAI et al., 2014). Accordingly, our evaluation protocol and experimental design provided a total of 24 perturbations (2 familiarization, 10 evaluation in each axis – AP and ML) in the reactive balance assessment followed by a 12-week interval for the CG to be reassessed. Considering the fast increment and long retention of balance control from just a few trials of exposure to external perturbations (BHATT; YANG; PAI, 2012; KÖNIG et al., 2019; PAI et al., 2014), and reduced generalizability following balance training (DIJKSTRA et al., 2015; HARPER et al., 2021; PAILLARD, 2017), it is plausible that the three groups in our experiment improved similarly as an effect of being equally exposed to the same perturbations in the evaluation protocol. Despite the received intervention, because perturbation direction and onset was unpredictable in this task, improvements from pre- to post-test cannot be explained by feedforward mechanisms. As response specification may differ from one trial to another, using feedforward processes based on the last perturbation trial can interfere with the feedback-based response of the current trial, thus leading to suboptimal motor responses (COELHO et al., 2018). This issue suggests that improved balance control in this unpredictable context can be related to more refined processes of selecting and scaling (AZZI; COELHO; TEIXEIRA, 2017) postural responses based on the available, online feedback of sensorial information induced by the perturbation (TAKAZONO et al., 2020). This mechanism of balance control is suggested to be responsible for the significant main effect of test showing reduced CP amplitude in the reactive task after training.

Equivalent to the observed in the dynamic and reactive balance assessment, all three groups improved similarly from pre- to post-test in all analyzed cognitive executive functions (e.g., short- and long-term memory, and attentional capacity), as well as in the dual motor-cognitive task. Cognitive executive functions and motor performance are functionally intertwined, both at behavioral and neural level of analysis (MARVEL; MORGAN; KRONEMER, 2019; STUHR; HUGHES; STÖCKEL, 2018). As such, the capacity to control balance is also related to cognitive performance (AMBROSE; PAUL; HAUSDORFF, 2013), especially in older adults (FAULKNER et al., 2007; SOMBRIC; TORRES-OVIEDO, 2021). Given this scenario, reciprocal gains in one capacity may lead to increments of performance in another and vice-versa. Because our training program was not specifically designed to stimulate, and potentially improve, dual-task conditions and cognitive functions, we also suggest the results are due to repeated testing effect. Accordingly, the most difficult test applied (e.g., TMT-B), which requires mental flexibility to shift between alpha-numerical sequencing for completion, did not show any improvement. Indeed, the most promising approach to promote cognitive benefits would be a general balance training program with dual-tasks (WOLLESEN; VOELCKER-REHAGE, 2014). Therefore, a dynamic balance training program, not focused on cognitive functions and dual-tasks, seems unable to provide gains in memory and attentional capacity above the repeated testing effects, as assessed by the RAVLT and TMT tests.

Results of the strength assessment provided differential results between groups. Both SBT and BBT groups showed improvements in the number of repetitions performed in the 30-s sit-to-stand test, while the CG did not. A previous review on balance and strength training in older adults suggested that balance training have the potential to improve strength in this population (GRANACHER et al., 2011), and our findings corroborate this assumption. Of increased relevance is the fact that the SBT group did not perform squatting-equivalent exercises in the training program. Even though balancing on one leg does require some level of knee and hip flexion, the range of motion practiced in training was not as large as the one required for sitting and standing. On the contrary, the BBT performed movements with the lower limbs in conditions much similar to a squatting posture. Given the specificity of strength gains (GRANACHER; MUEHLBAUER; GRUBER, 2012), and how range of motion plays an important role in strength adaptations (PALLARÉS et al., 2021), the fact that both groups improved similarly highlights how balancing on one leg is able to produce significant increments in strength and functional capacity of the lower limbs in older adults.

We applied a dynamic balance task throughout the intervention to evaluate the process of improvements in balance control. The single-leg reciprocal tapping task required stable balance on one leg and fine and fast motor control in the swing leg to move back and forth between targets, essentially demanding control in the AP axis. Results showed that both training groups improved progressively and significantly from each evaluation period, every three weeks (see Figure 11). Findings also revealed that compared to BBT the SBT had a greater improvement at week 6, which may be due to the similarity between the single leg training exercises and this evaluation. We must mention, however, that this specific task was not directly trained in neither group. This result, then represent evidence of generalization of results in balance control to a functional test of balance demanding control in the AP axis, and quicker gains for the SBT. However, from the evidence discussed above, we can suggest that the motor control requirements of this task are similar to those practiced during training (i.e., voluntary movements). Participants were required to accurately compensate self-generated body movements in order to increase performance speed and reciprocally tap faster between targets. This type of control, based both on feedback of previous trials and cycles, and feedforward due to predictability of the context, was constantly stimulated in the training exercises by application of complex coordinative tasks in demanding balance conditions. As a limitation, the CG was only assessed in the pre- and post-test. It is possible that repeated testing every three weeks favored the experimental groups.

The application of the Borg CR10 and Feeling scales in every training session complement the analysis of the training outcomes. As expected, the more challenging training condition (SBT) lead to an increased frequency of participants perceiving the training as more difficult (see Table 5). The difference in single leg balance time accumulated throughout the intervention between groups (SBT: 576 min.; BBT: 0 min.) can further aid interpret this finding. Hence, the initial goal of comparing two groups with different balance demands (higher vs. lower) can be confirmed by this finding, as the lower balance demanding group rated the training less difficult. Accordingly, the SBT participants also rated the training as slightly less pleasant. Because affective response to exercise is known to be modulated by perception of training intensity, with higher intensities leading to less pleasant perception (EKKEKAKIS; PARFITT; PETRUZZELLO, 2011), the findings of both scales are complementary and agree with previous evidence. This may also explain the subtle difference in drop-out rates in each of the intervention groups, with 27% in the SBT and 18% in the BBT.

4.1 Limitations and practical applications

Two main limitations of the present experimental design must be mentioned: a) lack of retention assessment leaves unsolved the question of whether these types of training (SBT vs. BBT) produce differences in how long adaptations are retained; and b) due to a reduced operational team, researchers were not blind to the experimental conditions, neither during training or evaluation assessments. Future investigations would benefit from different teams prescribing and applying the exercises, with another one evaluating the participants – especially during longer periods of time after the intervention.

From the observed results, a challenging dynamic balance training program is capable of producing significant improvements in dynamic and reactive balance. Training also led to increments in strength of the lower limbs, which have functional relevance for older adults in daily living activities. Moreover, it seems that both SBT and BBT had the same potential to promote adaptations in balance control, showing prescription of balance exercises between these two forms of training can be based on personal preference to better suit the individual. We suggest a complete balance training program may include both single leg and bipedal challenging exercises, as well as perturbations to balance induced by unpredictable external sources, and not only challenging self-generated movements. This approach is most likely to comprise the different requirements and mechanisms of balance control, thus leading to consistent improvements in balance for older adults.

5 CONCLUSIONS

As main conclusions, our results showed equivalent gains in dynamic and reactive balance control in all three groups (SBT, BBT and CG). It may be that balance control in reactive and dynamic tasks requiring responding to externally-induced movements of support base displacement can be improved by the simple exposure to these types of perturbation. Furthermore, because evaluation tasks were not directly trained, our results of equivalent gains in the CG suggest that balance training is highly specific. Despite this specificity of balance control, strength gains of equivalent magnitudes were only observed in the groups that underwent training intervention, demonstrating a challenging balance training program can also lead to increments in lower limbs' strength. This research fills the gap in the literature regarding differences of training effects from two balance training programs with distinct balance demands (SBT vs BBT), showing they have equivalent potential to promote gains in balance control, cognitive executive functions, and strength in older adults.

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ATTACHMENTS AND APPENDIX

ATTACHMENT A – FIRST PAGE OF PUBLISHED ARTICLE

Review

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Single Leg Balance Training: A Systematic Review

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Abstract

Single leg balance training promotes significant increments in balance control, but previous reviews on balance control have not analyzed this form of balance training. Accordingly, we aimed to review the single leg balance training literature to better understand the effects of applying this training to healthy individuals. We searched five databases—PubMed, EMBASE, Scopus, Lilacs, and Scielo—with the following inclusion criteria: (a) peer-reviewed articles published in English; (b) analysis of adult participants who had no musculoskeletal injuries or diseases that might impair balance control; and (c) use of methods containing at least a pre-test, exclusive single leg balance training, and a post-test assessment. We included 13 articles meeting these criteria and found that single leg balance training protocols were effective in inducing balance control gains in either single- or multiple-session training and with or without progression of difficulty. Balance control gains were achieved with different amounts of training, ranging from a single short session of 10 minutes to multiple sessions totaling as much as 390 min of unipedal balance time. Generalization of balance gains to untrained tasks and cross-education between legs from single leg balance training were consistent across studies. We concluded that single leg balance training can be used in various contexts to improve balance performance in healthy individuals. These results extend knowledge of expected outcomes from this form of training and aid single leg balance exercise prescription regarding volume, frequency, and potential progressions.

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ATTACHMENT B – ETHICAL COMMITTEE APPROVAL

USP - ESCOLA DE EDUCAÇÃO FÍSICA E ESPORTE DA UNIVERSIDADE DE SÃO PAULO / EEFE-USP

Plataforma Brasil

PARECER CONSUBSTANCIADO DO CEP

DADOS DO PROJETO DE PESQUISA

Título da Pesquisa: Treinamento de equilíbrio corporal dinâmico em associação com maleabilidade da base de suporte, demanda aeróbia e tarefa cognitiva: efeitos em indivíduos idosos saudáveis.

Pesquisador: Luis Augusto Teixeira

Área Temática:

Versão: 2

CAAE: 20284919.2.0000.5391

Instituição Proponente: UNIVERSIDADE DE SAO PAULO

Patrocinador Principal: Financiamento Próprio

DADOS DO PARECER

Número do Parecer: 3.681.879

Apresentação do Projeto:

O objetivo deste estudo é analisar os efeitos de um treinamento com alta demanda de equilíbrio corporal dinâmico em indivíduos idosos saudáveis, pensando acerca das possibilidades de melhorar a qualidade de vida e minimizar o risco de queda nesta população. Os experimentos serão realizados tendo como propósito a avaliação de diferentes dimensões potencialmente beneficiadas por treinamento de equilíbrio dinâmico com alta demanda de equilíbrio (TED). Serão selecionados 100 idosos (>65 anos), saudáveis, voluntários, de ambos os sexos, recrutados a partir de divulgação na comunidade e lista de espera de cursos comunitários da EEFE-USP. Os participantes serão aleatoriamente alocados em cinco grupos (n = 20 em cada): TED; TED com demanda aeróbia; TED com demanda cognitiva; TED em superfície maleável e controle. O experimento será conduzido em quatro etapas: 1) pré-teste; 2) intervenção (6 meses); 3) pósteste e 4) retenção. O pré-teste será aplicado imediatamente antes do início da intervenção, o pós-teste 48 h após e a retenção um mês após o término do treinamento. As sessões de treinamento serão executadas duas vezes por semana, com duração de 50 min. cada. O treinamento será baseado em movimentos coordenativos de membros superiores e inferiores durante apoio unipodal. A progressão do treinamento será organizada em função da dificuldade de manutenção do equilíbrio corporal, movimentos coordenativos, velocidade de execução e adição de sobrecarga. O treinamento será dividido em 6 blocos (um a cada mês), com 8 sessões em cada bloco. O

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treinamento do grupo controle consistirá em realizar os mesmos movimentos coordenativos de braços (com progressão semelhante) em postura bipodal, minimizando a demanda de equilíbrio corporal. Com este desenho experimental, busca-se avaliar treinamentos com demandas de equilíbrio distintas entre os grupos. A análise irá considerar os dados dos testes pré- e pós-intervenção, que auxiliarão a medir as capacidades mencionadas, verificando de forma mais global os efeitos do treinamento de equilíbrio na terceira idade.

Objetivo da Pesquisa:

Objetivo primário

Analisar os efeitos de um treinamento com alta demanda de equilíbrio corporal dinâmico em indivíduos idosos saudáveis sobre os seguintes fatores: (a) estabilidade em postura quieta, (b) estabilidade em equilíbrio dinâmico voluntário, (c) recuperação do equilíbrio corporal após perturbação postural imprevisível, (d) resistência aeróbia, (e) força muscular, e (f) funções cognitivas executivas. Avaliar as diferentes dimensões descritas no objetivo principal em função do treinamento com alta demanda de equilíbrio corporal dinâmico associado aos seguintes fatores:(a) Superfície de apoio maleável.(b) Demanda aumentada de consumo de oxigênio.(c) Realização simultânea de tarefa cognitiva.

Avaliação dos Riscos e Benefícios:

Embora no formulário com informações do projeto os pesquisadores informem se tratar de um projeto com riscos mínimos, no TCLE ele é classificado como risco baixo, parecendo ser esta última a classificação mais adequada. As tarefas motoras realizadas serão relativamente simples e haverá um auxiliar de pesquisa responsável pela segurança dos participantes durante todas as avaliações. Nas tarefas de equilíbrio dinâmico, além do auxiliar, será utilizado um colete de segurança fixado acima da altura da cabeça para prevenção de quedas. Caso o participante não pratique atividades físicas regularmente, é possível que haja alguma dor muscular nos membros inferiores nos dias subsequentes as avaliações e as sessões de treinamento. O participante receberá uma avaliação detalhada de sua capacidade de equilíbrio corporal estático e dinâmico, capacidade cognitiva, e condicionamento físico. Assim, será possível identificar possíveis limitações funcionais do equilíbrio corporal, e ter um diagnóstico completo das outras capacidades físicas e cognitivas. Como resultado do treinamento, espera-se melhoras no controle do equilíbrio corporal e aptidão física. É provável, também, que o treinamento traga ganhos de coordenação motora e funções cognitivas. Estas adaptações estão relacionadas a uma melhora na qualidade de vida, independência nas atividades

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da vida diária e diminuição no risco de quedas.

Comentários e Considerações sobre a Pesquisa:

Trata-se de uma pesquisa com desenho experimental bem descrito, com metodologia e referências apropriadas. O pesquisador apresenta uma declaração informando que a infraestrutura para desenvolvido deste projeto se encontra plenamente instalada e em funcionamento no Laboratório Sistemas Motores Humanos (LSMH), situado na Escola de Educação Física Esporte da USP, sob sua coordenação.

Considerações sobre os Termos de apresentação obrigatória:

Os termos obrigatórios são devidamente apresentados.

Conclusões ou Pendências e Lista de Inadequações:

O pesquisador atende adequadamente às solicitações de parecer anterior não havendo pendências.

Considerações Finais a critério do CEP:

Este parecer foi elaborado baseado nos documentos abaixo relacionados:

Tipo Documento	Arquivo	Postagem	Autor	Situação
Informações Básicas do Projeto	PB_INFORMAÇÕES_BÁSICAS_DO_PROJETO_1414922.pdf	24/10/2019 16:12:35		Aceito
TCLE / Termos de Assentimento / Justificativa de Ausência	TCLE.docx	24/10/2019 16:11:10	Luis Augusto Teixeira	Aceito
Declaração de Instituição e Infraestrutura	declara_infra.pdf	22/08/2019 07:35:51	Luis Augusto Teixeira	Aceito
Folha de Rosto	folhaderosto_ass_AJM.pdf	22/08/2019 07:29:41	Luis Augusto Teixeira	Aceito
Projeto Detalhado / Brochura Investigador	ProjetoDetalhado_TreinamentoEquilibrio.docx	14/08/2019 11:51:29	Luis Augusto Teixeira	Aceito

Situação do Parecer:

Aprovado

Necessita Apreciação da CONEP:

Não

Endereço: Av. Profº Mello Moraes, 65
Bairro: Cidade Universitária **CEP:** 05.508-030
UF: SP **Município:** SAO PAULO
Telefone: (11)3091-3097 **Fax:** (11)3812-4141 **E-mail:** cep39@usp.br

SAO PAULO, 04 de Novembro de 2019

Assinado por:
Edilamar Menezes de Oliveira
(Coordenador(a))

APPENDIX A – WRITTEN INFORMED CONSENT

TERMO DE CONSENTIMENTO LIVRE E ESCLARECIDO

I - DADOS DE IDENTIFICAÇÃO DO SUJEITO DA PESQUISA

1. DADOS DO INDIVÍDUO

Nome completo ____________________

Sexo ☐ Masculino
☐ Feminino

RG ____________________
Data de nascimento ____________________
Endereço completo ____________________
CEP ____________________
Fone ____________________
e-mail ____________________

2. RESPONSÁVEL LEGAL (caso seja menor de 18 anos)

Nome completo ____________________
Natureza (grau de parentesco, tutor, curador, etc.) ____________________

Sexo ☐ Masculino
☐ Feminino

RG ____________________
Data de nascimento ____________________
Endereço completo ____________________
CEP ____________________
Fone ____________________
e-mail ____________________

II - DADOS SOBRE A PESQUISA CIENTÍFICA

1. Título do Projeto de Pesquisa

Efeito do treinamento de equilíbrio dinâmico unipodal, com ou sem tarefa dupla cognitiva motora, sobre o equilíbrio de idosos

2. Pesquisador Responsável

Luis Augusto Teixeira

3. Cargo/Função

Professor Associado da Universidade de São Paulo, Coordenador do Laboratório Sistemas Motores Humanos

4. Avaliação do risco da pesquisa:

	RISCO MÍNIMO	x	RISCO BAIXO		RISCO MÉDIO		RISCO MAIOR

5. Duração da Pesquisa

Esta pesquisa terá duração de 5 meses.

III - EXPLICAÇÕES DO PESQUISADOR AO INDIVÍDUO OU SEU REPRESENTANTE LEGAL SOBRE A PESQUISA, DE FORMA CLARA E SIMPLES, CONSIGNANDO:

1. *Justificativa e objetivos da pesquisa*: O(A) Senhor(a) está sendo convidado(a) a participar deste projeto de pesquisa, que tem como objetivo fornecer um programa de treinamento para melhora do equilíbrio corporal em pessoas idosas, com ou sem a realização de tarefa cognitiva simultaneamente ao treinamento físico. Este objetivo foi proposto em função de pesquisas mostrando que o envelhecimento está frequentemente associado a uma redução de equilíbrio corporal, com aumento do risco de quedas.

2. *Procedimentos experimentais e propósitos*: Caso o(a) Senhor(a) aceite participar deste projeto, participará de um treinamento de duração de 4 meses, com aulas de 60 minutos, ministradas duas vezes por semana, com o objetivo de melhorar o seu equilíbrio corporal e também sua aptidão física. Antes e depois do treinamento, serão feitas as seguintes avaliações do seu equilíbrio: (1) Equilíbrio estático: permanecer em pé descalço (a) sobre uma base metálica durante um intervalo de 30 segundos; (2) Equilíbrio dinâmico: permanecer equilibrado em pé sobre uma base que será deslocada lenta e continuamente para frente e para trás; (3) Recuperação do equilíbrio: você terá seu equilíbrio corporal na posição em pé perturbado pelo deslocamento repentino de alguns centímetros da base de suporte. Cada um destes testes será repetido 3 vezes. Como avaliações complementares, você realizará os seguintes testes: 1) teste de força das pernas: sentar e levantar de uma cadeira por 30 segundos; 2) teste de memória: repetir um conjunto de palavras após ouvi-las; e 3) teste cognitivo: ligar número e letras espalhados aleatoriamente em uma folha de papel, em ordem crescente e alfabética. Este conjunto de avaliações está previsto para durar, aproximadamente, uma hora e trinta minutos. O(a) Senhor(a) será alocado em um dos seguintes grupos: (a) treinamento de equilíbrio corporal sobre base estreita (apoio unipodal, pontas dos pés) sem treinamento cognitivo, ou (b) treinamento de equilíbrio corporal sobre base estreita combinado com treinamento cognitivo (atenção e memória).

3. *Desconfortos e riscos esperados*: Não são previstos desconfortos durante a realização dos testes ou do treinamento. Caso o(a) Senhor(a) não pratique atividades físicas regularmente, é

possível que haja dores musculares nos dias seguintes às avaliações e às sessões iniciais de treinamento. Os riscos relacionados aos testes são baixos, pois usaremos tarefas motoras relativamente simples e haverá um auxiliar de pesquisa próximo a você durante todas as avaliações. Nas tarefas de equilíbrio dinâmico, você usará um colete de segurança fixado acima da altura da cabeça para prevenção de quedas.

4. *Benefícios que poderão ser obtidos*: O(A) Senhor(a) passará por uma avaliação detalhada de sua capacidade de equilíbrio corporal estático e dinâmico, capacidade cognitiva, e condicionamento físico. Assim, será possível identificar possíveis limitações funcionais de seu equilíbrio corporal, e ter um diagnóstico completo das outras capacidades físicas e cognitivas. Como resultado do treinamento, espera-se melhoras no controle do equilíbrio corporal e aptidão física. É possível ainda que o treinamento traga ganhos de coordenação motora e funções cognitivas. Estas adaptações estão relacionadas a uma melhora na qualidade de vida, independência nas atividades da vida diária e diminuição no risco de quedas.
5. *Procedimentos alternativos que possam ser vantajosos para o indivíduo*: Não são conhecidos procedimentos alternativos que possam trazer vantagens aos participantes. No semestre treinamento seguinte, será fornecida a possibilidade de os participantes do grupo de treinamento de equilíbrio puro realizarem o treinamento de equilíbrio associado com treinamento cognitivo.

IV - ESCLARECIMENTOS DADOS PELO PESQUISADOR:

1. Caso o(a) Senhor(a) concorde em participar do projeto, poderá a qualquer momento tirar dúvidas sobre os testes e treinamento que realizará.
2. O(A) Senhor(a) terá liberdade de retirar seu consentimento a qualquer momento e de deixar de participar do estudo, sem que isto te traga qualquer prejuízo.
3. Os dados de seus testes serão confidenciais, sendo usados apenas para fins de pesquisa.
4. Apesar de os procedimentos aqui empregados serem seguros, você terá disponibilidade de assistência no Hospital Universitário ou Hospital das Clínicas por qualquer intercorrência durante os testes e sessões de treinamento.

V - INFORMAÇÕES DE NOMES, ENDEREÇOS E TELEFONES DOS RESPONSÁVEIS PELO ACOMPANHAMENTO DA PESQUISA, PARA CONTATO EM CASO DE INTERCORRÊNCIAS CLÍNICAS E REAÇÕES ADVERSAS.

Alexandre Jehan Marcori, tel.: (11) 9 9994-9404
Prof. Dr. Luis Augusto Teixeira, tel.: (11) 3091-2129
Laboratório Sistemas Motores Humanos
Escola de Educação Física e Esporte da Universidade de São Paulo

VI. - OBSERVAÇÕES COMPLEMENTARES

Comitê de Ética em Pesquisa da EEFEUSP:
Endereço: Av. Prof. Mello Moraes, 65. USP. 05508-030
Tel.: 3091-3097
E-mail: cep39@usp.br

VII - CONSENTIMENTO PÓS-ESCLARECIDO

Declaro que, após convenientemente esclarecido pelo pesquisador e ter entendido o que me foi explicado, consinto em participar do presente Projeto de Pesquisa.

São Paulo, _____/_____/_____

Assinatura do sujeito da pesquisa

Luis Augusto Teixeira

APPENDIX B – LIST OF MOVEMENTS AND PROGRESSIONS OF THE SBT

Movements performed in single leg balance:

1- Hip-joint movements (flexion, extension, adduction, abduction, and rotation);
2- Knee-joint movements (flexion and extension);
3- Shoulder-joint movements (flexion, extension, adduction, abduction, and rotation);
4- Elbow-joint movements (flexion and extension);
5- Trunk movements (flexion, extension, and rotations);
6- Head movements (looking downward, upward, and sideways).

Progressions and increments of difficulty:

1- Combining movements in more than one joint;
2- Distinct axis of movement in two joints simultaneously (flexion-extension of the hip and adduction-abduction of the shoulders);
3- Combination of phase- and anti-phase movements between joints;
4- Execution speed;
5- Objects to manipulate while balancing and moving;
6- Visual suppression.
7- Combinations of the listed factors.

APPENDIX C – CORRELATION BETWEEN REACTIVE AND DYNAMIC BALANCE IN OLDER ADULTS

1 Participants

Sample size was calculated a priori with G*Power 3.1 (Franz Faul, Germany), for a one-tailed correlation test. We considered a moderate effect size (r = 0.3), significance at α = 0.05 and a power of (1-β) = 0.80, according to recommendations (FAUL et al., 2007). Based on these parameters, this calculation indicated a minimum of 67 participants.

After advertising in the local community around University of São Paulo, 80 participants, 17 men (68.8 ± 4.9 years old, 1.61 ± 0.09 m, 69.76 ± 14.02 kg) were conveniently selected based on the following inclusion criteria: age between 60 and 80 years old, no musculoskeletal, sensorial or neurological diseases that could impair participation, no continuous usage of balance-affecting medication, no involvement in systematic balance training in the previous year. Prior to research initiation, all individuals provided informed consent to participate, and procedures were approved by the ethical committee of the University of São Paulo (CAAE 20284919.2.0000.5391, Process N° 3.681.879; Attachment B, page 69).

2 Data acquisition

Evaluations were performed in a single session in different day times. Body balance was evaluated in two tasks: dynamic balance control on a rhythmic oscillatory support base, and reactive balance responses to unanticipated translations of the support base. Participants were excluded if unable to complete the entire evaluation protocol.

The data was collected using the exact same methods as those described in Chapter III, sections 2.4.1 Dynamic balance, and 2.4.2 Reactive balance.

3 Statistical analysis

After processing CP data in RStudio, average values of each participant were computed in SPSS for analysis (IBM Statistics, v.24, USA). Outliers, defined as individuals with scores above or below 2 standard deviations from the group mean, were excluded from the analysis.

As some variables deviated from normal distribution according to the Shapiro-Wilk's test ($p < 0.05$), correlations were performed with the one-tailed Spearman's test. Correlation pairs were analyzed only in the same direction and axis, correlating reactive and dynamic balance performance. Because we performed 4 correlation pairs, p value was divided by 4 to avoid type-I error, and set at $p < 0.0125$. Afterwards, using RStudio to investigate if the correlation strength differed between each correlation pair, r scores were compared in a pairwise manner (PEARSON; FILON, 1898), considering two dependent groups and nonoverlapping one-tailed correlations (DIEDENHOFEN; MUSCH, 2015). Because we had to perform 6 pairwise comparisons in this analysis, significance of these comparisons was divided by 6 and set at $p < 0.0083$.

4 Results

Abbreviations in the results section were made according to the following pattern: axis of balance perturbation – axis of CP analysis. Hence, AP-AP means anteroposterior displacement of the support base and CP analysis in the AP axis. A total of 72 participants completed the evaluation protocol. For descriptive purposes, average and standard deviation values of each variable, in each axis of perturbation and analysis, are presented below, in Table 6.

Graphical representation of the fitted correlation curves and individual plotted values are presented in Figure 12. Dynamic and reactive CP displacements were significantly correlated in the AP-AP pair only (Figure 12, Panel A). Correlation strength was considered moderate for the AP-AP pair, with $r^2 = 0.267$, and weak for the other pairs (AP-ML, $r^2 = 0.002$; ML-AP, $r^2 = 0.022$; ML-ML, $r^2 = 0.019$). Comparison of correlation strength revealed no difference between the r values of the non-significant correlations (AP-ML vs. ML-AP, $z = -1.219$, $p = 0.111$; AP-ML vs. ML-ML, $z = -1.146$, $p = 0.126$, ML-AP vs. ML-ML, $z = 0.076$, $p = 0.470$), while the dynamic-reactive AP-AP correlation pair presented a r value significantly stronger than the other 3 (vs. AP-ML, $z = 8.732$, $p < 0.001$; vs. ML-AP, $z = 2.803$, $p = 0.002$; vs. ML-ML, $z = 2.669$, $p = 0.004$).

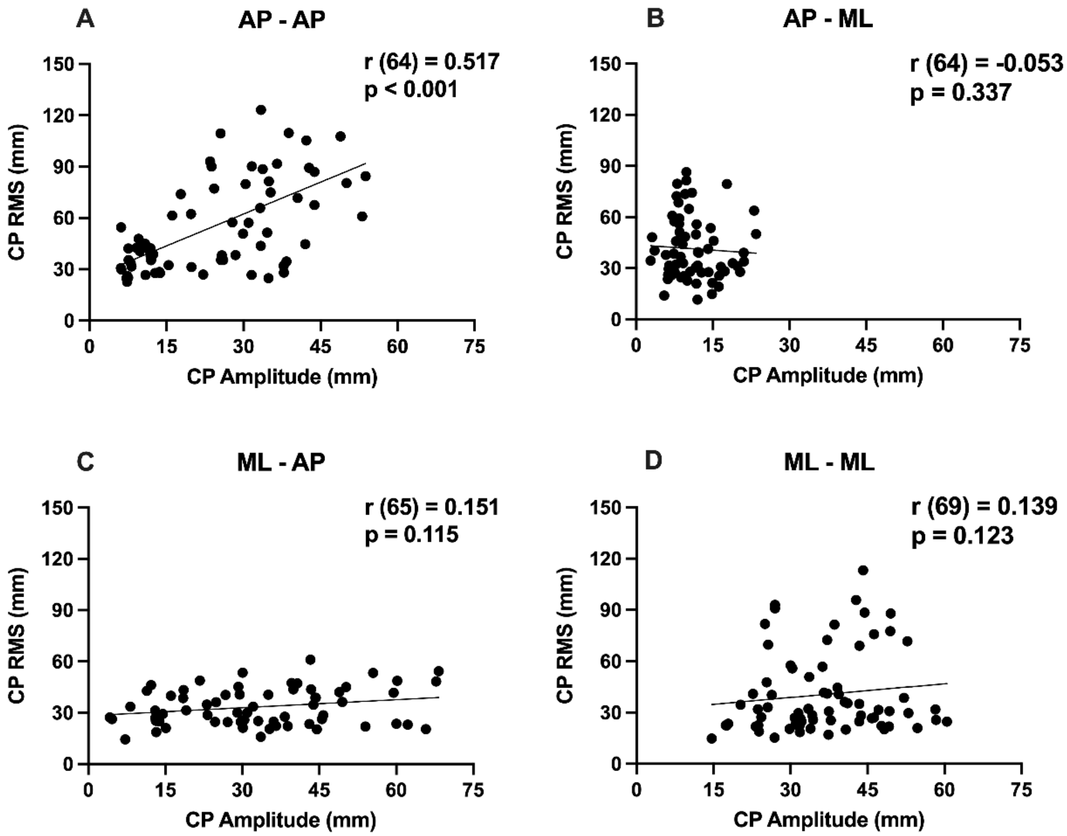

Figure 12. Correlation plots between dynamic (Y axis) and reactive (X axis) balance performance as a function of platform oscillation direction (AP/ML, left sided legend) and analyzed direction (AP/ML, right sided legend). CP = center of pressure; RMS = root mean square.

Table 6. Descriptive values of dynamic and reactive balance variables in each axis.

	Dynamic balance (CP RMS, mm)				Reactive balance (CP Range, mm)			
Perturbation axis	AP		ML		AP		ML	
Analysis axis	AP	ML	AP	ML	AP	ML	AP	ML
Average (SD)	24.5 (13.9)	11.2 (4.8)	34.1 (16.6)	36.5 (10.9)	49.6 (21.7)	41.0 (18.2)	33.8 (11.2)	40.3 (23.8)

Note. CP = center of pressure; RMS = root mean square; AP = anteroposterior; ML = mediolateral; SD = standard deviation.