Universidade de Évora - Instituto de Investigação e Formação Avançada

Programa de Doutoramento em Motricidade Humana

Tese de Doutoramento

Fall prevention in community-dwelling older adults. Effects of two programs: single psychomotor intervention versus combined with whole-body vibration. A randomized controlled trial

Hugo Filipe Zurzica Rosado

Orientador(es) | Armando Manuel Raimundo
Catarina Lino Pereira
Jorge Duarte Bravo

Évora 2023

Universidade de Évora - Instituto de Investigação e Formação Avançada

Programa de Doutoramento em Motricidade Humana

Tese de Doutoramento

Fall prevention in community-dwelling older adults. Effects of two programs: single psychomotor intervention versus combined with whole-body vibration. A randomized controlled trial

Hugo Filipe Zurzica Rosado

Orientador(es)	Armando Manuel Raimundo Catarina Lino Pereira Jorge Duarte Bravo

Évora 2023

A tese de doutoramento foi objeto de apreciação e discussão pública pelo seguinte júri nomeado pelo Diretor do Instituto de Investigação e Formação Avançada:

Presidente	Orlando de Jesus Fernandes (Universidade de Évora)
Vogais	Catarina Lino Pereira (Universidade de Évora) (Orientador) Maria Filomena Araújo Costa Cruz Carnide (Universidade de Lisboa - Faculdade de Motricidade Humana (FMH)) Maria Helena Rodrigues Moreira (Universidade de Trás-os-Montes e Alto Douro - Escola de Ciências Humanas e Sociais) Pablo Tomas-Carus (Universidade de Évora) Rita Alexandra Prior Falhas Santos Rocha (Instituto Politécnico de Santarém)

Évora 2023

This work was funded by the European Union (European Social Fund) and national funds by the Foundation for Science and Technology through a doctoral fellowship (SFRH/BD/147398/2019).

AGRADECIMENTOS

Quero agradecer a todas as instituições e pessoas que de alguma forma contribuíram para a realização desta investigação.

À Fundação para a Ciência e a Tecnologia pelo apoio financeiro através de uma bolsa de doutoramento. Espero que esta investigação faça justiça ao apoio disponibilizado.

À Professora Catarina Pereira, pela total disponibilidade, não só no âmbito da minha tese de doutoramento, mas pelos últimos 10 anos em que trabalhámos juntos e pela amizade que desenvolvemos. Sem a Professora Catarina nunca teria chegado onde cheguei hoje. Que venham os próximos 10 anos!

Ao Professor Jorge Bravo, pela amizade que desenvolvemos e por todo o conhecimento que me tem transmitido. Mesmo passado este tempo, todos os dias aprendo algo novo. É sem dúvida uma das minhas inspirações a nível académico.

Ao Professor Armando Raimundo, por toda a disponibilidade e apoio que me deu em todos os sentidos desde que iniciei o percurso académico e em particular o doutoramento.

À Professora Joana Carvalho, pela preciosa ajuda que me deu, nomeadamente em publicações científicas.

À Professora Felismina Mendes, por ter acreditado nas minhas competências e ter possibilitado a oportunidade de me iniciar no mundo da investigação. Sem a professora Felismina também nunca teria chegado a esta etapa.

A todos os docentes e investigadores do Departamento de Desporto e Saúde, da Universidade de Évora, pela entreajuda e apoio que me deram desde sempre. Sinto-me sempre como se estivesse em casa.

À Escola Superior de Enfermagem S. João de Deus, da Universidade de Évora, e respetivos funcionários por todo o apoio que me deram.

Aos meus avós, pais e à Rosarinho. Sem o apoio, compreensão e amor deles nada disto seria possível. Não podia ter melhores pessoas na vida para me acompanharem e me ajudarem em tudo o que for preciso.

Aos meus amigos e, em particular, ao Pedro pela nossa amizade.

Às pessoas idosas que participaram neste estudo e com as quais mantenho uma relação de amizade, pela confiança que depositaram em mim. Sem elas nada disto seria possível!

Fall prevention in community-dwelling older adults. Effects of two programs: single psychomotor intervention versus combined with whole-body vibration. A randomized controlled trial

ABSTRACT

The main goal of this investigation was to determine the effect of two intervention programs – psychomotor intervention vs. combined intervention (psychomotor intervention + whole-body vibration) – on risk factors for falls in community-dwelling older people who had fallen or were at high risk of falling.

The investigation involved a literature review, an instrument development and validation study, and a randomized control trial study (RCT).

The literature review suggests that, for fall prevention, the interventions performing simultaneously cognitive and motor stimulation induced additional benefits compared to cognitive or motor single interventions.

The developed stepping-forward affordance perception test showed strong internal consistency and was demonstrated to be accurate, reliable, and valid for fall risk assessment (model AUC for fallers: 0.665, 95% CI: 0.608–0.723; model AUC for recurrent fallers: 0.728, 95% CI: 0.655–0.797).

The RCT results (51 participants: 75.4 ± 5.6 years) suggest that the participants well tolerated the intervention programs. After the 24-week intervention (3x/week), both programs significantly improved processing speed, selective and sustained attention, dual-task performance, mobility, lower-body strength, balance, and bone mineral density, $p < 0.05$. In addition, the combined intervention induced significant improvements in reaction time and bone mineral content, $p < 0.05$. Both programs decreased the incidence of falls, especially the combined intervention. Overall, after 12 weeks of follow-up, the improvements in cognitive function were maintained, while physical function and bone mass results were reversed. No significant differences between programs were found. The control group maintained their results.

In conclusion, although the combined program induced additional improvements, both programs were effective and are recommended for fall prevention.

Keywords: Aging; Risk factors for falls; Physical function; Affordance perception; Dual-task.

Prevenção da queda em idosos residentes na comunidade. Efeitos de dois programas: intervenção psicomotora singular versus combinada com exercício vibratório. Um estudo randomizado controlado

RESUMO

Esta investigação teve como principal objetivo determinar o efeito de dois programas de intervenção – intervenção psicomotora vs. intervenção combinada (intervenção psicomotora + exercício vibratório) – nos fatores de risco de queda em pessoas idosas a residir em comunidade, caidoras ou em risco elevado de queda.

A investigação incluiu uma revisão de literatura, o desenvolvimento e validação de um instrumento, e um estudo randomizado controlado (RCT).

A revisão de literatura realizada sugere que em programas para a prevenção de queda, intervenções que realizaram simultaneamente uma estimulação cognitiva e motora induziram a benefícios adicionais, comparando com intervenções cognitivas ou motoras singulares.

O stepping-forward affordance perception test desenvolvido apresentou uma consistência interna forte e demonstrou ser preciso, fiável e válido para avaliar o risco de queda (área por baixo da curva de 0.665 (95% IC: 0.608–0.723) para caidores e de 0.728 (95% IC: 0.655–0.797) para caidores recorrentes.

Os resultados do RCT (51 participantes: 75.4 ± 5.6 anos) sugerem que os programas de intervenção foram bem tolerados. Após 24 semanas de intervenção (3x/semana), ambos os programas induziram a melhorias significativas no processamento de informação, atenção seletiva e sustentada, capacidade de dupla tarefa, mobilidade, força dos membros inferiores, equilíbrio e densidade mineral óssea, $p < 0.05$. Adicionalmente, a intervenção combinada induziu a melhorias significativas no tempo de reação e conteúdo mineral ósseo, $p < 0.05$. A ocorrência de queda diminuiu em ambos os programas, especialmente na intervenção combinada. Globalmente, após 12 semanas de follow-up, as melhorias no funcionamento cognitivo foram mantidas, enquanto na aptidão física e massa óssea pioraram. Não existiram diferenças entre os programas de intervenção. O grupo de controlo manteve os seus resultados.

Como conclusões, embora a intervenção combinada induza benefícios adicionais, tanto o programa de intervenção psicomotora, como o programa combinado mostraram ser eficazes e recomendados para a prevenção das quedas.

Palavras-chave: Envelhecimento; Fatores de risco de quedas; Aptidão física; Perceção de affordances; Dupla tarefa.

Publications related to this thesis

Papers in international scientific journals

Almeida, G., Bravo, J., Folgado, H., Rosado, H., Mendes, F., & Pereira, C. (2019). Reliability and construct validity of the stepping-forward affordance perception test for fall risk assessment in community-dwelling older adults. *PLoS ONE*, 14(11), e0225118. https://doi.org/10.1371/journal.pone.0225118

Rosado, H., Bravo, J., Raimundo, A., Carvalho, J., Marmeleira, J., & Pereira, C. (2021). Effects of two 24-week multimodal exercise programs on reaction time, mobility, and dual-task performance in community-dwelling older adults at risk of falling: a randomized controlled trial. *BMC Public Health*, *21*(2), 408. https://doi.org/10.1186/s12889-021-10448-x

Rosado, H., Pereira, C., Bravo, J., Carvalho, J., & Raimundo, A. (2022). Benefits of Two 24-Week Interactive Cognitive–Motor Programs on Body Composition, Lower-Body Strength, and Processing Speed in Community Dwellings at Risk of Falling: A Randomized Controlled Trial. *International Journal of Environmental Research and Public Health*, 19(12), 7117. https://doi.org/10.3390/ijerph19127117

Rosado, H., Bravo, J., Raimundo, A., Carvalho, J., Almeida, G., & Pereira, C. (2022). Can two multimodal psychomotor exercise programs improve attention, affordance perception, and balance in community dwellings at risk of falling? A randomized controlled trial. *BMC Public Health*, 21(2), 2336. https://doi.org/10.1186/s12889-022-13725-5

Rosado, H., Pereira, C., Bravo, J., Carvalho, J., & Raimundo, A. Which lower- or higher-functioning older adults can improve more on cognitive and physical functions? Effects of interactive cognitive-motor programs considering the functional level. *Submitted for publication.*

Abstracts

Rosado, H., Bravo, J., Raimundo, A., Mendes, F., Branco, L., Pereira, C. (2019). A 12-week multimodal exercise program can improve physical and cognitive functioning risk factors for falls in community-dwelling older adults: preliminary results of a psychomotor intervention. *European Journal of Public Health*, 29 (1). https://doi.org/10.1093/eurpub/ckz034

Rosado, H., Bravo, J., Raimundo, A., Mendes, F., Pelado, A., Pereira, C. (2019). A 12-week physical exercise, cognitive and whole-body vibration program can improve physical and cognitive functioning risk factors for falls and fractures in community-dwelling older adults: preliminary results. *European Journal of Public Health*, 29 (1). https://doi.org/10.1093/eurpub/ckz034.001

Rosado, H., Bravo, J., Raimundo, A., Almeida, G., Mendes, F., & Pereira, C. (2020). The effect of 12-week multimodal programs on the affordances perception: a risk factor for falls in community-dwelling older adults. Preliminary results. In: Repositório Comum do Instituto Politécnico de Coimbra.

Rosado, H., Bravo, J., Raimundo, A., Mendes, F., & Pereira, C. (2020). Twelve-week multimodal programs can improve dual-task performance in risk factors for falls in community-dwelling older adults: a pilot study. *European Journal of Public Health*, 30 (2). https://doi.org/10.1093/eurpub/ckaa040.013

Rosado, H., Bravo, J., Raimundo, A., Mendes, F., & Pereira, C. (2020). Can two multimodal programs improve dual-task performance in community-dwelling older adults at high risk of falling? *RIASE: Revista Ibero-Americana de Saúde e Envelhecimento*, 6(3), 1–90. http://dx.doi.org/10.24902/r.riase.2020.6(3).487.1-90

Rosado, H., Bravo, J., Raimundo, A., Carvalho, J., Leite, N., & Pereira, C. (2021). Novel approaches to reduce the risk of falling in community dwellings: effects of two multimodal programs in lower-body strength. A pilot study. *European Journal of Public Health*, 31 (2). https://doi.org/10.1093/eurpub/ckab120.064

Rosado, H., Bravo, J., Raimundo, A., Marmeleira, J., Mendes, F., & Pereira, C. (2021). Benefits of two twelve-week multimodal programs on reaction time in community dwellings at risk of falling: preliminary results. *European Journal of Public Health*, 31 (2). https://doi.org/10.1093/eurpub/ckab120.062

Rosado, H., Bravo, J., Raimundo, A., Mendes, F., Teixeira, S., & Pereira, C. Benefits of a fall prevention psychomotor program in dual-task cost and interference: two cognitive-motor paradigms. *Portuguese Journal of Public Health*, 40(suppl 1):1-24. https://doi.org/10.1159/000527366

Rosado, H., Bravo, J., Raimundo, A., Mendes, F., Tibúrcio, R., & Pereira, C. (2023). Effects of a psychomotor intervention in physical function according to baseline functioning. *Portuguese Journal of Public Health,* 41 (Suppl. 1): 0. https://doi.org/10.1159/000530767

Rosado, H., Bravo, J., Raimundo, A., Mendes, F., Tibúrcio, R., & Pereira, C. (2023). Benefits of a psychomotor intervention in processing speed and reaction time depending on the baseline functioning. *Portuguese Journal of Public Health,* 41 (Suppl. 1): 0. https://doi.org/10.1159/000530767

Book chapters

Rosado, H., Bravo, J., Raimundo, A., & Pereira, C. (2020). Programas de intervenção para a prevenção de quedas em pessoas idosas residentes na comunidade. In: Mendes, F., Pereira, C., & Bravo, J. (Universidade de Évora, Ed.). *Envelhecer em Segurança no Alentejo. Compreender para agir*. ISBN: 978-989-99122-9-8. Évora, PT. http://hdl.handle.net/10174/31137

Scientific presentations related to this thesis

Rosado, H., Bravo, J., Raimundo, A., Mendes, F., Pelado, A., & Pereira, C. (2019, april). A 12-week physical exercise, cognitive and whole-body vibration program can improve physical and cognitive functioning risk factors for falls and fractures in community-dwelling older adults: preliminary results. Annual Meeting 2019. Cuidados de Saúde Primários: Desafios e oportunidades. Escola Superior de Tecnologia da Saúde de Coimbra. Coimbra. Portugal.

Rosado, H., Bravo, J., Raimundo, A., Mendes, F., Branco, L., & Pereira, C. (2019, april). A 12-week multimodal exercise program can improve physical and cognitive functioning risk factors for falls in community-dwelling older adults: preliminary results of a psychomotor intervention. Annual Meeting 2019. Cuidados de Saúde Primários: Desafios e oportunidades. Escola Superior de Tecnologia da Saúde de Coimbra. Coimbra. Portugal.

Rosado, H., Bravo, J., Raimundo, A., Mendes, F., & Pereira, C. (2020, june). Twelve-week multimodal programs can improve dual-task performance in risk factors for falls in community-dwelling older adults: a pilot study. Annual Meeting 2020: Saúde 4.0: Desenhar a Saúde de Amanhã. Escola Superior de Tecnologia da Saúde de Coimbra. Coimbra. Portugal.

Rosado, H., Bravo, J., Raimundo, A., Carvalho, J., Leite, N., & Pereira, C. (2021, june). Novel approaches to reduce the risk of falling in community dwellings: effects of two multimodal programs in lower-body strength. A pilot study. Annual Meeting Global Health: New Trends. Escola Superior de Tecnologia da Saúde de Coimbra. Coimbra. Portugal.

Rosado, H., Bravo, J., Raimundo, A., Marmeleira, J., Mendes, F., & Pereira, C. (2021, june). Benefits of two twelve-week multimodal programs on reaction time in community dwellings at risk of falling: preliminary results. Annual Meeting Global Health: New Trends. Escola Superior de Tecnologia da Saúde de Coimbra. Coimbra. Portugal.

Rosado, H., Bravo, J., Raimundo, A., Mendes, F., Teixeira, S., & Pereira, C. (2022, may). Benefits of a fall prevention psychomotor program in dual-task cost and interference: two cognitive-motor paradigms. 2nd Comprehensive Health Research Centre Annual Summit (CHRC). Universidade de Évora. Évora. Portugal.

Rosado, H., Bravo, J., Raimundo, A., Mendes, F., Tibúrcio, R., & Pereira, C. (2022, november). Effects of a psychomotor intervention in physical function according to baseline functioning. 3rd Comprehensive Health Research Centre Annual Summit (CHRC). NOVA Medical School. Lisboa. Portugal.

Rosado, H., Bravo, J., Raimundo, A., Mendes, F., Tibúrcio, R., & Pereira, C. (2022, november). Benefits of a psychomotor intervention in processing speed and reaction time depending on the baseline functioning. 3rd Comprehensive Health Research Centre Annual Summit (CHRC). NOVA Medical School. Lisboa. Portugal.

Table of Contents

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

ACSM: American College of Sports Medicine

AGS: American Geriatrics Society

ANOVA: Analysis of variance

AUC: Area under the curve

BGS: British Geriatrics Society

BMC: Bone mineral content

BMD: Bone mineral density

BMI: Body mass index

CG: Control group

CI: Confidence interval

CogTUG: Cognitive timed up and go

CPF: Composite Physical Function

CRT: Choice reaction time

CTS: Caregiver Treatment Satisfaction

CV: Coefficient of variation

DLRT: Deary-Liewald reaction time task

DT: Dual-task

DXA: Dual-energy X-ray absorptiometry

EF: Executive function

EG: Experimental group

EG1: Experimental group 1

EG2: Experimental group 2

ES: Effect size

FAB: Fullerton Advanced Balance

ICC: Intraclass correlation

ICM: Interactive Cognitive-Motor

IPAQ: International Physical Activity Questionnaire

MET: Metabolic equivalent of task

ORs: Odds ratios

RCT: Randomized controlled trial

ROC: Receiver operating characteristic

RPE: Borg Rating of Perceived Exertion

RT: Reaction time

SD: Standard deviation

SEM: Standard error of measurement

SF-APT: Stepping-forward affordance perception test

SPSS: Statistical Package for the Social Sciences

SRT: Simple reaction time

TMT-A: Trail Making Test Part A

TMT-B: Trail Making Test Part B

TUG: Timed up and go

WBV: Whole-body vibration

WHO: World Health Organization

30CST: 30-s chair stand test

CHAPTER 1

Introduction

Introduction

Globally, the worldwide population is aging. For example, it's estimated that by 2050 the number of older people aged 65 and over will at least double, exceeding 1.5 billion persons. Similarly, the number of older people aged 80 years or over is projected to triple to 426 million (United Nations, 2019). Portugal also follows this trend (Instituto Nacional de Estatística, 2020).

Despite this good news, which can be associated with new opportunities, aging is also considered challenging. Several factors or events can influence healthy aging and the quality of life. One of the most crucial events is falls. According to the World Health Organization (WHO) (World Health Organization, 2018), falls are a major health problem and the second most common cause of unintentional injury deaths. In addition, fall-related injuries or fractures lead to considerable medical costs and dependence, whereby effective prevention strategies to reduce fall risk are needed (Florence et al., 2018; World Health Organization, 2018). Furthermore, evaluating the fall risk in community-dwelling older adults with accurate and valid assessments is essential. For instance, an accurate assessment can identify potential fallers and direct them to proper fall prevention programs.

Falls have a multifactorial etiology (described in more detail in chapter two). Concerning intrinsic fall risk factors, age-related changes can negatively affect functionality, particularly cognitive and physical function (Cunningham et al., 2020). Cognitive impairments in abilities such as executive functions, processing speed, attention, reaction time, or dual-task performance are considered risk factors for falls (Ambrose et al., 2013). Likewise, decreased physical function, particularly in mobility, lower-body strength, and balance, can also enhance the risk of falling (Jehu et al., 2021; Uusi-Rasi et al., 2019). Moreover, locomotor skills impairments in action boundaries or body composition change, especially in bone mineral density or lower limb muscle mass, can be related to falls and consequent injuries (Pereira et al., 2022; Uusi-Rasi et al., 2019).

More than following the guidelines for physical activity provided by WHO (World Health Organization, 2020), it is essential that older people integrate intervention programs adequate to their needs. Recent systematic reviews and meta-analyses have been suggesting the efficacy and additional benefits in cognitive and physical function of combined interventions - which perform cognitive and physical stimulation simultaneously - compared to other single interventions, such as exercise alone or cognitive training (Gavelin et al., 2021; Rieker et al., 2022). The systematic review of Schoene and colleagues (Schoene et al., 2014) also provided evidence of the interactive cognitive-motor training benefits, particularly with improvements in fall risk factors. In addition, literature reported that this type of intervention achieves higher gains when performed in a social context (Rieker et al., 2022). The mechanisms of the synergistic response between cognition and physical activity were further explored in the scientific papers related to this doctoral thesis (chapter four). It is also important to note that multimodal or interactive cognitive-motor programs are similar if cognitive and motor stimulation are performed simultaneously.

Given the above, designing effective fall prevention programs becomes evident. In recent years, psychomotor intervention has evidenced the potential to promote cognitive and physical function improvements in older people (Pereira et al., 2018). Psychomotor intervention is a body mediation therapy focused mainly on cognitive, motor, and relational stimulation (Fernandes, 2014; Martins, 2001). To our knowledge, only one study investigated the effects of a psychomotor intervention as a fall prevention in community dwellings (Freiberger et al., 2007). However, more studies are needed to generalize the findings in community-dwelling older people.

Similarly, whole-body vibration (WBV) training has demonstrated positive effects in older adults. WBV is a neuromuscular training method that uses a vibrating platform to produce oscillations sent to the body and promote physiological changes (Awan et al., 2017). WBV has been related to physical function enhancements in older adults, particularly in mobility, lower-body strength, and balance (Awan et al., 2017). The systematic review by Jepsen and colleagues (Jepsen et al., 2017) also suggests that WBV reduces the fall rate and may prevent fractures. Concerning bone mass, despite the improvements reported in the systematic review and meta-analyses conducted by DadeMatthews and colleagues (DadeMatthews et al., 2022), the WBV training's impact on bone mass still needs more studies for a better understating. Furthermore, the recent systematic review of Wen and colleagues (Wen et al., 2023) suggested that, although WBV may positively affect cognition, additional and more extensive studies are required to generalize these findings.

Given the positive effects of WBV training in older adults, it can be seen as a complement to the psychomotor intervention. However, this therapy is not aimed at bone mass improvements, an essential factor to include in a fall prevention program. To our knowledge, the randomized controlled trial (RCT) in the present investigation was the first study combining these two interventions. In addition, it's essential to investigate the effects of both psychomotor intervention and combined intervention (psychomotor intervention + WBV) as fall prevention programs and the respective detraining effects.

In addition, our literature review evidenced affordance perception impairment as a potential risk factor for falls (Delbaere et al., 2010). Since we found no instrument in the literature to assess this parameter, particularly action boundaries, developing and validating an instrument for that purpose became relevant. Consequently, the RCT performed in the present investigation will be the first study to evaluate the effect of intervention programs on this potential risk factor for falls.

This thesis is organized into six chapters. The first chapter includes this general introduction and aims to present the main conceptual framework to be approached in more detail in the scientific papers addressed subsequently.

The second chapter is a literature review focusing on fall prevention intervention programs tailored to community-dwelling older adults. This chapter also includes the etiology of falls, risk factors for falls, general recommendations for physical activity/exercise in older people, and types of training.

The third chapter reports the study performed to determine the reliability and validity of a new test for fall risk assessment in community-dwelling older adults. The stepping-forward affordance perception test (SF-APT) evaluates the estimation and actual performance of locomotor ability in older adults. The development of this test comes from the need to use valid, reliable, practical, and quick-to-administer instruments to assess psychomotor parameters that potentially are risk factors for falls. Through a frontal step, it is assessed whether the older person underestimated or overestimated their perception of the step and, consequently, whether they are at risk of falling.

The experimental study conducted to carry out this thesis is reported in chapter four. This chapter included three scientific papers. The main aim was to evaluate the effects of two intervention programs on older people who had fallen or were at high risk of falling.

All three papers concerning the experimental study included in this thesis presented the same methods. The experimental study was conducted between March 2018 and January

2019 and had a RCT design. Participants (community dwellings) were randomly divided into three groups: experimental group 1 (which performed a psychomotor intervention program), experimental group 2 (which underwent a combined program: psychomotor intervention program + WBV), and control group (in which participants were asked to maintain their daily life routines).

The experimental study lasted for 24 weeks, and the participants were assessed at baseline, post-intervention (24 weeks), and after a 12-week follow-up. The addressed outcome measures varied from paper to paper, according to the objectives of each one. However, as stated above, the intervention programs were always the same. The statistical analysis performed in the three papers was based on comparisons between each evaluation moment and between groups and the magnitude of the treatment effect. The experimental study protocol was registered at ClinicalTrials.gov (NCT03446352) in February 2018.

In chapter five, a general discussion was performed based on the scientific evidence achieved in the previous papers. Finally, chapter six included the conclusions and practical implications/suggestions for future investigations.

Objectives and Hypotheses of this thesis

The present investigation has general and specific objectives.

General objective:

To investigate the effect of two intervention programs – psychomotor intervention vs. combined intervention (psychomotor intervention + WBV) – on risk factors for falls in community-dwelling older people who had fallen or were at high risk of falling.

Specific objectives:

1) Specific objectives of the Literature Review:

   1.1) To identify the etiology of falls and the respective fall risk factors.

   1.2) To identify fall prevention intervention programs described in the literature and analyze their effectiveness.

2) Specific objectives of the instrument development and validation study:

2.1) To develop and validate a new test for fall risk assessment in community-dwelling older adults.

3) Specific objectives of the RCT study:

3.1) To determine the effect of two intervention programs – psychomotor intervention vs. combined intervention (psychomotor intervention + WBV) – on falls occurrence in community-dwelling older people who had fallen or were at high risk of falling.

3.2) To determine the effect of two intervention programs – psychomotor intervention vs. combined intervention (psychomotor intervention + WBV) – on cognitive function, namely in executive functions, processing speed, selective and sustained attention, reaction time, and dual-task performance in community-dwelling older people who had fallen or were at high risk of falling.

3.3) To determine the effect of two intervention programs – psychomotor intervention vs. combined intervention (psychomotor intervention + WBV) – on physical function, namely in mobility, lower-body strength, and balance in community-dwelling older people who had fallen or were at high risk of falling.

3.4) To determine the effect of two intervention programs – psychomotor intervention vs. combined intervention (psychomotor intervention + WBV) – on body composition, namely on bone mineral density, bone mineral content, fat mass, and lean body mass in community-dwelling older people who had fallen or were at high risk of falling.

3.5) To determine the effect of two intervention programs – psychomotor intervention vs. combined intervention (psychomotor intervention + WBV) – in action boundaries in community-dwelling older people who had fallen or were at high risk of falling.

3.6) To determine the detraining effect of two intervention programs – psychomotor intervention vs. combined intervention (psychomotor intervention + WBV) – in the studied cognitive and physical function variables and the body composition variables in community-dwelling older people who had fallen or were at high risk of falling.

The present investigation has hypothesized that:

Hypothesis 1: The ability to perceive action boundaries accurately for the stepping-forward skill may indicate the risk of fall occurrence in community-dwelling older adults.

Hypothesis 2: The psychomotor intervention program and the combined program (psychomotor intervention + WBV) positively impact fall risk factors and are effective interventions to prevent falls in community-dwelling older adults.

Hypothesis 3: The combined intervention program (psychomotor intervention + WBV) led to a larger decrease in fall occurrence in community-dwelling older adults than in the psychomotor intervention program.

Hypothesis 4: Both interventions led to similar effects on the cognitive function variables: executive functions, processing speed, selective and sustained attention, and reaction time.

Hypothesis 5: The combined intervention (psychomotor intervention + WBV) led to a larger effect on dual-task performance.

Hypothesis 6: The combined intervention (psychomotor intervention + WBV) led to a larger effect on physical function: mobility, lower-body strength, and balance.

Hypothesis 7: The combined intervention (psychomotor intervention + WBV) led to a larger effect on body composition, namely in bone mineral density and bone mineral content.

Hypothesis 8: Both interventions led to similar effects in action boundaries.

Hypothesis 9: The detraining led to larger losses in the studied physical function and body composition variables compared to the cognitive function variables.

References

Ambrose, A. F., Paul, G., & Hausdorff, J. M. (2013). Risk factors for falls among older adults: a review of the literature. *Maturitas*, *75*(1), 51-61. https://doi.org/10.1016/j.maturitas.2013.02.009

Awan, R. I., N., K., & S., P. (2017). The Effect of WBV on Balance, Mobility and Strength in Aging Adults: A Systematic Review. *Biological Systems: Open Access*, *6*(1). https://doi.org/10.4172/2329-6577.1000179

Cunningham, C., R, O. S., Caserotti, P., & Tully, M. A. (2020). Consequences of physical inactivity in older adults: A systematic review of reviews and meta-analyses. *Scandinavian Journal of Medicine and Science in Sports*, *30*(5), 816-827. https://doi.org/10.1111/sms.13616

DadeMatthews, O. O., Agostinelli, P. J., Neal, F. K., Oladipupo, S. O., Hirschhorn, R. M., Wilson, A. E., & Sefton, J. M. (2022). Systematic review and meta-analyses on the effects of whole-body vibration on bone health. *Complementary Therapies in Medicine*, *65*, 102811. https://doi.org/10.1016/j.ctim.2022.102811

Delbaere, K., Close, J. C., Brodaty, H., Sachdev, P., & Lord, S. R. (2010). Determinants of disparities between perceived and physiological risk of falling among elderly people: cohort study. *BMJ*, *341*, c4165. https://doi.org/10.1136/bmj.

Fernandes, J. (2014). A Gerontopsicomotricidade como Práxis Terapêutica de Mediação Corporal. *Journal of Aging and Innovation*, *3*(3), 1-3.

Florence, C. S., Bergen, G., Atherly, A., Burns, E., Stevens, J., & Drake, C. (2018). Medical Costs of Fatal and Nonfatal Falls in Older Adults. *Journal of the American Geriatrics Society*, *66*(4), 693-698. https://doi.org/10.1111/jgs.15304

Freiberger, E., Menz, H. B., Abu-Omar, K., & Rutten, A. (2007). Preventing falls in physically active community-dwelling older people: a comparison of two intervention techniques. *Gerontology*, *53*(5), 298-305. https://doi.org/10.1159/000103256

Gavelin, H. M., Dong, C., Minkov, R., Bahar-Fuchs, A., Ellis, K. A., Lautenschlager, N. T., Mellow, M. L., Wade, A. T., Smith, A. E., Finke, C., Krohn, S., & Lampit, A. (2021). Combined physical and cognitive training for older adults with and without cognitive impairment: A systematic review and network meta-analysis of randomized controlled trials. *Ageing Research Reviews*, *66*, 101232. https://doi.org/10.1016/j.arr.2020.101232

Instituto Nacional de Estatística. (2020). *Projeções de População Residente 2018-2080*. https://www.ine.pt/xportal/xmain?xpid=INE&xpgid=ine_destaques&DESTAQUESdest_boui=406534255&DESTAQUESmodo=2&xlang=pt

Jehu, D. A., Davis, J. C., Falck, R. S., Bennett, K. J., Tai, D., Souza, M. F., Cavalcante, B. R., Zhao, M., & Liu-Ambrose, T. (2021). Risk factors for recurrent falls in older adults: A systematic review with meta-analysis. *Maturitas*, *144*, 23-28. https://doi.org/10.1016/j.maturitas.2020.10.021

Jepsen, D. B., Thomsen, K., Hansen, S., Jorgensen, N. R., Masud, T., & Ryg, J. (2017). Effect of whole-body vibration exercise in preventing falls and fractures: a systematic review and meta-analysis. *BMJ Open*, *7*(12), e018342. https://doi.org/10.1136/bmjopen-2017-018342

Martins, R. (2001). Questões Sobre a Identidade da Psicomotricidade. In V. Fonseca & R. Martins (Eds.), *Progressos em Psicomotricidade* (pp. 29-40). FMH.

Pereira, C., Rosado, H., Almeida, G., & Bravo, J. (2022). Dynamic performance-exposure algorithm for falling risk assessment and prevention of falls in community-dwelling older adults. *Geriatric Nursing (New York, N.Y.)*, *47*, 135-144. https://doi.org/10.1016/j.gerinurse.2022.07.004

Pereira, C., Rosado, H., Cruz-Ferreira, A., & Marmeleira, J. (2018). Effects of a 10-week multimodal exercise program on physical and cognitive function of nursing home residents: a psychomotor intervention pilot study. *Aging Clinical and Experimental Research*, *30*(5), 471-479. https://doi.org/10.1007/s40520-017-0803-y

Rieker, J. A., Reales, J. M., Muinos, M., & Ballesteros, S. (2022). The Effects of Combined Cognitive-Physical Interventions on Cognitive Functioning in Healthy Older Adults: A Systematic Review and Multilevel Meta-Analysis. *Frontiers in Human Neuroscience*, *16*, 838968. https://doi.org/10.3389/fnhum.2022.838968

Schoene, D., Valenzuela, T., Lord, S. R., & de Bruin, E. D. (2014). The effect of interactive cognitive-motor training in reducing fall risk in older people: a systematic review. *BMC Geriatrics*, *14*, 107. https://doi.org/10.1186/1471-2318-14-107

United Nations. (2019). *World Population Prospects 2019: Highlights*. United Nations. https://population.un.org/wpp/Publications/Files/WPP2019_Highlights.pdf

Uusi-Rasi, K., Karinkanta, S., Tokola, K., Kannus, P., & Sievanen, H. (2019). Bone Mass and Strength and Fall-Related Fractures in Older Age. *Journal of Osteoporosis*, *2019*, 5134690. https://doi.org/10.1155/2019/5134690

Wen, J., Leng, L., Hu, M., Hou, X., & Huang, J. (2023). Effects of whole-body vibration training on cognitive function: A systematic review. *Frontiers in Human Neuroscience*, *17*, 854515. https://doi.org/10.3389/fnhum.2023.854515

World Health Organization. (2018). *Falls*. https://www.who.int/news-room/fact-sheets/detail/falls

World Health Organization. (2020). *WHO Guidelines on Physical Activity and Sedentary Behaviour*. https://www.who.int/publications/i/item/9789240015128

CHAPTER 2

Literature Review

Literature Review

Fall prevention intervention programs in community-dwelling older people

Hugo Rosado[1,2]*, Jorge Bravo[1,2], Armando Raimundo[1,2], Catarina Pereira[1,2]

[1] Departamento de Desporto e Saúde, Escola de Saúde e Desenvolvimento Humano, Universidade de Évora, Évora, Portugal.

[2] Comprehensive Health Research Centre (CHRC), Universidade de Évora, Évora, Portugal.

* Corresponding author: hrosado@uevora.pt

Abstract

Falls have a multifactorial etiology and are associated with dependence, morbidity, and mortality in older people. Therefore, it is crucial to test the individual susceptibility to the risk of falling and implement intervention programs. Furthermore, it is essential to identify the risk factors using accurate, reliable, and valid fall risk assessments. The evaluation and respective results analysis make it possible to refer older people to the appropriate intervention. Moreover, before outlining an intervention program, the health professional must consider the general recommendations regarding physical activity and exercise in older people. The health professional should also consider the individual's characteristics and functional level to determine the main components and activities to be included in the intervention program without neglecting the training specificity. This literature review approaches the etiology of falls, the respective fall risk factors, and the singular, combined, or personalized fall prevention intervention programs that stand out as a solution to fall prevention.

1. Introduction

According to the study results of Moniz-Pereira and colleagues (Moniz-Pereira et al., 2013), it was found that 38% of Portuguese older people fall at least once a year, with 61% reporting one fall (episodic falls), and 39% reported two or more falls per year (recurrent falls). The previous authors also reported that 43% of older people who fell suffered injuries, which could lead to a restriction of daily activities and greater dependence. These data highlight the need to test more fall prevention programs.

Before implementing fall prevention programs in community-dwelling older people it's essential to identify the risk factors that can lead to falls, particularly impairments in cognitive and physical function, or body composition (Ambrose et al., 2013; Jehu et al., 2021; Uusi-Rasi et al., 2019). In addition, changes in the previous functions can contribute to an inaccurate perception of action boundaries and lead to a higher risk of falling (Luyat et al., 2008). Furthermore, the association among the risk factors analysis is also critical since falls have a multifactorial etiology. This way, if adequate assessments identify the fall causes, their occurrence can be prevented (Kenny et al., 2011). Nevertheless, accurate, reliable, and valid instruments for fall risk assessment are still needed in community-dwelling older adults, particularly to assess the stepping-forward affordance perception.

The risk factors that promote the occurrence of falls can be classified as intrinsic (individual), extrinsic (environmental), or behavioral. The intrinsic factors (e.g., physical or cognitive function impairment, vision or vitamin D deficits, and polymedication), extrinsic factors (e.g., characteristics of the environment or inappropriate footwear), or behavioral factors (e.g., sedentary lifestyle or emotional state) can be modified. However, not all of them can be eliminated. Therefore, the strategy to be adopted in fall prevention should consist of the risk factors assessment and monitoring and the implementation of specific intervention programs aimed at determining risk factors related to falls to improve older people´s quality of life and to reduce the socioeconomic costs resulting from fall (Kenny et al., 2011), as it will be detailed below.

Literature references several types of intervention programs for fall prevention in community dwellings (Guirguis-Blake et al., 2018; Joubert & Chainay, 2018; Robinson & Kiely, 2017). Among these stand out the singular programs (involving a single intervention component, e.g., balance training) and the combined programs (combining two or more intervention components of a similar or different category, e.g., strength training plus cognitive training). In addition, there are also personalized programs (considering the results of an individual assessment, such as the multifactorial intervention, e.g., balance training plus an assessment of visual acuity), with or without supervision and individually or in groups. In this chapter, those indicated as most relevant will be presented.

2. From evaluation to intervention

Before carrying out fall prevention programs tailored to older people, it is necessary to understand how the body, mind, brain, and movement are related and influence each other. (Printes et al., 2016). This can be performed in different stages. All sessions will be planned based on the initial evaluation results and will include well-defined general and specific objectives established in the intervention program. Moreover, the planning must allow the analysis of the intervention program's effect (e.g., initial vs. final evaluation) and effectiveness. Thus, it is essential to assess human dimensions, such as physical or cognitive functions, despite never separating the mind from the body, according to the individual's holistic and global perspective. This is because aging is associated with a decline in all these human dimensions, contributing to an increase in the risk of falling (Printes et al., 2016).

2.1. General physical activity and exercise recommendations for older people

Once the intervention program and respective session plans have been defined, to maximize its benefits in terms of health and quality of life, it is important to consider the recommendations regarding the ideal type and amount of physical activity and exercise to be included in the intervention program. In this way, the American College of Sports Medicine (ACSM) presented some recommendations for exercise prescriptions in older people.

It's also important to distinguish the difference between physical activity and exercise. According to Caspersen and colleagues (Caspersen et al., 1985), "*physical activity is defined as any bodily movement produced by skeletal muscles that results in energy expenditure*". On the other hand, "*exercise is a subset of physical activity that is planned, structured, and repetitive and has as a final or an intermediate objective the improvement or maintenance of physical fitness*" (Caspersen et al., 1985).

The ACSM (Chodzko-Zajko et al., 2009; Garber et al., 2011) recommends exercise, including several functional and neuromotor fitness components, to benefit fall prevention. The exercise must include different frequencies, intensities, times, or progressions, in the following training components: cardiorespiratory, resistance, flexibility, and neuromotor (e.g., agility, balance, proprioceptive training, or yoga).

Balance training is highly recommended for older people with recurrent falls or mobility difficulties. Exercises that gradually decrease the support base and activities, including dynamic movements that disturb the center of gravity, are recommended. Furthermore, activities that promote the postural muscle groups and reduce the incoming sensory information are also suggested (Chodzko-Zajko et al., 2009).

The World Health Organization (World Health Organization, 2010) recommends that people aged 65 years or older attend at least 150 minutes of moderate-intensity aerobic exercise or at least 75 minutes per week of vigorous-intensity aerobic activity in cycles of 10 minutes. It's also recommended 300 minutes of moderate-intensity activity or 150 minutes of vigorous-intensity activity per week for additional health benefits. Along with these recommendations, strength exercises are proposed, at least twice a week, promoting bone mineral density (Garber et al., 2011; World Health Organization, 2010).

The performance of the recommended exercise must be progressive and personalized, considering the physical activity level, response to exercise intensity, and functional level of each older adult. Regarding frequency or periodicity, many of the recommendations will be achieved in a gerontopsychomotricity program with three weekly sessions (Printes et al., 2016), described later in this chapter. However, the previous authors advise that older people stay active every day of the week, even when no organized exercise sessions exist.

2.2. Types of training: continuous training versus interval training

The type of training (continuous or interval training) selected to include in fall prevention programs is essential. Continuous training consists of performing exercises maintaining intensity, typically low to moderate-intensity aerobics. Interval training is characterized by brief and intermittent periods of vigorous activity, intercalated with periods of rest or low-intensity (Garcia-Pinillos et al., 2017). Garcia-Pinillos and colleagues (Garcia-Pinillos et al., 2017) compared the effect of low-volume interval training performed by the experimental group (EG) with the impact of continuous training (low to moderate intensity) carried out by the control group (CG). The previous 12-week study concluded that, despite the reduced training volume, there were significant improvements in the EG in physical function (namely in muscle strength, mobility, and balance) and body composition parameters, $p < 0.05$.

In addition, to analyze the effect of interval training versus continuous training on physical function, it is also essential to analyze its effects on cognitive functioning. The study by Coetsee and Terblanche (Coetsee & Terblanche, 2017) compared the impact of three 16-week training programs in sedentary older people (1: resistance training; 2: high-intensity aerobic interval training; and 3: moderate-intensity aerobic continuous training). The previous study found that, compared to the other groups, the interval training group showed additional benefits in physical function, particularly in walking resistance and functional mobility, as well as in cognitive function, specifically in processing speed.

3. Fall prevention intervention programs in community-dwelling older people

3.1. Exercise alone

Literature refers to exercise as one of the most used interventions for fall prevention in older adults (Guirguis-Blake et al., 2018). The systematic review and meta-analysis carried out by Sherrington and colleagues (Sherrington et al., 2017) revealed that exercise programs, as a single intervention, reduce the rate of falls in community-dwelling older people by 21% (incidence rate, 0.79 [95% CI, 0.73 – 0.85]). The previous study also points out that the greatest effects were seen in exercise programs that stimulated balance, involving at least three hours of weekly training.

The previous research is in line with the systematic review carried out by Guirguis-Blake and colleagues (Guirguis-Blake et al., 2018), which evidenced an association between participation in exercise programs and a significant reduction in the risk of older people experiencing falls (relative risk, 0.89 [95% CI, 0.81 – 0.97]), as well as of having experienced severe falls (incidence rate, 0.81 [95% CI, 0.73 – 0.90]). The exercise programs included in the previous study had an average of 12 months of duration, with a frequency of three sessions per week, with different types of intensity. The exercise programs for fall prevention should integrate gait, balance, strength, resistance, flexibility, or walking training (Guirguis-Blake et al., 2018; Sherrington et al., 2017).

However, there is evidence in the literature that exercise programs with a shorter duration promote effective results. For example, whole-body vibration (WBV) training, which can lead to neuromuscular and physiological changes at several levels, has emerged as a method that reduces fall risk in older people. According to the 8-week study conducted by Yang and colleagues (Yang et al., 2015), this method positively affects balance, functional mobility, muscle strength and power, and bone mineral density. The previous study also observed additional improvements ($p < 0.05$) in the sensory perception of the plantar foot, the ankle's range of motion, and a decrease in fear of falling. In addition, it’s suggested that WBV reduces the fall rate (Jepsen et al., 2017), and may positively affect cognition (Wen et al., 2023).

In addition to the traditional and above-described exercise programs, there are alternative intervention programs for fall prevention, such as the Pilates method or exergames (digital games combined with exercise). According to the 12-week study by Josephs and colleagues (Josephs et al., 2016), the Pilates method seems to induce positive benefits, mainly in balance and confidence. Regarding exergames, the study conducted by Jorgensen and colleagues (Jorgensen et al., 2013) showed that the 10-week training program (2x/week, 35 minutes) of " biofeedback " through the Wii console induced greater improvements in the maximum muscle strength of the lower limbs by 18%, compared to the CG. These two methods showed very positive levels of adherence and motivation and can be considered alternatives to traditional exercise programs, also having the advantage of being possibly performed at home (Jorgensen et al., 2013).

3.2 Cognitive-based interventions

Evidence is established in the literature between physical activity or exercise practice and benefits in cognitive function; however, their reciprocity is still not well known (Robinson & Kiely, 2017). Cognitive function, namely executive functions (e.g., attention or processing speed), plays an important role in balance and gait. Therefore, cognitive decline can lead to falls in older people (Kearney et al., 2013). This relation is observed in several daily life activities, even the simplest ones, such as walking, in which different executive functions are involved, allowing the brain to switch functions quickly. As a result, decision-making to carry out daily life activities is performed together with motor planning and execution, allowing older people to regulate the gait and postural stability necessary for the performance of tasks, reducing the risk of falling (Robinson & Kiely, 2017).

The systematic review conducted by Kearney and colleagues (Kearney et al., 2013) (2013) revealed an association between impaired executive function, the decline in gait speed, and the increased risk of falling. More recently, two randomized controlled trials showed similar associations. For example, the EG of the 10-week study carried out by Smith and colleagues (Smith-Ray et al., 2015) integrated a computerized cognitive training program (3x/week, 35 minutes). Computerized cognitive training is a digital platform (e.g., computer, tablets, mobile devices) that allows users to access engaging cognitive activities, such as visuospatial working memory, processing speed, or inhibition control tasks (Geng, Yang, Ge, & Hesketh, 2022). Compared to the CG, the EG of the Smith and colleagues' study (Smith-Ray et al., 2015) slowed the decline in balance and improved gait speed. On the other hand, the 8-week study carried out by Azadian and colleagues (Azadian et al., 2016) showed that the EG who integrated an executive function program (3x/week, 45 minutes) improved in gait parameters, as well as in symmetry of limbs and inter-coordination, compared to the GC.

3.3. Combined interventions

3.3.1. Multimodal exercise programs

Despite the effectiveness and potential of single intervention programs such as exercise alone or computerized cognitive training, the literature refers to other programs that can enhance positive effects in fall prevention. Among these are intervention programs combining exercises/activities focused on physical function with exercises/activities focused on cognitive function. The combination of these types of intervention often referred to as multimodal or interactive-cognitive motor programs, comes from the fact that there is evidence that their implementation positively influences the brain structure and its functioning, as well as cognition (Joubert & Chainay, 2018). Therefore, these combined programs can lead to additional benefits compared to single intervention programs (Nishiguchi et al., 2015), particularly with improvements in fall risk factors (Schoene et al., 2014).

The systematic review conducted by Joubert and Chainay (Joubert & Chainay, 2018) refers to multimodal programs' different methodologies and specificity. The authors of the previous study highlight the distinction between sequential and simultaneous training. In sequential training, the combined program's motor and cognitive components are not performed simultaneously, and there is no reciprocal interaction. On the other hand, in simultaneous training, the combined program's motor and cognitive components are performed simultaneously, allowing interaction between motor and cognitive mechanisms (e.g., dual-task exercises). Although there is still no consensus, the previous study emphasizes the positive effects that may result from simultaneous training.

Following the previous mechanisms, Nishiguchi and colleagues (Nishiguchi et al., 2015) performed a 12-week multimodal program (1x/week, 90 minutes) based on dual-task and walking exercises. The EG of the previous study showed significant improvements after the intervention in memory and executive functioning; moreover, it was revealed less activation in several brain regions associated with short-term memory, including the prefrontal cortex. Likewise, the study by Falbo and colleagues (Falbo et al., 2016) compared the effect of exercise alone with combined dual-task training (cognitive-motor) on executive function and gait. Results showed an increase in performance in gait parameters in both groups, while inhibitory control tended to improve only in the combined dual-task training group.

3.3.2. Multifactorial intervention programs

The “American Geriatrics Society” (AGS) and the “British Geriatrics Society” (BGS) (Kenny et al., 2011) recommend the implementation of multifactorial interventions, including different types of interventions simultaneously. These interventions should be tailored toward fall risk factors identified by health professionals. According to the same organizations, all multifactorial interventions must include an exercise program (e.g., balance, gait, strength, and coordination training) in a group or home-based. In this type of intervention, one older person may be part of a program that includes a supervised exercise program and environmental changes. At the same time, another may receive medication adjustments and educational sessions (Hopewell et al., 2018).

Additionally, it has been observed that exercise programs can be more effective when performed together with other interventions. In this sense, the AGS and BGS also suggest intervening in other factors, such as the reduction and adjustment of medication (mainly psychotropics), adaptations/modifications in the surrounding environment, to reduce the environmental hazards and promote the performance of activities of daily living safely; daily vitamin D supplementation (800 IU); assessment of visual acuity; monitoring of orthostatic hypotension; podiatry and footwear evaluation; as well as counseling and educational sessions for fall prevention (Kenny et al., 2011).

Similarly, the study by Moniz-Pereira and colleagues (Moniz-Pereira et al., 2013), comprising 1416 Portuguese older people, also recommends a multifactorial approach for fall risk assessment or for planning a fall prevention program. This approach should be focused not only on cognitive-behavioral aspects but also on physical activity and healthy lifestyles. More recently, the systematic review conducted by Guirguis-Blake and colleagues (Guirguis-Blake et al., 2018) revealed that multifactorial intervention is one of the three most common types of interventions for fall prevention in older adults. The previous study showed that multifactorial interventions are associated with reduced falls (incidence rate, 0.79 [95% CI, 0.68–0.91]). However, participation in these programs was not associated with a reduction in fall-related morbidity and mortality.

Finally, the systematic review carried out by Hopewell and colleagues (Hopewell et al., 2018) is in line with the previous investigations, in which multifactorial interventions can reduce the rate of falls (incidence rate, 0.77 [CI 95%, 0.67–0.87]). However, even though the multifactorial approach is recommended, the previous study showed that this intervention might have some or no effect on other events related to falls, presenting low-quality evidence that can reduce the risk of fall-related fractures (incidence rate, 0.73 [95% CI, 0.53–1.01]). In addition, the authors highlight as limitations of the implementation of multifactorial interventions the time and costs involved due to the presence and supervision of several health professionals. This aligns with the systematic review and meta-analysis by Lacroix and colleagues (Lacroix et al., 2017), which showed that supervised intervention programs aimed at older people significantly affected balance and muscle strength/power components more than unsupervised intervention programs.

3.4. Psychomotor intervention

Aging is associated with human biopsychosocial development following progressive a psychomotor loss. This change can be expressed through psychomotor slowness, loss of strength, increased fatigue, praxis impairments, spatiotemporal structuring problems, emotional disorders, depreciation of body image, or fear of falling (Fernandes, 2014). In addition, Albaret and Aubert (Albaret & Aubert, 2001) also highlight changes in cardiorespiratory capacity, gait (oscillation phase or cadence), flexibility, processing speed, selective attention, and programming/execution of the motor response. The same authors point out that the neurophysiological decline, resulting from the reduction in the number of neurons, the alteration of the myelination process, and the modification of certain neurotransmitters, increases the reaction time.

The psychomotor intervention (i.e., gerontopsychomotricity if tailored to older people) uses the body as a mediator. It focuses on the human being considering the relationship and interaction between motricity, psyche, cognition, and emotions (Martins, 2001). Fernandes (Fernandes, 2014) also emphasizes that these characteristics make it possible to differentiate the psychomotor intervention from the other intervention programs previously described since the essence of the psychomotor intervention is not in the isolated body but in the body in relation. Thus, gerontopsychomotricity can be described as a body mediation therapy that helps older people to revalue their body image and focuses on stimulating cognitive, motor, sensory, and emotional abilities through neuroplasticity (Fernandes, 2014; Martins, 2001). The sessions (~ 60 minutes) should include and combine neurocognitive, sensorimotor, and relational activities using different mediators, such as creative dance or therapeutic relaxation techniques (Motta, 2020; Printes et al., 2016). Also, the rediscovery of body awareness and the process of body weight transference or plantar sensitivity are important aspects to promote in the sessions of fall prevention programs (Modange & Chaumont, 2001).

Although psychomotor intervention can potentially prevent falls by delaying or reducing changes resulting from aging, few published studies are tailored to community-dwelling older people, demonstrating its effectiveness (Freiberger et al., 2007). Among the most recent publications that used psychomotor intervention to prevent fall risk factors is the 12-week study by Rosado and colleagues (Rosado et al., 2019). The previous study included community-dwelling older people who had fallen or were at high risk of falling (74.1 ± 5.3 years), and it was observed that the psychomotor intervention induced significant improvements in several risk factors for falls, namely in processing speed, balance, mobility, and lower-body strength ($p < 0.05$). Nevertheless, more studies are needed to generalize these findings.

4. Final considerations

According to the literature review performed it’s possible to conclude that:

-Falls have a multifactorial etiology (i.e., intrinsic, extrinsic, or behavioral factors).

-Identifying the falling risk through accurate and appropriate instruments is essential. An inaccurate perception of action boundaries was considered a fall risk factor and may be an important risk factor to consider for increasing the discriminatory power of fall prediction models. To the best of our knowledge, there are no valid tests to assess this variable in community-dwelling older people. In addition, the risk of falling can be reduced if this fall risk factor is integrated into a fall prevention program.

-WHO recommends 300 minutes of moderate-intensity activity or 150 minutes of vigorous-intensity activity per week for additional health benefits.

-Interval training showed additional benefits compared to continuous training.

-Combined programs (performing cognitive and physical stimulation simultaneously) can lead to additional benefits compared to single intervention programs, particularly with improvements in fall risk factors.

Among the intervention programs presented, the psychomotor intervention has shown promising results for the prevention of fall risk factors, promoting neurocognitive, sensorimotor, and relational stimulation (Rosado et al., 2019). WBV training is another method that has shown improvements in physical function in older adults (Yang et al., 2015). In addition, it may present a positive impact on body composition (particularly on bone mass) and reduce the incidence of falls (Jepsen et al., 2017). Furthermore, little is known about the effect of WBV on cognition (Wen et al., 2023), whereby more studies are needed to generalize these findings.

The rationale for using these interventions in the RCT study (chapter four) was that considering the positive effects of WBV in older people, it can be used as a complement to psychomotor intervention. This is due to the principles of psychomotor intervention not specifically focusing on vigorous physical activity, as well as improving bone mass, which can help to prevent the incidence of falls or fall-related fractures. Furthermore, to our knowledge, and until the present investigation began, only one study had investigated the effects of a psychomotor intervention as a fall prevention program in community dwellings (Freigberger et al., 2007). In this way, it is important to investigate the effects of a psychomotor intervention and a combined program (psychomotor intervention + WBV) on risk factors for falls.

References

Albaret, J. M., & Aubert, E. (2001). Aspects psychomoteurs du vieillissement normal. In De Boeck Supérieur (Ed.), *Vieillissement et Psychomotricité* (pp. 15-43).

Ambrose, A. F., Paul, G., & Hausdorff, J. M. (2013). Risk factors for falls among older adults: a review of the literature. *Maturitas*, *75*(1), 51-61. https://doi.org/10.1016/j.maturitas.2013.02.009

Azadian, E., Torbati, H. R., Kakhki, A. R., & Farahpour, N. (2016). The effect of dual task and executive training on pattern of gait in older adults with balance impairment: A Randomized controlled trial. *Archives of Gerontology and Geriatrics*, *62*, 83-89. https://doi.org/10.1016/j.archger.2015.10.001

Caspersen, C. J., Powell, K. E., & Christenson, G. M. (1985). Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. *Public Health Reports*, 100(2), 126–131.

Chodzko-Zajko, W. J., Proctor, D. N., Fiatarone Singh, M. A., Minson, C. T., Nigg, C. R., Salem, G. J., & Skinner, J. S. (2009). American College of Sports Medicine position stand. Exercise and physical activity for older adults. *Medicine and Science in Sports and Exercise*, *41*(7), 1510-1530. https://doi.org/10.1249/MSS.0b013e3181a0c95c

Coetsee, C., & Terblanche, E. (2017). The effect of three different exercise training modalities on cognitive and physical function in a healthy older population. *European Review of Aging and Physical Activity*, *14*, 13. https://doi.org/10.1186/s11556-017-0183-5

Falbo, S., Condello, G., Capranica, L., Forte, R., & Pesce, C. (2016). Effects of Physical-Cognitive Dual Task Training on Executive Function and Gait Performance in Older Adults: A Randomized Controlled Trial. *BioMed Research International*, *2016*, 5812092. https://doi.org/10.1155/2016/5812092

Fernandes, J. (2014). A Gerontopsicomotricidade como Práxis Terapêutica de Mediação Corporal. *Journal of Aging and Innovation*, *3*(3), 1-3.

Freiberger, E., Menz, H. B., Abu-Omar, K., & Rutten, A. (2007). Preventing falls in physically active community-dwelling older people: a comparison of two intervention techniques. *Gerontology*, *53*(5), 298-305. https://doi.org/10.1159/000103256

Garber, C. E., Blissmer, B., Deschenes, M. R., Franklin, B. A., Lamonte, M. J., Lee, I. M., Nieman, D. C., Swain, D. P., & American College of Sports, M. (2011). American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. *Medicine and Science in Sports and Exercise*, *43*(7), 1334-1359. https://doi.org/10.1249/MSS.0b013e318213fefb

Garcia-Pinillos, F., Camara-Perez, J. C., Soto-Hermoso, V. M., & Latorre-Roman, P. A. (2017). A High Intensity Interval Training (HIIT)-Based Running Plan Improves Athletic Performance by Improving Muscle Power. *Journal of Strength and Conditioning Research*, *31*(1), 146-153. https://doi.org/10.1519/JSC.0000000000001473

Guirguis-Blake, J. M., Michael, Y. L., Perdue, L. A., Coppola, E. L., & Beil, T. L. (2018). Interventions to Prevent Falls in Older Adults: Updated Evidence Report and Systematic Review for the US Preventive Services Task Force. *JAMA*, *319*(16), 1705-1716. https://doi.org/10.1001/jama.2017.21962

Hopewell, S., Adedire, O., Copsey, B. J., Boniface, G. J., Sherrington, C., Clemson, L., Close, J. C., & Lamb, S. E. (2018). Multifactorial and multiple component interventions for preventing falls in older people living in the community. *Cochrane Database of Systematic Reviews*, *7*(7), CD012221. https://doi.org/10.1002/14651858.CD012221.pub2

Jehu, D. A., Davis, J. C., Falck, R. S., Bennett, K. J., Tai, D., Souza, M. F., Cavalcante, B. R., Zhao, M., & Liu-Ambrose, T. (2021). Risk factors for recurrent falls in older adults: A systematic review with meta-analysis. *Maturitas*, *144*, 23-28. https://doi.org/10.1016/j.maturitas.2020.10.021

Jepsen, D. B., Thomsen, K., Hansen, S., Jorgensen, N. R., Masud, T., & Ryg, J. (2017). Effect of whole-body vibration exercise in preventing falls and fractures: a systematic review and meta-analysis. *BMJ Open*, *7*(12), e018342. https://doi.org/10.1136/bmjopen-2017-018342

Jorgensen, M. G., Laessoe, U., Hendriksen, C., Nielsen, O. B., & Aagaard, P. (2013). Efficacy of Nintendo Wii training on mechanical leg muscle function and postural balance in community-dwelling older adults: a randomized controlled trial. *Journals of Gerontology. Series A: Biological Sciences and Medical Sciences*, *68*(7), 845-852. https://doi.org/10.1093/gerona/gls222

Josephs, S., Pratt, M. L., Calk Meadows, E., Thurmond, S., & Wagner, A. (2016). The effectiveness of Pilates on balance and falls in community dwelling older adults. *Journal of Bodywork and Movement Therapies*, *20*(4), 815-823. https://doi.org/10.1016/j.jbmt.2016.02.003

Joubert, C., & Chainay, H. (2018). Aging brain: the effect of combined cognitive and physical training on cognition as compared to cognitive and physical training alone - a systematic review. *Clinical Interventions in Aging*, *13*, 1267-1301. https://doi.org/10.2147/CIA.S165399

Kearney, F. C., Harwood, R. H., Gladman, J. R., Lincoln, N., & Masud, T. (2013). The relationship between executive function and falls and gait abnormalities in older adults: a systematic review. *Dementia and Geriatric Cognitive Disorders*, *36*(1-2), 20-35. https://doi.org/10.1159/000350031

Kenny, R. A. M., Rubenstein, L. Z., Mary E Tinetti, M. E., Brewer, K., Cameron, K. A., Capezuti, E. A., John, D. P., Lamb, S., Martin, F., Rockey, P. H., Suther, M., Peterson, E., Susskind, O., Radcliff, S., Addleman, K., Drootin, M., Ickowicz, E., & Lundebjerg, N. (2011). Summary of the Updated American Geriatrics Society/British Geriatrics Society clinical practice guideline for prevention of falls in older persons. *Journal of the American Geriatrics Society*, *59*(1), 148-157. https://doi.org/10.1111/j.1532-5415.2010.03234.x

Lacroix, A., Hortobagyi, T., Beurskens, R., & Granacher, U. (2017). Effects of Supervised vs. Unsupervised Training Programs on Balance and Muscle Strength in Older Adults: A Systematic Review and Meta-Analysis. *Sports Medicine*, *47*(11), 2341-2361. https://doi.org/10.1007/s40279-017-0747-6

Li, R., Geng, J., Yang, R., Ge, Y., & Hesketh, T. (2022). Effectiveness of Computerized Cognitive Training in Delaying Cognitive Function Decline in People With Mild Cognitive Impairment: Systematic Review and Meta-analysis. *Journal of Medical Internet Research*, 24(10), e38624. https://doi.org/10.2196/38624

Luyat, M., Domino, D., & Noël, M. (2008). Can overestimating one's own capacities of action lead to fall? A study on the perception of affordance in the elderly. *Psychologie & Neuropsychiatrie du Vieillissement*, *6*(4), 287-297. https://doi.org/10.1684/pnv.2008.0149

Martins, R. (2001). Questões Sobre a Identidade da Psicomotricidade. In V. Fonseca & R. Martins (Eds.), *Progressos em Psicomotricidade* (pp. 29-40). FMH.

Modange, L., & Chaumont, V. (2001). La chute du sujet âge: aproche psychologique et pratique psychomotrice. In Albaret & Aubert (Eds.), *Vieillissement et Psychomotricité*. De Boeck Solal.

Moniz-Pereira, V., Carnide, F., Ramalho, F., Andre, H., Machado, M., Santos-Rocha, R., & Veloso, A. P. (2013). Using a multifactorial approach to determine fall risk profiles in portuguese older adults. *Acta Reumatologica Portuguesa*, *38*(4), 263-272. https://www.ncbi.nlm.nih.gov/pubmed/24435031

Motta, P. (2020). *Os efeitos de um programa terapêutico mediado pela dança criativa no estado depressivo e nos parâmetros psicomotores da pessoa idosa.* Universidade de Évora]. Évora. http://hdl.handle.net/10174/28127

Nishiguchi, S., Yamada, M., Tanigawa, T., Sekiyama, K., Kawagoe, T., Suzuki, M., Yoshikawa, S., Abe, N., Otsuka, Y., Nakai, R., Aoyama, T., & Tsuboyama, T. (2015). A 12-Week Physical and Cognitive Exercise Program Can Improve Cognitive Function and Neural Efficiency in Community-Dwelling Older Adults: A Randomized Controlled Trial. *Journal of the American Geriatrics Society*, *63*(7), 1355-1363. https://doi.org/10.1111/jgs.13481

Printes, C., Costa, A., Marmeleira, J., & Tomas-Carus, P. (2016). *Gerontomotricidade: Programa de exercício físico para pessoas idosas*. Editorial Self PT.

Robinson, J. E., & Kiely, J. (2017). Preventing falls in older adults: Can improving cognitive capacity help? *Cogent Psychology*, *4*(1), 1405866. https://doi.org/10.1080/23311908.2017.1405866

Rosado, H., Bravo, J., Raimundo, A., Mendes, F., Branco, L., & Pereira, C. (2019). A 12-week multimodal exercise program can improve physical and cognitive functioning risk factors for falls in community-dwelling older adults: preliminary results of a psychomotor intervention. *European Journal of Public Health*, *29*(1). https://doi.org/https://doi.org/10.1093/eurpub/ckz034

Schoene, D., Valenzuela, T., Lord, S. R., & de Bruin, E. D. (2014). The effect of interactive cognitive-motor training in reducing fall risk in older people: a systematic review. BMC Geriatrics, 14, 107. https://doi.org/10.1186/1471-2318-14-107

Sherrington, C., Michaleff, Z. A., Fairhall, N., Paul, S. S., Tiedemann, A., Whitney, J., Cumming, R. G., Herbert, R. D., Close, J. C. T., & Lord, S. R. (2017). Exercise to prevent falls in older adults: an updated systematic review and meta-analysis. *British Journal of Sports Medicine*, *51*(24), 1750-1758. https://doi.org/10.1136/bjsports-2016-096547

Smith-Ray, R. L., Hughes, S. L., Prohaska, T. R., Little, D. M., Jurivich, D. A., & Hedeker, D. (2015). Impact of Cognitive Training on Balance and Gait in Older Adults. *Journals of Gerontology. Series B: Psychological Sciences and Social Sciences*, *70*(3), 357-366. https://doi.org/10.1093/geronb/gbt097

Uusi-Rasi, K., Karinkanta, S., Tokola, K., Kannus, P., & Sievanen, H. (2019). Bone Mass and Strength and Fall-Related Fractures in Older Age. *Journal of Osteoporosis*, *2019*, 5134690. https://doi.org/10.1155/2019/5134690

Wen, J., Leng, L., Hu, M., Hou, X., & Huang, J. (2023). Effects of whole-body vibration training on cognitive function: A systematic review. *Frontiers in Human Neuroscience*, *17*, 854515. https://doi.org/10.3389/fnhum.2023.854515

World Health Organization. (2010). *Global recommendations on physical activity for health*. https://www.who.int/publications/i/item/9789241599979

Yang, F., King, G. A., Dillon, L., & Su, X. (2015). Controlled whole-body vibration training reduces risk of falls among community-dwelling older adults. *Journal of Biomechanics*, *48*(12), 3206-3212. https://doi.org/10.1016/j.jbiomech.2015.06.029

CHAPTER 3

Stepping-forward affordance perception test

Reliability and construct validity of the stepping-forward affordance perception test for fall risk assessment in community-dwelling older adults

Gabriela Almeida[1,2]*, Jorge Bravo[1,2], Hugo Folgado[1,2], Hugo Rosado[1,2], Felismina Mendes[2,3], Catarina Pereira[1,2]

[1] Departamento de Desporto e Saúde, Escola de Saúde e Desenvolvimento Humano, Universidade de Évora, Évora, Portugal.

[2] Comprehensive Health Research Centre (CHRC), Universidade de Évora, Évora, Portugal.

[3] Escola Superior de Enfermagem S. João de Deus, Universidade de Évora, Évora Portugal.

* Corresponding author: gsna@uevora.pt

Abstract

Background: Thus far, few studies have examined the estimation and actual performance of locomotor ability in older adults. To our knowledge, there are no studies examining the relationship between stepping-forward estimation versus ability and fall occurrence. The aim of this study was to develop and assess the reliability and validity of a new test for fall risk assessment in community-dwelling older adults.

Methods: In total, 347 participants (73.1 ± 6.2 years; 266 women) were assessed for their perception of maximum distance for the stepping-forward and action boundary. The test was developed following the existing literature and expert opinions.

Results: The task showed strong internal consistency. Intraclass correlation ranged from 0.99 to 1 for intrarater agreement and from 0.83 to 0.97 for interrater agreement. Multivariate binary regression analysis models revealed an area under the curve (AUC) of 0.665 (95% CI: 0.608–0.723) for fallers and 0.728 (95% CI: 0.655–0.797) for recurrent fallers. The stepping-forward affordance perception test (SF-APT) was demonstrated to be accurate, reliable, and valid for fall risk assessment.

Conclusions: The results showed that a large estimated stepping- forward associated with an underestimated absolute error works as a protective mechanism for fallers and recurrent fallers in community-dwelling older adults. SF-APT is safe, quick, easy to administer, well accepted and reproducible for application in community or clinical settings by either clinical or nonclinical care professionals.

1. Introduction

Falls cause death, morbidity, dependence, and loss of quality life (World Health Organization, 2007). An accurate assessment of the risk of falling in older adults is essential to design proper interventions for those who are at risk of falling. Several studies have focused on identifying risk factors that are determinants of fall occurrence, such as environmental hazards, physical activity levels, physical fitness or cognition status (Gill et al., 2009; Lord et al., 2006; Pereira et al., 2014; Yang et al., 2018; Zhou et al., 2018). However, the predictive and discriminative ability of these models and instruments to explain fall occurrence is generally low to moderate (Lusardi et al., 2017; Palumbo et al., 2015), suggesting that there is a gap that traditional fall risk assessment instruments do not fill (Klenk et al., 2017). The assessment of affordance perception could be one of the key components considered in the current assessment of fall risk.

To successfully perform an action in the environment, each person needs to recognize their action boundaries. The possibilities for action are dependent on the fit between the environment and an individual's action capabilities; that is, individuals need to be able to perceive what actions are possible within the limits of their capabilities (Fajen et al., 2011). This relation between perception and action is based on Gibson's ecological framework (Gibson, 1979; Gibson, 1977). A central concept of his theory of perception and action is affordances, that is, opportunities for actions under a particular set of conditions and body characteristics (Fajen et al., 2009). Aging decline and changes in functions and capabilities can contribute to an inaccurate perception of action boundaries and can lead to a perceptual misestimation, particularly in postural (Luyat et al., 2008) and locomotor skills (Noel et al., 2011). Any perceptual misestimation in locomotor skills in older adults can potentially lead to balance loss or accidental falls (Butler et al., 2015; Delbaere et al., 2010). Hence, what at an early stage of life was perceived as an affordance, in older ages, may not be. Therefore, aging-associated misperception of affordance perception can lead to a higher risk of falling in older adults, perhaps due to difficulties in actualizing the new limits for action (Luyat et al., 2008) considering individual characteristics and perceptual attunement with the information.

Studies targeting perception-action capabilities under the ecological approach conducted on older adults have focused mainly on stair climbing (Konczak et al., 1992), which represents a common everyday action. Since previous studies showed that falls occur during ordinary actions in daily life, such as walking (Ambrose et al., 2013), it is important to design tools measuring the perception of affordances for locomotor skills.

We hypothesized that the ability to perceive action boundary accurately for the stepping-forward skill may serve as an indicator of the risk of fall occurrence on community-dwelling older adults. Nonetheless, to the best of our knowledge, there are no valid tests to evaluate older adults' perception of their maximum stepping-forward distance, particularly to assess their risk of being a faller or a recurrent faller. Therefore, we designed a test to assess the stepping-forward affordance perception using the locomotor task of stepping forward. The test design was motivated by Gibson's ecological approach (Gibson, 1979; Gibson, 1977), which underlies the potential actions afforded by the environment. The test's protocol is within that of other experiments to study affordance perception in older adults, wherein participants were first asked to identify the perceived maximum performance, following an action boundary establishment (Konczak et al., 1992). Considering the above, the aim of the present study was to develop and assess the validity and reliability of the stepping-forward affordance perception test (SF-APT) for fall risk assessment in community-dwelling older adults.

2. Methods

2.1. Participants

Volunteers for this study (367 Portuguese community-dwelling older adults) were enrolled via pamphlets placed in community settings (health, recreational, sports, cultural and senior centers). The inclusion criteria were as follows: adults ≥ 65 years old with independent mobility, absence of fall occurrence due to the performance of hazardous and unusual tasks, and absence of cognitive impairment. The sample size was estimated to be 271 by the online OpenEpi software (http://www.openepi.com/SampleSize/SSCohort.htm), keeping the confidence interval (CI) at 90% and level of significance at 5%. Eleven volunteers did not meet the criterion of absence of cognitive impairment, and 9 did not meet the criterion of absence of fall occurrence due to the performance of unusual and hazardous tasks. A total of 347 participants (266 women and 81 men) remained.

Participants aged 73.1 ± 6.2 years, with 5.2 ± 3.3 years of school attendance, a body mass index of 28.8 ± 3.9 m/kg^2, a body fat mass percentage of 37.6 ± 8.9% and a body lean mass percentage of 26.7 ± 4.6%. Of the 347 participants, 201 did not fall in the previous year, and 146 had falls at least once in the previous year, of which 62 had fallen more than once. Thirty participants (73.3 ± 5.83 years) participated in the intrarater reliability procedure, and 34 (75 ± 6.7 years) participated in the interrater reliability procedure. Written informed consent was obtained from all participants, and ethical approval was granted by the Universidade de Évora – Comissão de Ética para a Investigação Científica nas Áreas de Saúde Humana e Bem-Estar (reference number 16012).

2.2. Procedures

The SF-APT was inductively designed from a review of the literature in order to identify the conceptual frameworks related within the perception of affordances and falls and expert consulting. The task, goals, instructions, and measured variables that should be included in the test were outlined, and a refinement was performed based on experts opinion and against observed task performance, ensuring content validity.

2.3. The stepping-forward affordance perception test

SF-APT performance involves a first training attempt (trial) and a second measurable attempt (scoring). Both test trial and scoring tasks are performed on a uniform floor surface but in different locations. The test begins with the rater providing a verbal explanation followed by the trial, with no feedback.

First, for the estimated stepping-forward measure, the participant is placed behind a line and is instructed to predict his/her maximum distance for stepping forward (Figure 1). Once the participant indicates he/she understood the procedure, the estimation is collected. For this, the participant stays behind the takeoff line, which is clearly marked on the floor, while the rater, starting at the feet of the participant, slowly and steadily moves a thin wooden stick marker until the participant tells him or her to stop, indicating the maximum estimated distance for stepping forward. Fine adjustments are allowed after the participant gives the order to stop. The estimated measure corresponds to the distance between the line and the wooden stick marker (cm). Second, for the real stepping-forward measure, the participant turns in the opposite direction, staying behind the line (standing in an upright start position with feet slightly apart, head straight and forward, and arms down by the sides of the body) and is instructed to step forward as far as possible, so that both feet pass the takeoff line. The real stepping-forward measure corresponds to the distance between the takeoff line and the foot that is farthest back (cm).

To avoid the learning bias effect between measurements, each participant is tested individually, performing the trial and scoring with a minimum of a 5-min rest break, during which the starting reference line location is changed between trial and scoring attempts.

Figure 1. Estimation of the stepping-forward task in one direction (a) and the real performance of the stepping-forward task in the opposite direction (b, c).

A test-retest reliability was performed, and intra- and interrater reliability was determined. For the reliability evaluation, a test–retest design was performed in a controlled environment by two fixed raters. The instructions, measuring instruments and test conditions were standardized in order to minimize measurement errors. Each rater measured the same participant twice for the intrarater reliability procedure with a week-long interval between measures. Interrater reliability assessment was performed by two raters, measuring the same participant twice, alternating the instruction randomly. Finally, the construct validity of SF-APT to predict fall occurrence was assessed considering the trial and scoring attempts.

2.4. Data collection

Participants were assessed individually by two trained raters. Participants and raters were blinded to the study's objectives.

2.4.1. Perceptual and stepping-forward boundary

The following outcomes were computed from the distances collected by SF-APT regarding each participant: estimated stepping-forward distance (cm), real stepping-forward distance (cm), algebraic error (difference between real and estimated distances), absolute error (|algebraic error|), absolute percent error (|1–estimated/real performance| x 100), and error tendency frequencies concerning algebraic error (overestimation: real < estimated; underestimation: real > estimated) (Almeida et al., 2017). These variables measure the error or bias magnitude. Error tendency indicates the error direction, that is, if the bias is under- or overestimated.

2.4.2. Falls

Falls were defined as "*an unexpected event in which the participants come to rest on the ground, floor, or lower level*" (Lamb et al., 2005). Falls resulting from risky and dangerous circumstances or traffic accidents were not considered. Therefore, only falls occurring during common daily life movements or activities were considered. Fall occurrence in the previous 12 months and the circumstances surrounding each fall (e.g., location of fall, type, fall-related injuries) were assessed by a questionnaire filled by the evaluator in the form of an interview. A nonfaller was defined as a subject who had not fallen in the previous 12 months, a faller as a subject who had fallen at least once in this period, and a recurrent faller as a subject who had fallen more than once in the same period (Gill et al., 2009; Pereira et al., 2014).

2.4.3. Complementary measures

Sociodemographic characteristics were assessed by a questionnaire filled by the interviewer. Body composition was evaluated by using a stadiometer (Seca 770, Hamburg, Germany) and an electronic scale (Seca Bella 840) to compute body mass index (kg/m^2) and by bioimpedance (Omron BF 511, USA) to evaluate body fat and lean mass (Załuska et al., 2004).

2.5. Data analysis

Statistical analyses were performed using the SPSS package version 24 (SPSS Inc., Chicago, IL, USA) and Microsoft Excel (version 16.9, Redmond, USA). Statistical significance was set to $p < 0.05$.

2.5.1. SF-APT reliability (inter and intra agreement)

The intraclass correlation (ICC) was used for assessing reliability (Shrout & Fleiss, 1979). In this study, repeated measures analysis of variance (ANOVA) was performed for fixed raters ($ICC_{2,k}$) to evaluate intra- and interrater relative reliability, while the standard error of measurement (SEM) (de Vet et al., 2006) and coefficient of variation (CV) were used to assess the absolute reliability of each parameter (Hopkins, 2000; Weir, 2005). Systematic bias was verified by the F-ratio (with true value 0). The ICC estimates (α - level = 0.05) were calculated using SPSS software, based on a mean-rating (k = 2), absolute agreement, 2-way random average model. Microsoft Excel was used for SEM, CV and F-ratio calculation.

2.5.2. SF-APT data exploratory analysis

Descriptive statistics were used to characterize SF-APT participants' data on absolute error, algebraic error, absolute percent error (mean and standard deviation) and on error tendency (over- and underestimation frequencies). Comparisons between the trial and scoring attempts and between estimated and real stepping-forward distance were performed by a paired sample t-test. Normality was assumed based on the central limit theorem for these quantitative variables (Ross, 2017). Qualitative variables comparisons between trial and scoring attempts were performed using the McNemar Test (Joseph et al., 2010).

An exploratory analysis using univariate binary logistic regressions was performed in order to explore the risk for fall occurrence associated with every single variable accessed by the test. Data are presented as odds ratios (ORs) and 95% CI.

2.5.3. Construct validity

The multivariate binary logistic regression analysis and receiver operating characteristic (ROC) analysis were used to select key variables from the SF-APT, which should be included in the fall risk assessment tool, as well as to test the need for a trial prior to the scoring test.

The analyses were performed considering fallers vs. nonfallers and recurrent-fallers vs. non- fallers for both trial and scoring attempt data. A similar methodology was used by Pereira et al. (Pereira et al., 2016). First, the fittest multivariate binary logistic regression model was determined by using a traditional approach. For this, all variables that yielded a p-value < 0.20 in the univariate analysis were candidates for the multivariable model. A model containing all the variables of reported importance was created. Variables that did not meet a significance of $p < 0.05$ in the Wald test were eliminated, and a new model was built. Therefore, the most parsimonious model was built by using the Wald statistic to test the significance of each variable added to the model, and the likelihood ratio was used to compare each new model with the previous model without the variable. The assumption of linearity in continuous variables was checked using the logit function. Outliers and influential points were identified. The overall fit was evaluated using the Hosmer-Lemeshow goodness-of-fit test; a nonsignificant result in the test means a good goodness-of-fit. Second, ROC analysis, based on the area under the curve (AUC), was used to examine the ability of the build models to discriminate fallers from nonfallers and recurrent-fallers from nonfallers.

3. Results

The SF-APT was well tolerated since all the participants were able to perform the test correctly, and no adverse events were reported. Moreover, the test accurately assessed the community-dwelling older adults' perceptions of affordances.

3.1. SF-APT reliability (inter- and intrarater agreement)

The results concerning reliability are shown in Table 1. Intrarater reliability results for SF-APT outcomes were as follows: $ICC_{2,k} = 0.95$; SEM = 2.99 cm for estimated stepping-forward; $ICC_{2,k} = 0.97$; SEM = 2.70 cm for real stepping-forward; $ICC_{2,k} = 0.93$; SEM = 2.53 cm for algebraic error; $ICC_{2,k} = 0.89$; SEM = 2.18 cm for absolute error and $ICC_{2,k} = 0.83$; SEM = 4.28% for absolute percent error. Interrater correlations ranged between $ICC_{2,k} = 0.99$ for estimated stepping-forward, algebraic error, absolute error and absolute percent error and $ICC_{2,k} = 1.00$ for real stepping-forward. The SEM results between raters were 0.49 cm for estimated stepping-forward, 0.00 cm for real stepping-forward, 0.43 cm for algebraic error, 0.33 cm for absolute error and 0.39% for absolute percent error. No systematic bias was detected with the F test (Table 1).

Table 1. Relative and absolute intra- (n = 30) and interrater (n = 34) reliability for the SF-APT outcomes.

Outcomes		**Mean ± SD**	**Relative reliability**	**Absolute reliability**		***F* test**	
			ICC$_{2.k}$	**SEM**	**CV**	***F***	***p***
Intrarater							
ESF (cm)	test	58.2 ± 12.3	0.95	± 2.99	± 4.57	0.81	0.72
	retest	60.2 ± 13.6					
RSF (cm)	test	64.9 ± 15.3	0.97	± 2.70	± 4.09	0.83	0.69
	retest	66.9 ± 16.9					
AlE (cm)	test	4.3 ± 9.6	0.93	± 2.53	± 0.35	0.95	0.56
	retest	2.5 ± 9.9					
AE (cm)	test	7.8 ± 6.9	0.89	± 2.18	± 1.18	1.23	0.29
	retest	7.9 ± 6.3					
APE (%)	test	12.1 ± 11.3	0.83	± 4.28	± 1.17	1.54	0.13
	retest	12.0 ± 9.1					
Interrater							
ESF (cm)	rater 1	47.1 ± 11.0	0.99	± 0.49	± 4.26	0.99	0.51
	rater 2	46.9 ± 11.1					
RSF (cm)	rater 1	57.1 ± 17.3	1.00	± 0.00	± 3.29	0.99	0.50
	rater 2	57.1 ± 17.4					
AlE (cm)	rater 1	10.1 ± 13.6	0.99	± 0.43	± 0.75	1.01	0.48
	rater 2	10.2 ± 13.5					
AE (cm)	rater 1	13.2 ± 10.5	0.99	± 0.33	± 1.26	1.00	0.50
	rater 2	13.2 ± 10.5					
APE (%)	rater 1	21.8 ± 12.3	0.99	± 0.39	± 1.77	0.99	0.50
	rater 2	21.9 ± 12.3					

SD: standard deviation; ICC: intraclass correlation coefficient; SEM: standard error of measurement; CV: coefficient of variation; ESF: estimated step forward; RSF: real step forward; AlE: algebraic error; AE: absolute error; APE: absolute percent error.

3.2. SF-APT data exploratory analysis

The SF-APT variables on the participants' results are shown in Table 2. In general, the estimated maximum distance for stepping-forward was less than the performed action (underestimation tendency) (algebraic error: trial attempt 4.7 ± 9.8 cm; scoring attempt 6.0 ± 8.5 cm, $p < 0.001$), which is confirmed by the prevalence of an underestimation bias (error tendency: trial attempt 68.0%; scoring attempt 77.2%). However, with other participants, the opposite occurred. These participants showed an overestimation bias (error tendency: trial attempt 32.0%; scoring attempt 22.8%), that is, they estimated a greater distance than what was actually performed (see the algebraic error standard deviations, which are greater than the average value).

Table 2. Descriptive statistics for the SF-APT variables (n = 347).

Variables	**Trial attempt**	**Scoring attempt**
Estimated stepping-forward (cm)	59.7 ± 15.0*,**	60.9 ± 15.5
Real stepping-forward (cm)	64.4 ± 15.9*,**	66.9 ± 15.4
Algebraic error† (cm)	4.7 ± 9.8*	6.0 ± 8.5
Absolute error (cm)	7.5 ± 7.8	7.7 ± 7.0
Absolute percent error (%)	11.6 ± 11.2	11.5 ± 9.8
Error tendency (%)		
Overestimation	32.0*	22.8
Underestimation	68.0	77.2

†[Real-Estimated]; *Significant difference between trial and scoring attempt, $p < 0.05$; **Significant difference between the estimated and real step forward, $p < 0.05$; The data are expressed as the mean and standard deviation (± SD) or prevalence in percentage (%).

The absolute and percent errors results showed that participants have a lack of accuracy in estimating distance for the stepping-forward task on the trial and scoring attempts of approximately 7.5 cm and 11.5%, respectively. Comparisons between trial and scoring attempts showed that in the trial attempt, the estimated and the real stepping-forward distance results were smaller (estimated less ~ 1.2 and real less ~ 2.5 cm), as was the algebraic error (less ~ 1.3 cm), $p < 0.05$. Moreover, the underestimation bias increased from the trial to the scoring attempt to 9.2%, $p < 0.05$.

The univariate binary regression analysis presented in Figure 2 shows three variables explaining fall occurrence at the trial attempt (OR ranging from 0.957 for real stepping-forward to 0.969 for estimated stepping-forward), and two variables explaining recurrent fall occurrence (OR of 0.957 for estimated stepping-forward and 0.948 for real stepping-forward), $p < 0.05$. In the scoring attempt, five variables explained fall occurrence (OR ranging from 0.523 for underestimation ET to 0.971 for estimated stepping-forward) and four variables explained recurrent fall occurrence (OR ranging from 0.426 for underestimation bias to 0.994 for absolute percent error). Thus, a higher value in all these variables decreased the likelihood of being a faller or a recurrent faller, as well as the error tendency of underestimation bias (Figure 2).

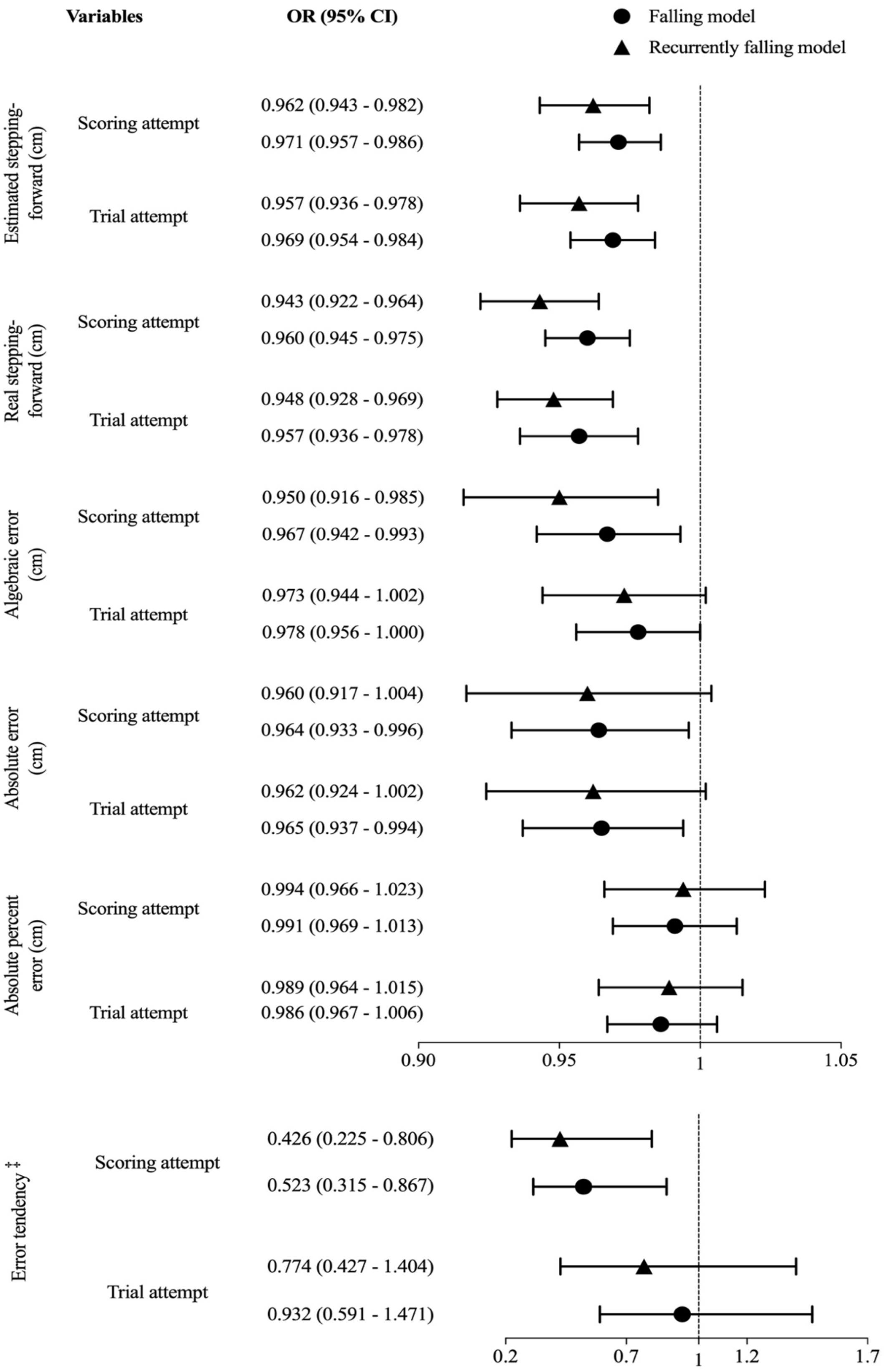

Figure 2. Odds ratio (OR) and 95% confidence interval (CI) of SF-APT variables for the univariate risk of being a faller (n = 347) and of being a recurrent faller (n = 263). ‡Underestimation vs. overestimation.

3.3. SF-APT construct validity

Multivariate binary regression analysis (Table 3) selected the variables estimated stepping-forward and absolute error in interaction with error tendency as the key variables from the SF-APT, which should be included on the fall risk assessment tool, $p < 0.05$. Note that these results only refer to scoring attempt data. In fact, there were no significant results from multivariate regression analysis for the trial attempt data, and it was not possible to build any model with these data.

The Hosmer-Lemeshow goodness-of-fit test was not significant regarding either the falling model ($p = 0.591$) or the recurrently falling model ($p = 0.241$). These two most fit models showed that, for each additional cm on the estimated stepping-forward distance variable, the likelihood of being a faller decreased by 3.6%, OR: 0.964 (95% CI: 0.948–0.979), and the likelihood of being a recurrent faller decreased by 4.9%, OR: 0.951 (95% CI: 0.931–0.973). The modeling results also showed that when the tendency was underestimated, for each additional cm on absolute error, the likelihood of being a faller decreased by 5.9%, OR: 0.941 (95% CI: 0.910–0.973), and the likelihood of being a recurrent faller decreased by 8.6%, OR: 0.914 (95% CI: 0.868–0.962). The falling model revealed an AUC of 0.665 (95% CI: 0.608–0.723), and the recurrently falling model revealed an AUC of 0.728 (95% CI: 0.655–0.797).

Table 3. Selection of the variables used to access the risk of being a faller and of being a recurrent faller based on multivariate binary logistic regression modeling (Falling vs. Nonfalling Model: n = 347; Recurrent falling vs. Nonfalling Model: n = 263).

Model	**Key variables**	**OR (95% CI)**	**Model** **AUC (95% CI)**
Falling	Scoring attempt for the estimated stepping-forward (cm)	0.964 (0.948-0.979)	0.665 (0.608-0.723)
	Scoring attempt absolute error (cm)† and error tendency‡		
	Overestimation		
	Underestimation	0.941 (0.910-0.973)	
Falling recurrently	Scoring attempt estimated stepping-forward (cm)	0.951 (0.931-0.973)	0.728 (0.655-0.797)
	Scoring attempt absolute error (cm)† and error tendency‡		
	Overestimation		
	Underestimation	0.914 (0.868-0.962)	

*Interaction between variables; †[Real-Estimated]; ‡Overestimation as reverence; Data are multivariate odds ratios (ORs) and 95% confidence intervals (CIs), cut-off points for π, specificity, sensibility, and area under the ROC curve (AUC) and 95% CI.

4. Discussion

The objective of the present study was to develop and assess the validity and reliability of the SF-APT for fall risk assessment in community-dwelling older adults. Based on our results, in the literature review (Gibson) and feedback from the expert reviewers, the SF-APT was shown to be a valid and reliable tool to assess fall risk in community-dwelling older adults. Reliability tests indicated excellent correlations and small standard errors between measurements (Koo & Li, 2016) for both intrarater and interrater analyses. The criterion validity could not be established due to the lack of a similar assessment tool. As an indication of construct validity, the SF-APT was able to significantly discriminate individuals who were regular fallers and those who were occasional fallers, namely, at the scoring attempt.

These results confirmed the expert opinions and participant feedback that there is a need for a trial in the assessment protocol in order to ensure that participants could understand the administration procedures. Therefore, the trial ensures that participants are able to estimate and perform their maximum stepping-forward distance at the scoring attempt. In addition, the experts' observation of the test application confirmed that the estimation and action boundary should be measured in different places to avoid the presence of any allocentric frame of reference. Single SF-APT outcomes were shown to significantly explain fall occurrence; however, the estimated stepping-forward and absolute error in interaction with error tendency were selected as the key outcomes to explain this negative event. The results showed that a large stepping-forward estimation associated with an underestimation bias works as a protective mechanism for falling and recurrent falling.

Our findings complement the results of previous studies regarding the perception of affordances in young and older adults (Cesari et al., 2003; Konczak et al., 1992; Noel et al., 2011). Noel and colleagues found that older adults perform an overestimation judgment error of 11 cm in the stepping over an obstacle task compared to young adults (Noel et al., 2011). Furthermore, the studies of Konczak et al. and Cesari et al. in the stair climbing task concluded that older adults could perceive their actual stair capability as well as young adults could, despite the change in the action capability with aging (Cesari et al., 2003; Konczak et al., 1992). Nevertheless, it should be noted that the studies mentioned above examined the perception of action boundary but did not examine fall occurrence. Moreover, our findings are in accordance with those of Noel and colleagues (Noel et al., 2011), who hypothesized that an overestimation bias on stepping over an obstacle could be a risk for falls by showing that, in opposition to overestimation bias, the underestimation bias decreases the likelihood of falls. Thus, within the framework of the ecological approach, falls can be regarded as failed actions that result from inaccurate affordance perception, our study results indicate that falls may occur due to an overestimation mismatch between what the older adults believe they are able to do and what they are actually capable of doing. Such a discrepancy could lead to older adults endangering themselves by performing actions that they are no longer physically capable of performing.

Therefore, SF-APT was shown to address key components useable for the assessment of fall risk. The calculated AUCs for fallers and for recurrent fallers discrimination were low/moderate, suggesting that the test complements other methods for fall risk assessment, such as balance or gait tests. For example, the Fullerton Advanced Balance (FAB) scale, which showed an overall perdition success rate of 71.4% (Hernandez & Rose, 2008). This would consider the multifactor nature of fall occurrence (intrinsic vs. extrinsic factors, plus accidental, or exposure over time) based on Palumbo et al. and Klenk et al. (Klenk et al., 2017; Palumbo et al., 2015) and therefore address the causes of falls that the affordance´s perception assessment does not address.

Considering the results, we believe that for fall risk assessment, it would be relevant to address other locomotor tasks, such as stepping to the side, stepping up onto a platform or stepping over an obstacle, instead of one single task. In fact, Kuft et al. (Kluft et al., 2017) observed that the task of stepping over a raised bar best integrated the criteria for the affordance construct with regard to perceived and actual physical ability, particularly for stepping. In addition, the reliability tests could be assessed in real-life environments/situations because the secure environment provided may not be generalizable risky real-life situations. A limitation of the present study was that falls were assessed retrospectively; nonetheless, we observed that similar methodology was used to validate several fall risk assessment instruments, such as the BERG scale (Berg et al., 1989) and, more recently, the FAB scale (Hernandez & Rose, 2008; Rose et al., 2006). Future research focusing on this subject should address prospective falls in order to improve construct validity accuracy and involve populations with cognitive impairments or institutionalized older adults. Moreover, it would be of interest to investigate the associations between SF-APT outcomes and fear of falling or balance, for instance.

Reference values for both men and women regarding SF-APT outcomes and respective cut-offs to discriminate fallers from nonfallers should be investigated.

Finally, participants and raters revealed good acceptance of the SF-APT, considering it as a quick (10–15 min), easy and inexpensive way to assess the ability and accuracy to perceive action boundary for stepping-forward in community-dwelling older adults. Moreover, the material used is widely available and easy to transport. The SF-APT was well tolerated since all the participants were able to perform the test correctly, and no adverse events were reported. This new field test might complement the easy test (Swanenburg et al., 2013) and relevant batteries for functional assessment in older adults (Hernandez & Rose, 2008; Morais et al., 2016; Rikli & Jones, 2013; Tinetti, 1986), adding a specific exam to evaluate the perception of affordances and potentially increasing their ability to discriminate the older adults who are at risk for falling, despite being based on retrospective fall occurrence. SF-APT assesses the ability and accuracy to perceive action boundaries, filling a gap that the determinant factors addressed in previous studies failed to explain. Moreover, the test outcomes matched the test aims.

5. Conclusions

SF-APT accurately measured the perceptual and stepping-forward boundary, quantifying the accuracy bias and proving to be a reliable and valid method for fall risk assessment in community-dwelling older adults.

There must be a trial prior to the test scoring. Selected fall risk assessment key outcomes showed that a large estimated stepping forward associated with an underestimated absolute error works as a protective mechanism for falling and recurrently falling.

SF-APT is safe, quick, easy to administer, well accepted and reproducible for application for community-dwelling older adults in community or clinical settings by either clinical or nonclinical care professionals.

Funding

This work was supported by European Fund for regional development through Horizon 2020 - Portugal 2020 - Programa Operacional Regional do Alentejo (ALT20-03-0145-FEDER- 000007) with respect to the ESACA Portuguese study - Ageing Safety in Alentejo. Understanding for action. The sponsors had no role in the design, analysis, or preparation of this manuscript.

Acknowledgments

The authors would like to thank all the volunteers who participated in this study. Special thanks are due to Filipe Alves for drawing the illustrations.

6. References

Almeida, G., Luz, C., Martins, R., & Cordovil, R. (2017). Do children accurately estimate their performance of fundamental movement skills? *Journal of Motor Learning and Development*, *5*(2), 193-206. https://doi.org/10.1123/jmld.2016-0030

Ambrose, A. F., Paul, G., & Hausdorff, J. M. (2013). Risk factors for falls among older adults: A review of the literature. *Maturitas*, *75*(1), 51-61. https://doi.org/10.1016/j.maturitas.2013.02.009

Berg, K., Wood-Dauphine, S., Williams, J., & Gayton, D. (1989). Measuring balance in the elderly: preliminary development of an instrument. *Physiotherapy Canada 41*(6), 304-311. https://doi.org/10.3138/ptc.41.6.304

Butler, A. A., Lord, S. R., Taylor, J. L., & Fitzpatrick, R. C. (2015). Ability versus hazard: risk-taking and falls in older people. *Journals of Gerontology. Series A: Biological Sciences and Medical Sciences*, *70*(5), 628-634. https://doi.org/10.1093/gerona/glu201

Cesari, P., Formenti, F., & Olivato, P. (2003). A common perceptual parameter for stair climbing for children, young and old adults. *Human Movement Science*, *22*(1), 111-124. https://doi.org/10.1016/s0167-9457(03)00003-4

de Vet, H. C., Terwee, C. B., Ostelo, R. W., Beckerman, H., Knol, D. L., & Bouter, L. M. (2006). Minimal changes in health status questionnaires: distinction between minimally detectable change and minimally important change. *Health and Quality of Life Outcomes*, *4*(1), 54. https://doi.org/10.1186/1477-7525-4-54

Delbaere, K., Close, J. C. T., Brodaty, H., Sachdev, P., & Lord, S. R. (2010). Determinants of disparities between perceived and physiological risk of falling among elderly people: cohort study. *British Medical Journal*, *341*, c4165. https://doi.org/10.1136/bmj.c4165

Fajen, B. R., Diaz, G., & Cramer, C. (2011). Reconsidering the role of movement in perceiving action-scaled affordances. *Human Movement Science*, *30*(3), 504-533. https://doi.org/10.1016/j.humov.2010.07.016

Fajen, B. R., Riley, M. A., & Turvey, M. T. (2009). Information, affordances, and the control of action in sport. *International Journal of Sport Psychology*, *40*(1), 79-107.

Gibson, J. (1979). The theory of affordances. The Ecological Approach to Visual Perception (pp. 127-143). In: Boston: Houghton Miffin.

Gibson, J. J. (1977). The theory of affordances, In” Perceiving, Acting and Knowing”, Eds. RE Shaw and J. Bransford. In: Erlbaum.

Gill, D. P., Zou, G. Y., Jones, G. R., & Speechley, M. (2009). Comparison of regression models for the analysis of fall risk factors in older veterans. *Annals of Epidemiology*, *19*(8), 523-530. https://doi.org/10.1016/j.annepidem.2009.03.012

Hernandez, D., & Rose, D. J. (2008). Predicting which older adults will or will not fall using the Fullerton Advanced Balance scale. *Archives of Physical Medicine and Rehabilitation*, *89*(12), 2309-2315. https://doi.org/10.1016/j.apmr.2008.05.020

Hopkins, W. G. (2000). Measures of reliability in sports medicine and science. *Sports Medicine*, *30*(1), 1-15. https://doi.org/10.2165/00007256-200030010-00001

Joseph, F., Hair, J., Black, W., Babin, B., & Anderson, R. (2010). Multivariate data analysis: a global perspective (7th (Global Edition) ed.). In: United States: Prentice Hall.

Klenk, J., Becker, C., Palumbo, P., Schwickert, L., Rapp, K., Helbostad, J. L., Todd, C., Lord, S. R., & Kerse, N. (2017). Conceptualizing a Dynamic Fall Risk Model Including Intrinsic Risks and Exposures. *Journal of the American Medical Directors Association*, *18*(11), 921-927. https://doi.org/10.1016/j.jamda.2017.08.001

Kluft, N., Bruijn, S. M., Weijer, R. H. A., van Dieen, J. H., & Pijnappels, M. (2017). On the validity and consistency of misjudgment of stepping ability in young and older adults. *PloS One*, *12*(12), e0190088. https://doi.org/10.1371/journal.pone.0190088

Konczak, J., Meeuwsen, H. J., & Cress, M. E. (1992). Changing affordances in stair climbing: the perception of maximum climbability in young and older adults. *Journal of Experimental Psychology: Human Perception and Performance*, *18*(3), 691-697. https://doi.org/10.1037//0096-1523.18.3.691

Koo, T. K., & Li, M. Y. (2016). A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. *Journal of Chiropractic Medicine*, *15*(2), 155-163. https://doi.org/10.1016/j.jcm.2016.02.012

Lamb, S. E., Jorstad-Stein, E. C., Hauer, K., Becker, C., Prevention of Falls Network, E., & Outcomes Consensus, G. (2005). Development of a common outcome data set for fall injury prevention trials: the Prevention of Falls Network Europe consensus. *Journal of* *the American Geriatrics Society*, *53*(9), 1618-1622. https://doi.org/10.1111/j.1532-5415.2005.53455.x

Lord, S. R., Menz, H. B., & Sherrington, C. (2006). Home environment risk factors for falls in older people and the efficacy of home modifications. *Age and Ageing*, *35 Suppl 2*(suppl_2), ii55-ii59. https://doi.org/10.1093/ageing/afl088

Lusardi, M. M., Fritz, S., Middleton, A., Allison, L., Wingood, M., Phillips, E., Criss, M., Verma, S., Osborne, J., & Chui, K. K. (2017). Determining Risk of Falls in Community Dwelling Older Adults: A Systematic Review and Meta-analysis Using Posttest Probability. *Journal of Geriatric Physical Therapy*, *40*(1), 1-36. https://doi.org/10.1519/Jpt.0000000000000099

Luyat, M., Domino, D., & Noël, M. (2008). Can overestimating one's own capacities of action lead to fall? A study on the perception of affordance in the elderly. *Psychologie & Neuropsychiatrie du Vieillissement*, *6*(4), 287-297. https://doi.org/10.1684/pnv.2008.0149

Morais, A., Santos, S., & Lebre, P. (2016). Psychometric properties of the Portuguese version of the Examen Geronto-Psychomoteur (P-EGP). *Educational Gerontology*, *42*(7), 516-527. https://doi.org/10.1080/03601277.2016.1165068

Noel, M., Bernard, A., & Luyat, M. (2011). [The overestimation of performance: a specific bias of aging?]. *Gériatrie et Psychologie Neuropsychiatrie du Vieillissement*, *9*(3), 287-294. https://doi.org/10.1684/pnv.2011.0290

Palumbo, P., Palmerini, L., Bandinelli, S., & Chiari, L. (2015). Fall risk assessment tools for elderly living in the community: can we do better? *PloS One*, *10*(12), e0146247. https://doi.org/10.1371/journal.pone.0146247

Pereira, C., Fernandes, J., Raimundo, A., Biehl-Printes, C., Marmeleira, J., & Tomas-Carus, P. (2016). Increased Physical Activity and Fitness above the 50th Percentile Avoid the Threat of Older Adults Becoming Institutionalized: A Cross-sectional Pilot Study. *Rejuvenation Research*, *19*(1), 13-20. https://doi.org/10.1089/rej.2015.1669

Pereira, C. L., Baptista, F., & Infante, P. (2014). Role of physical activity in the occurrence of falls and fall-related injuries in community-dwelling adults over 50 years old. *Disability and Rehabilitation*, *36*(2), 117-124. https://doi.org/10.3109/09638288.2013.782355

Rikli, R. E., & Jones, C. J. (2013). Development and validation of criterion-referenced clinically relevant fitness standards for maintaining physical independence in later years. *Gerontologist*, *53*(2), 255-267. https://doi.org/10.1093/geront/gns071

Rose, D. J., Lucchese, N., & Wiersma, L. D. (2006). Development of a multidimensional balance scale for use with functionally independent older adults. *Archives of Physical Medicine and Rehabilitation*, *87*(11), 1478-1485. https://doi.org/10.1016/j.apmr.2006.07.263

Ross, S. (2017). Chapter 7 - Distributions of Sampling Statistics. In Sheldon M. Ross, *Introductory Statistics* (Fourth edition, pp. 297-328). Academic Press. https://doi.org/10.1016/B978-0-12-804317-2.00007-2

Shrout, P. E., & Fleiss, J. L. (1979). Intraclass correlations: uses in assessing rater reliability. *Psychological Bulletin*, *86*(2), 420-428. https://doi.org/10.1037//0033-2909.86.2.420

Swanenburg, J., Nevzati, A., Mittaz Hager, A. G., de Bruin, E. D., & Klipstein, A. (2013). The maximal width of the base of support (BSW): clinical applicability and reliability of a preferred-standing test for measuring the risk of falling. *Archives of Gerontology and Geriatrics*, *57*(2), 204-210. https://doi.org/10.1016/j.archger.2013.04.010

Tinetti, M. E. (1986). Performance-oriented assessment of mobility problems in elderly patients. *Journal of the American Geriatrics Society*, *34*(2), 119-126. https://doi.org/10.1111/j.1532-5415.1986.tb05480.x

Weir, J. P. (2005). Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM. *Journal of Strength and Conditioning Research*, *19*(1), 231-240. https://doi.org/10.1519/15184.1

World Health Organization. (2007). *WHO Global Report on Falls: Prevention in Older Age*.

Yang, N. P., Hsu, N. W., Lin, C. H., Chen, H. C., Tsao, H. M., Lo, S. S., & Chou, P. (2018). Relationship between muscle strength and fall episodes among the elderly: the Yilan study, Taiwan. *BMC Geriatrics*, *18*(1), 90. https://doi.org/10.1186/s12877-018-0779-2

Załuska, W., Małecka, T., Mozul, S., & Ksiazek, A. (2004). [Whole body versus segmental bioimpedance measurements (BIS) of electrical resistance (Re) and extracellular volume (ECV) for assessment of dry weight in end-stage renal patients treated by hemodialysis]. *Przeglad Lekarski*, *61*(2), 70-73.

Zhou, H., Peng, K., Tiedemann, A., Peng, J., & Sherrington, C. (2018). Risk factors for falls among older community dwellers in Shenzhen, China. *Injury Prevention*, *25*(1), 31-35. https://doi.org/10.1136/injuryprev-2017-042597

CHAPTER 4

Scientific papers related to the RCT

Paper 1

Effects of two 24-week multimodal exercise programs on reaction time, mobility, and dual-task performance in community-dwelling older adults at risk of falling: a randomized controlled trial

Hugo Rosado[1,2]*, Jorge Bravo[1,2], Armando Raimundo[1,2], Joana Carvalho[3,4], José Marmeleira[1,2], Catarina Pereira[1,2]

[1] Departamento de Desporto e Saúde, Escola de Saúde e Desenvolvimento Humano, Universidade de Évora, Évora, Portugal.

[2] Comprehensive Health Research Centre (CHRC), Universidade de Évora, Évora, Portugal.

[3] Faculdade de Desporto, Universidade do Porto, Porto, Portugal.

[4] CIAFEL - Research Centre in Physical Activity, Health and Leisure, Universidade do Porto, Portugal

* Corresponding author: hrosado@uevora.pt

Abstract

Background: Falls in older adults are considered a major public health problem. Declines in cognitive and physical functions, as measured by parameters including reaction time, mobility, and dual-task performance, have been reported to be important risk factors for falls. The aim of this study was to investigate the effects of two multimodal programs on reaction time, mobility, and dual-task performance in community-dwelling older adults at risk of falling.

Methods: In this randomized controlled trial, fifty-one participants (75.4 ± 5.6 years) were allocated into two experimental groups (EGs) (with sessions 3 times per week for 24 weeks), and a control group: EG1 was enrolled in a psychomotor intervention program, EG2 was enrolled in a combined exercise program (psychomotor intervention program + whole-body vibration program), and the control group maintained their usual daily activities. The participants were assessed at baseline, after the intervention, and after a 12-week no-intervention follow-up period.

Results: The comparisons revealed significant improvements in mobility and dual-task performance after the intervention in EG1, while there were improvements in reaction time, mobility, and dual-task performance in EG2 ($p \leq 0.05$). The size of the interventions' clinical effect was medium in EG1 and ranged from medium to large in EG2. The comparisons also showed a reduction in the fall rate in both EGs (EG1: −44.2%; EG2: −63.0%, $p \leq 0.05$) from baseline to post-intervention. The interventions' effects on reaction time, mobility, and dual-task performance were no longer evident after the 12-week no-intervention follow-up period.

Conclusions: The results suggest that multimodal psychomotor programs were well tolerated by community-dwelling older adults and were effective for fall prevention, as well as for the prevention of cognitive and physical functional decline, particularly if the programs are combined with whole-body vibration exercise. The discontinuation of these programs could lead to the fast reversal of the positive outcomes achieved.

Keywords: Aging, Falls, Psychomotor intervention, Whole-body vibration, Cognitive function, Physical function

1. Introduction

By 2050, the number of people aged 60 or more years is expected to double to 2 billion (Word Health Organization, 2018a). Additionally, the World Health Organization (WHO) considers aging a determinant risk factor for falls and fall-related injuries (Word Health Organization, 2018b). Falls are considered a major public health problem and are associated with injuries, dependence in activities of daily living, disability, and extremely high annual health costs (Taylor-Piliae et al., 2017; Word Health Organization, 2018b).

Falls have a multifactorial etiology based on the relationships between different risk factors (Lajoie & Gallagher, 2004). Among the intrinsic risk factors, the deterioration of cognitive and physical functions in older people is particularly evident (Lajoie & Gallagher, 2004). The aging process leads to biological and physio- logical changes in the brain and cognitive function, with effects on reaction time (RT) and dual-task (DT) performance (Joubert & Chainay, 2018; Tait et al., 2017). Importantly, the scientific community has established clear evidence that there are strong associations between cognitive function and the risk of falling; specifically, increases in RT have been consistently shown to be related to falls, and the association is so strong that RT is reported as one of the most important and sensitive indicators of changes in the central nervous system (Graveson et al., 2016; Lajoie & Gallagher, 2004). Lajoie and Gallagher's study showed that fallers also have a slower RT than do non-fallers (Lajoie & Gallagher, 2004). In addition, a reduced ability to perform two tasks simultaneously (e.g., a cognitive task while walking), referred to as DT, has been associated with an increased risk of falls (Tait et al., 2017). Concerning physical function, the sensorimotor and neuromuscular impairments that result from aging are associated with reduced levels of mobility and are considered risk factors for falls (Donath et al., 2016). Therefore, exercise-based fall prevention programs should modify the complexity and intensity of tasks, particularly those related to mobility and cognitive training, according to the participant's capacity (Donath et al., 2016).

Previous studies have shown that single cognitive training programs can induce positive effects on fall risk factors in community-dwelling older adults (Blackwood et al., 2016). These positive effects have also been observed in studies involving single physical training programs. However, several studies on fall intervention programs have shown that exercise alone is one of the most effective interventions to reduce falls in community-dwelling older people (Sherrington et al., 2017), but exercise alone may not be enough to improve cognitive functions, especially in terms of DT performance (Gobbo et al., 2014). Despite cognitive or physical training programs being able to induce positive effects on fall risk factors, studies in the literature have shown that multimodal exercise programs have additional advantages (Schoene et al., 2014). In fact, recent systematic reviews and meta-analysis (Joubert & Chainay, 2018; Zhu et al., 2016) demonstrated the additional benefits of multimodal exercise programs combining cognitive with physical training for older adults. However, no definitive conclusions have been drawn, showing the need for additional investigations, particularly on the effects of multimodal exercise programs on fall risk factors.

A psychomotor intervention is a therapy that uses the body and movement as intervention mediators to optimize cognitive, motor, and relational competences of psychomotor functioning, through a holistic view (Probst et al., 2010), and has been shown to prevent the sensorimotor and neurocognitive declines associated with aging (Pereira et al., 2018). Regarding the whole-body vibration (WBV) intervention, a recent systematic review and meta-analysis suggested that WBV may prevent fractures by reducing falls and improving determinants of falling, particularly physical function-related risk factors (Jepsen et al., 2017). WBV may also improve cognitive function (Regterschot et al., 2014). Nonetheless, as these two methods are reported to potentially be beneficial, it is not known whether an intervention program that combines both methods had additional benefits.

To the best of our knowledge, only one study (Freiberger et al., 2007) has implemented a psychomotor intervention program in community-dwelling older adults to reduce the risk for falls. Given the lack of studies about these intervention programs, new and effective interventions that can prevent and reduce falls and thus its consequences, such as fall-related injuries or associated health costs, are needed (Graveson et al., 2016).

Therefore, this study aimed to investigate the effects of two multimodal exercise programs on RT, mobility, and DT performance in community-dwelling older adults at risk of falling.

2. Methods

2.1. Trial design

A single-blinded randomized controlled trial (RCT), including a 24-week intervention, 12-week no-intervention follow-up period, and with a parallel three-arm design, was conducted between March 2018 and January 2019. Three groups of community-dwelling older adults from Évora (Portugal) were compared: experimental group 1 (EG1) was enrolled in a psychomotor intervention program, experimental group 2 (EG2) was enrolled in a combined exercise program (psychomotor intervention program + WBV), and the control group (CG) maintained their daily level of physical activity. This study followed the CONSORT guidelines for RCTs (http://www.consort-statement.org). The protocol was registered in ClinicalTrials.gov (NCT03446352), and no significant changes were made.

2.2. Participants

The participants were community-dwelling older adults and were recruited via pamphlets distributed in strategic locations and verbal communication (recreational and senior centers). The minimum sample size needed was estimated to be 15 participants/group, for a total of 45 participants, by the online G*Power software, with $\alpha = 0.05$ and power = 0.95. The sample size was increased to a minimum of 60 participants (20 in each group) to account for the expected dropout rate of 20%.

The inclusion criteria were: 1) male or female community-dwelling older adults who were aged ≥ 65 years; 2) had a moderate or high level of physical independence (≥ 18 points), as assessed by the 12-item Composite Physical Function (CPF) scale (Rikli & Jones, 2013); and 3) reported at least one fall in the previous 6 months or who were at high risk of falling (a score of ≤ 25 points on the Fullerton Advanced Balance Scale) (Hernandez & Rose, 2008). The exclusion criteria were: 1) cognitive impairment; 2) the presence of motor impairment compromising program participation; 3) a musculoskeletal condition (diagnosis of severe osteoporosis [index $T \leq -2.5$], lower limb fracture < 4 months ago, hip or knee prostheses); 4) a cardiovascular condition (e.g., pacemaker); 5) a neurological condition (epilepsy, loss of consciousness leading to a fall [e.g. vertigo syndrome]), tumors or metastases (Tomás et al., 2011); and 6) participation in a structured exercise program in the previous 6 months (Focht et al., 2007).

Sixty-one participants were enrolled in this study (Figure 3). Five participants were excluded: 2 were excluded due to the presence of motor impairment, and 3 were excluded because they did not report experiencing at least one fall in the previous 6 months or were not at high risk of falling. A total of 56 participants met the inclusion criteria (47 women and 9 men) and were randomly assigned to three groups, with an allocation ratio of 1:1:1, with sequential numbers using the online "random team generator" (https://www.randomlists.com/team-generator). A total of 18 participants were included in EG1, 19 participants were included in EG2, and 19 participants were included in the CG. From baseline to post-intervention, 5 participants (EG1: 2; EG2: 3) dropped out: 3 dropped out due to an illness unrelated to falls, and 2 dropped out because they moved to another city.

This study was approved by the University of Évora Ethics Committee - Health and Well-Being (reference number 16012) and was performed in accordance with the Declaration of Helsinki. All participants provided written informed consent.

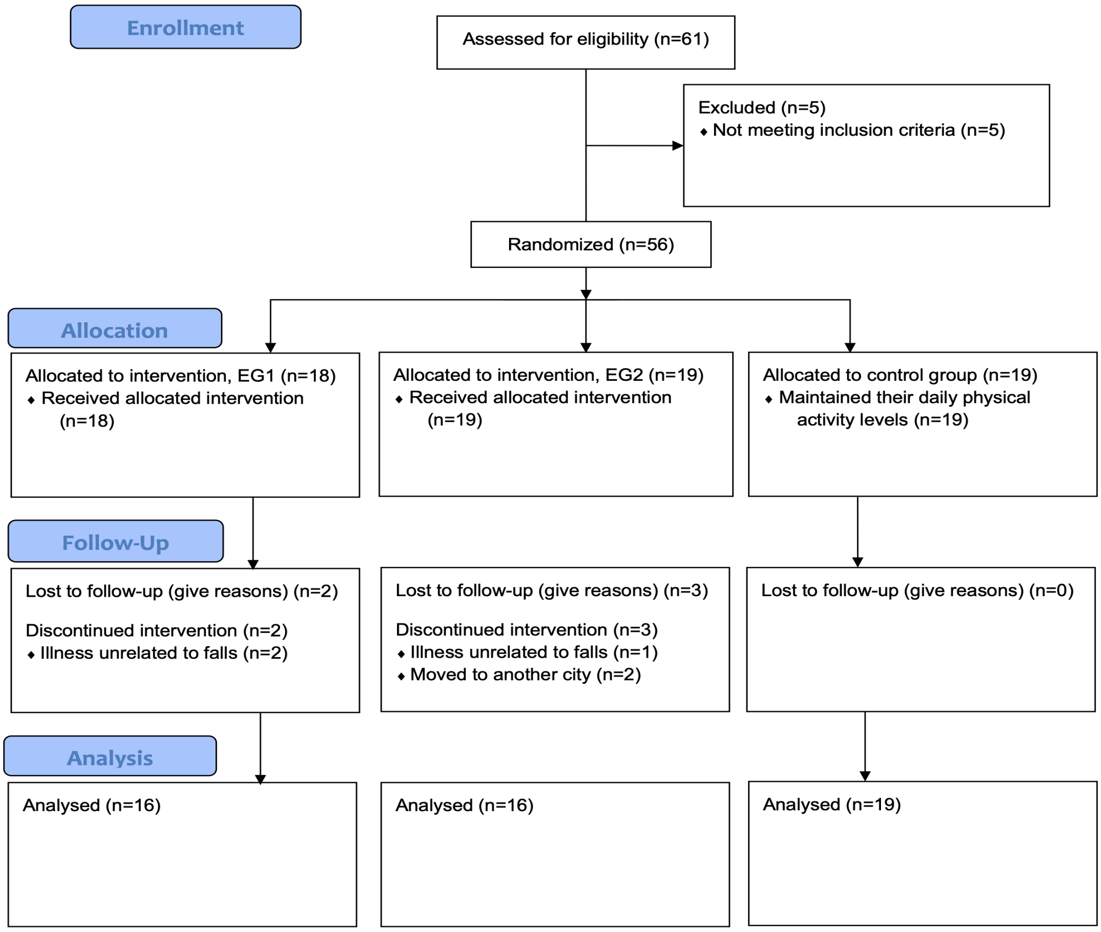

Figure 3. Flow diagram of participant's recruitment.

2.3. Procedures

The participants were assessed individually at baseline, at 24 weeks, and at the 12-week follow-up by the same trained evaluator who had an academic degree in rehabilitation sciences. The measures recorded included cognitive and physical functions, fall occurrence, the results of scales/questionnaires, sociodemographic characteristics, and body composition. The questionnaires and cognitive variable assessment were performed in a quiet room. To familiarize the participants with the assessments, the cognitive and physical outcome assessments included verbal instructions provided by the evaluator and a practice trial before the testing trial. For the physical outcomes assessment, the evaluator also demonstrated the task before each testing trial. The data were collected in laboratories at the University of Évora.

2.4. Outcome measures

2.4.1. Reaction time

Simple reaction time (SRT) and choice reaction time (CRT) were assessed in the single and DT conditions by the Deary-Liewald reaction time task (DLRT) (Deary et al., 2011). In the SRT task, a stimulus (cross) appeared in one box on the monitor, and the participants had to press a key as quickly as they could each time it appeared. In the CRT task, a cross appeared in one of four boxes on the monitor, and the participants had to press the corresponding key as quickly as they could whenever it appeared. The DT conditions involved asking the participants to simultaneously count by twos (starting at the number 0) while performing the SRT and CRT tasks.

The SRT and CRT tasks in the single and DT condi- tions included 8 practice trials. There were 20 testing trials for the SRT tasks in the single and DT conditions, and there were 40 testing trials for the CRT tasks in the single and DT conditions. For the SRT and CRT tasks, the response time ranged from 150 to 1500 (ms) and 200–1500 (ms), respectively. Both tasks had an inter- stimulus interval ranging from 1000 to 3000 (ms). The median RT (ms) for the four tasks (SRT in the single and DT conditions; CRT in the single and DT conditions) and the number of errors in the CRT tasks (wrong key presses) were recorded for each participant.

2.4.2. Timed up and go test

The timed up and go (TUG) test (Rikli & Jones, 2013) was used to assess functional mobility. The participants were asked to stand up from a chair (height: 46 cm), walk to the 2.44 m mark as quickly and safely as possible, turn approximately 180 degrees and sit down again. The commands were “Ready? Set, go!”, and the period from when the command “Go!” was given to when the participant sat down completely in the chair was recorded with a stopwatch. Two test trials were performed, and the best time (s) was chosen.

2.4.3. Cognitive TUG test

DT performance was assessed by the cognitive TUG (CogTUG) test, which was performed 5min after the TUG test. This task follows the methodology of the 2.44 m TUG test, and the same instructions with the inclusion of the cognitive task instructions were given to the participants. The participants were asked to perform the TUG test while counting backward from a predetermined number. In the practice trial, the participants were asked to start counting backward by one from 150. At 145, the evaluator said “Go!” and the participants stood up from the chair and executed both tasks simultaneously as quickly and safely as possible. After a recovery period, the participants performed one testing trial. For that trial, they were asked to start counting backward by one from 100. At 95, the evaluator said “Go!” and the participants stood up from the chair and executed the DT.

The CogTUG test variables were assessed in accordance with the methodology proposed by Tomas-Carus et al. (Tomas-Carus et al., 2019); the variables included the time spent on the DT task (s), the number of cognitive errors (n), the number of cognitive stops (n), the number of motor stops (n), and the final number (n) (the last number counted before the participant sat down). All CogTUG test trials were recorded by video for further analysis.

2.4.4. Falls

The number of falls in the previous 6 months was assessed at baseline and post-intervention. A fall was defined by WHO (Word Health Organization, 2018b) “*as an event which results in a person coming to rest inadvertently on the ground or floor or other lower level”*, and a questionnaire was used to determine the type and circumstances of each fall (e.g. indoor/outdoor; accidental fall during a usual or an unusual task; consequent injuries).

2.4.5. Secondary outcome measures

The Borg Rating of Perceived Exertion (RPE) scale (Borg, 1982) was used to monitor exercise intensity, with scores ranging from 6 points (very, very light) to 20 points (very, very hard). The Caregiver Treatment Satisfaction (CTS) questionnaire (Yoshihara et al., 2015) through a "face scale" was used to assess the participants' satisfaction level, with scores ranging from 1 point (extremely dissatisfied) to 5 points (extremely satisfied). Both the RPE scale and the CTS questionnaire were used to observe the participants' ability to tolerate the multimodal exercise programs. A questionnaire was used to record the participants' sociodemographic characteristics. Body mass index (BMI) was calculated by the formula kg/m^2, and the weight (kg) and height (m) were measured using an electronic scale (Seca 760, Hamburg, Germany) and a stadiometer (Seca 206, Hamburg, Germany), respectively. The 12-item CPF scale (Rikli & Jones, 2013) was used to assess physical independence across a wide variety of activities of daily living. The scores of the previous scale ranged from 0 (worst) to 24 (best) points, and participants were categorized as having "a high level of function" (24 points), "a moderate level of function" (18–23 points), and "a low level of function" (<18 points). Last, the International Physical Activity Questionnaire (IPAQ) (Craig et al., 2003) was used to assess metabolic expenditure (metabolic equivalent of task [MET]-min/ week), which was calculated as follows: time (min/day)*frequency*(days/week)*MET intensity (walking or moderate/vigorous-intensity activities).

2.5. Multimodal exercise programs

The psychomotor intervention program (24weeks; 75 min/session; 3x/week on alternate days) included exercises simultaneously promoting motor stimulation (e.g., mobility, body awareness) and cognitive stimulation (e.g., problem-solving, cognitive inhibition, or RT training under single and DT conditions). The combined exercise program included the psychomotor intervention program + WBV program (beginning with 72 + 3 min/ session and ending with 69 + 6 min/session, respectively; 3x/week on alternate days).

Regarding the WBV program (Galileo® Med35), the vibration amplitude (mm) and resting time between series (s) were always 3 and 60, respectively. Throughout the intervention, the exercise time (s) in the WBV program progressively increased from 45 to 60, the series (n) increased from 4 to 6, and the frequency (Hz) increased from 12.6 to 15. Participants performed the WBV program while they stood without shoes and with bent knees. For the intervention, each EG was divided into two classes until 10 participants. There were no differences between the EG1 and EG2 session classes.

Each session was structured to include a beginning ritual (~ 5 m), a warm-up (~ 10 m), the main section (~ 50 m), a cool down (~ 5 m), and a finishing ritual (~ 5 m). At the initial stage, different muscle groups were activated, increasing the neurophysiological parameters. The main section (multimodal exercises) was focused on the specific objectives through sensory, motor, and neurocognitive activities. This section included exercise periods ranging from 10 to 15 min that alternated between exercises focused on motor stimulation, i.e., physical fitness (e.g., moving around cones with a fitball as fast as possible, forward, and backward), and exercises focused on cognitive stimulation, i.e., executive functions (e.g., drawing a 3, 8 and a Z on the floor, reciting the days of the week backward while walking). During the cool down (e.g., stretching or breathing exercises), the physiological parameters returned to normal. At the finishing ritual, the participants signed an attendance sheet and recorded their exercise intensity level on the RPE scale and their satisfaction level on the CTS questionnaire.

The multimodal exercises were intended to be moderate intensity (~ 13 points on the RPE scale) and were conducted by a therapist with a master’s degree in psychomotor therapy. A sports sciences professor at the university supervised the intervention.

After the study, the CG participants were invited to attend a similar fall prevention program.

2.6. Data analysis

The assumptions of normality and homogeneity were tested through the Kolmogorov-Smirnov and Levene tests, respectively. Since most of the sample variables did not follow a normal distribution, non-parametric statistical analyses were conducted. Between-group comparisons were performed using the Kruskal-Wallis test, and within-group comparisons were performed using the Friedman test; both tests were followed by post hoc pairwise comparisons. The Wilcoxon test was performed for within-group comparisons of the number of falls. The means and standard deviations were calculated for all variables.

The delta value (Δ: moment_{x} - moment_{x-1}) and the respective proportional change delta value (Δ%: [(moment_{x} - moment_{x-1})/moment_{x-1}] × 100) were computed for all variables: post-intervention vs. baseline, the follow-up vs. post-intervention, and the follow-up vs. baseline.

The effect size (ES) was calculated using Cohen's method since the data were not normally distributed (Fritz et al., 2012). Thus, the ES was calculated as $r = (Z/\sqrt{N})$ for all analyses to determine the magnitude of the treatment effect and thus the interventions' clinical significance. Cohen's thresholds were used, and standardized differences of 0.10, 0.30, and 0.50 indicated small, medium, and large effects, respectively (Cohen, 1998).

Analyses were performed using the SPSS software package (version 24.0 for Windows, IMB Statistics). A value of $p \leq 0.05$ was considered statistically significant for all analyses.

A code was assigned to each participant to preserve their anonymity.

3. Results

At baseline, the participant's characteristics, namely, the sociodemographic characteristics, BMI, CPF, IPAQ, and fall occurrence, were similar, and no significant differences were observed between groups ($p \leq 0.05$), as shown in Table 4.

Table 4. Participant's characteristics at baseline.

	EG1 Prevalence or Mean ± SD	EG2 Prevalence or Mean ± SD	CG Prevalence or Mean ± SD	*p*-value
Age (years)	74.3 ± 5.4	74.7 ± 5.5	76.8 ± 5.8	0.407
Sex, female (%)	14 (87.5)	15 (93.8)	13 (68.4)	0.124
Educational level (years)	6.0 ± 2.6	6.1 ± 3.4	7.0 ± 5.3	0.997
BMI (kg/m^2)	29.1 ± 3.0	28.6 ± 4.3	28.1 ± 4.4	0.648
CPF (points)	21.5 ± 2.7	20.8 ± 2.2	21.5 ± 2.8	0.554
IPAQ (MET-min/week)	927.0 ± 557.9	953.4 ± 638.5	740.4 ± 520.9	0.611
Number of falls within the last six months (n)	1.13 ± 0.8	1.19 ± 1.0	1.11 ± 0.3	0.993

SD: standard deviation; EG1: experimental group attending the psychomotor intervention program (n = 16); EG2: experimental group attending the combined exercise program: psychomotor intervention program + WBV (n = 16); GC: control group (n = 19); BMI: Body mass index; CPF: Composite Physical Function; IPAQ: International Physical Activity Questionnaire. Significant differences within groups, $p \leq 0.05$.

Fifty-one participants completed the multimodal exercise programs, and the five dropout participants had characteristics to similar those who completed the study. Seventy-five sessions were held, and the adherence rate was similar between the two EGs (EG1: 82.3% vs. EG2: 84.3%). According to the Borg RPE scale scores, both EGs tolerated the interventions well (EG1: 12.9 ± 0.4 points vs. EG2: 13.2 ± 0.3 points). Additionally, the EGs presented similar levels of satisfaction (EG1: 4.98 ± 0.3 points vs. EG2: 4.99 ± 0.1 points).

At baseline, no significant differences were found between groups in the cognitive and physical functional variables or in the number of falls.

The comparisons within groups concerning the RT variables (Table 5) showed significant differences between the baseline and post-intervention evaluation in both EG2 and the CG. After the 24-week intervention, the CG had poorer results and spent more time performing the "CRT" task (Δ%: 10.9%, $p = 0.045$), and EG2 showed improvements in "CRT DT" task performance, as the task time decreased (Δ%: −8.3%, $p = 0.040$). The post hoc pairwise comparisons also revealed significant differences between the post-intervention and follow-up evaluations, in the variable "SRT" within EG2, where the performance decreased, as the participants required more time to perform the task (Δ%:

14.3%, *p* = 0.013). For EG2, the ESs for the change from baseline to the post-intervention evaluation in the variable “CRT DT” (r = 0.43), and between the post-intervention and follow-up evaluations in the variable “SRT” (r = 0.44) were medium.

The comparisons between groups in the RT variables showed significant differences only at the post-intervention evaluation. Those differences were evident between EG2 and the CG, particularly in the variables “CRT” and “CRT DT”. For the “CRT” variable, EG2 performed better than the CG did, as the participants needed less than 158.5 ms to perform the task; for the variable “CRT DT”, EG2 performed better than the CG, as they spent less than 142.8 ms on the task ($p \leq 0.05$). Concerning the ESs between EG2 and the CG, it was medium in the variables “CRT” (r = 0.46) and “CRT DT” (r = 0.44).

Table 5. Impact of the multimodal exercise programs on reaction time.

		Baseline (A) (Mean ± SD)	Post-intervention (B) (Mean ± SD)	Follow-up (C) (Mean ± SD)	*p*-value	Pairwise Comparison
Reaction Time						
SRT (ms)						
	EG1	480.2 ± 194.8	390.9 ± 77.3	410.5 ± 109.1	0.444	--
	EG2	448.1 ± 159.5	371.6 ± 89.4	424.8 ± 134.5	0.047	--
	CG	418.7 ± 143.6	460.5 ± 192.1	463.6 ± 196.7	0.104	--
SRT DT (ms)						
	EG1	676.3 ± 218.6	569.7 ± 223.2	605.6 ± 208.6	0.099	--
	EG2	621.1 ± 201.8	516.3 ± 149.5	599.5 ± 232.4	0.185	--
	CG	576.9 ± 121.2	600.2 ± 219.3	577.5 ± 169.8	0.854	--
CRT (ms)						
	EG1	935.1 ± 166.1	908.0 ± 154.9	909.9 ± 186.9	0.444	--
	EG2	927.1 ± 179.5	857.4 ± 168.2 [a]	924.4 ± 155.4	0.144	--
	CG	916.4 ± 172.7	1015.9 ± 177.4	962.8 ± 197.9	0.050	A < B
CRT errors (n)						
	EG1	1.3 ± 1.8	0.7 ± 1.2	0.9 ± 1.1	0.636	--
	EG2	0.5 ± 0.7	0.6 ± 0.9	0.9 ± 1.1	0.172	--
	CG	0.6 ± 0.8	0.3 ± 0.6	0.3 ± 0.7	0.328	--
CRT DT (ms)						
	EG1	1070.4 ± 141.6	996.9 ± 203.8	1012.8 ± 155.2	0.444	--
	EG2	1035.0 ± 164.7	949.5 ± 171.8 [a]	1054.3 ± 188.9	0.022	A > B
	CG	1036.6 ± 173.0	1092.3 ± 161.3	1064.3 ± 189.6	0.128	--
CRT DT errors (n)						
	EG1	1.1 ± 1.6	0.9 ± 1.3	0.5 ± 1.0	0.307	--
	EG2	0.9 ± 1.2	0.7 ± 1.0	0.6 ± 1.3	0.598	--
	CG	0.9 ± 1.5	0.7 ± 1.2	0.6 ± 1.0	0.770	--

SD: standard deviation; EG1: experimental group attending the psychomotor intervention program (n = 16); EG2: experimental group attending the combined exercise program: psychomotor intervention program + WBV (n = 16); CG: control group (n = 19); SRT: simple reaction time; DT: dual-task; CRT: choice reaction time. > or <: significant differences within groups, $p \leq 0.05$. [a]: significant differences between EG2 and CG, $p \leq 0.05$

Concerning the mobility and DT performance variables (Table 6), the comparisons within groups revealed significant differences, particularly in the EGs. Improvements were observed in both EGs between the baseline and post-intervention evaluation in the “TUG” mobility variable (EG1Δ%: −7.0%, $p = 0.011$; EG2 Δ%: −12.2%, $p = 0.004$) and in the “CogTUG” DT variables, namely, in “time” (EG1Δ%: −10.8%, $p = 0.002$) and in “cognitive stops” (EG2Δ%: −90.9%, $p = 0.006$). The post hoc pairwise comparisons also revealed significant improvements in the “cognitive stops” variable within EG1 (Δ%: −66.7%, $p = 0.020$). Additionally, significant differences were observed in both EGs from post-intervention to the follow-up evaluations, where the performance at the follow-up decreased, particularly in the “TUG” mobility variable (EG1Δ%: 12.1%, $p = 0.002$; EG2: 15.4%, $p = 0.024$), in the CogTUG variables, namely, “time” (EG1Δ%: 11%, $p = 0.024$; EG2Δ%: 16.5%, $p = 0.014$) and the number of cognitive errors (EG2Δ%: 166.7%, $p = 0.040$). Concerning the CG, differences were observed between the baseline and the follow-up evaluation only in the “TUG” variable, in which the CG required more time to perform the task (Δ%: 11.4%, $p = 0.017$). Regarding these variables, the ES of the changes within groups between the baseline and the post-intervention evaluation ranged from 0.41 (medium) to 0.49 (medium) in EG1 and ranged from 0.47 (medium) to 0.53 (large) in EG2, while the ES between post-intervention and follow-up evaluations ranged from 0.41 (medium) to 0.57 (large) in EG1 and from 0.41 (medium) to 0.55 (large) in EG2. These ESs regarding the changes over follow-up period show that the performance decreased markedly.

No significant differences between groups were observed in the mobility and CogTUG variables ($p \leq 0.05$).

Regarding the number of falls, the comparisons within groups between the baseline and the post-intervention showed that the number of falls decreased in both EGs (EG1: 1.13 ± 0.8 vs. 0.63 ± 0.7, $p = 0.021$; EG2: 1.19 ± 1.0 vs. 0.44 ± 0.7, $p = 0.007$), while that in the CG remained the same (1.11 ± 0.3 vs. 0.95 ± 1.0, $p = 0.405$). No significant differences between groups were observed ($p \leq 0.05$).

Table 6. Impact of the multimodal exercise programs on mobility and dual-task performance.

		Baseline (A) (Mean ± SD)	**Post-intervention (B) (Mean ± SD)**	**Follow-up (C) (Mean ± SD)**	***p*-value**	**Pairwise Comparison**
Mobility						
TUG (s)						
	EG1	7.1 ± 1.3	6.6 ± 1.0	7.4 ± 1.1	0.001	A > B; B < C
	EG2	7.4 ± 1.6	6.5 ± 1.0	7.5 ± 1.9	0.003	A > B; B < C
	CG	7.0 ± 1.5	7.5 ± 1.8	7.8 ± 2.2	0.021	A < C
CogTUG						
Time (s)						
	EG1	10.2 ± 2.9	9.1 ± 2.3	10.1 ± 2.8	0.001	A > B; B < C
	EG2	10.1 ± 2.5	9.1 ± 2.0	10.6 ± 2.7	0.015	B < C
	CG	9.5 ± 3.1	10.2 ± 3.3	10.7 ± 3.4	0.692	--
Cognitive errors (n)						
	EG1	1.0 ± 1.3	0.8 ± 0.8	1.3 ± 1.1	0.262	--
	EG2	1.1 ± 0.8	0.6 ± 0.9	1.6 ± 1.3	0.012	B < C
	CG	0.8 ± 1.0	0.8 ± 1.3	0.8 ± 1.1	0.682	--
Cognitive stops (n)						
	EG1	0.9 ± 1.0	0.3 ± 0.5	0.5 ± 0.7	0.020	--
	EG2	1.1 ± 0.8	0.1 ± 0.3	0.6 ± 0.6	< 0.001	A > B
	CG	0.8 ± 0.7	0.6 ± 1.0	0.5 ± 0.8	0.148	--
Motor Stops (n)						
	EG1	0.3 ± 0.4	0.2 ± 0.4	0.3 ± 0.4	0.819	--
	EG2	0.3 ± 0.5	0.1 ± 0.3	0.1 ± 0.3	0.074	--
	CG	0.3 ± 0.6	0.2 ± 0.5	0.3 ± 0.5	0.651	--
Final number (n)						
	EG1	88.9 ± 2.4	88.6 ± 2.9	88.4 ± 2.8	0.328	--
	EG2	88.6 ± 2.3	88.0 ± 2.8	88.1 ± 3.5	0.346	--
	CG	88.6 ± 2.8	88.4 ± 2.7	88.1 ± 2.7	0.302	--

SD: standard deviation; EG1: experimental group attending the psychomotor intervention program (n = 16); EG2: experimental group attending the combined exercise program: psychomotor intervention program + WBV (n = 16); CG control group (n = 19); TUG: timed up and go; CogTUG: cognitive timed up and go test. > or <: significant differences within groups, $p \leq 0.05$.

4. Discussion

This RCT showed that both multimodal exercise programs designed for community-dwelling older adults at risk of falling were well tolerated and effective for fall prevention. Both intervention programs promoted a decrease in the fall rate and induced clinically significant effects on physical and cognitive risk factors for falls, particularly RT, mobility, and DT performance. The results showed that the magnitude of the treatment effect was higher for the intervention combining the psychomotor intervention program and the WBV exercise program, providing evidence that the intervention program combining both methods has additional benefits. In addition, contrary to other researchers' findings (Eggenberger et al., 2015; Finnegan et al., 2019), the follow-up results in the present study showed that the benefits observed in RT, mobility, and DT performance by both intervention programs in community-dwelling older adults were reversed after the programs were discontinued.

The fact that the multimodal exercise programs in this study were supervised, instead of, for example, home-based, may have led to the programs being more effective (Lacroix et al., 2016). Moreover, the adherence rate in the EGs in the present study (83.3%) was slightly higher than that in other studies on 24-week intervention programs (70%) (Boa Sorte Silva et al., 2018) carried out in community-dwelling older adults. Concerning the Borg RPE scale results, the two EGs in the present study showed results similar to those in other studies on moderate-intensity intervention programs in community-dwelling adults (Kutsuna et al., 2019).

Regarding cognitive function, the within-group comparisons showed that only the combined exercise program induced improvements in the RT variables, particularly in "CRT DT", with medium ES. These improvements were also evidenced by between-group comparisons, concerning the combined exercise program and the CG, in the variables "CRT" and "CRT DT". A previous 16-week study by Linde and Alfermann (Linde & Alfermann, 2014) showed that a combined intervention (physical + cognitive) also increases cognitive speed, with a medium ES. However, that 16-week study showed no changes in RT variables in the EG. Few studies in community-dwelling adults have included DLRT evaluations, especially for multimodal exercise programs (Vaughan et al., 2014), making the findings of the present study relevant. In the present study, the CG participants demonstrated decreased performance in RT variables, particularly "CRT", which is in line with the neurocognitive losses associated with aging reported in other studies (Joubert & Chainay, 2018; Tait et al., 2017). Comparing the EGs, although both programs led to improvements in cognitive function, the combined exercise program may have improved RT performance more. To our knowledge, no studies on the effects of active WBV on cognitive function in community-dwelling older adults have been conducted. Few studies have investigated these effects in healthy young adults (Regterschot et al., 2014), and they found acute positive effects on cognitive function, despite the study participants having high executive function. At the follow-up evaluation, the benefits from the intervention in EG2 were no longer evident, particularly in the "CRT DT" variable, since no significant differences were found between the baseline and the follow-up evaluations, and in the variable "SRT". The magnitude of the treatment effect of the combined exercise program in the variable "CRT DT" after the no-intervention follow-up period followed this performance decrease, with a reversed magnitude of 0.44. Consistent with our findings, in a 12-week follow-up study, Linde and Alfermann (Linde & Alfermann, 2014) also found that the ES of the combined intervention decreased from medium to small, and in cognitive speed in particular, the ES decreased from large to medium.

Regarding physical function, the within-group comparisons between the baseline and post-intervention evaluations showed that both multimodal exercise programs induced significant improvements in mobility and Cog-TUG variables, with a medium ES in EG1, and ranging from medium to large in EG2. Regarding mobility, these results are consistent with those of the study by Freiberger et al. (Freiberger et al., 2007), in which the fitness intervention group, focusing more on strength and endurance training, exhibited slightly better TUG test results than did the psychomotor intervention group. The multimodal exercise program studied by Vaughan et al. (Vaughan et al., 2014), which was focused on physical function, led to a larger ES in TUG performance than did the programs implemented in the present study; the test time decreased from 6.6 ± 1.4 to 4.9 ± 0.7 s. The slight discrepancy in results between that study and the present study may be related to the fact that the mean age of the EG in the previous study was approximately 5 years younger than those of the two EGs in the present study. The WBV can also lead to improvements in mobility as reported by an 8-week singular WBV intervention study conducted by Yang et al. (Yang et al., 2015) in community-dwelling adults, measured by the TUG test (9.96 ± 2.49 vs. 9.06 ± 1.60). Furthermore, the comparisons between groups demonstrated that both EGs had similar results concerning mobility, with a medium ES.

At the follow-up evaluation, the TUG time increased in all groups (including the EGs). Contrary to EGs in other studies with no-intervention follow-up periods of at least 12 months (Finnegan et al., 2019), the EGs in the present study did not exhibit long-term effects of the psychomotor or combined intervention programs regarding mobility, and the TUG time increased by 12.1% in EG1 and by 15.4% in EG2 from post-intervention to the follow-up evaluation. Moreover, the decreasing trend observed in the intervention period continued in the CG, and the TUG time increased by 4.0% during the follow-up period.

Concerning DT performance, both multimodal exercise programs significantly improved the CogTUG variables. However, the combined exercise program induced improvements with larger treatment effects than did the singular psychomotor intervention program. This observation was especially evident in the variable “cognitive stops”, for which the ES of the combined exercise program was 0.53 and that of the psychomotor intervention program was 0.41. This finding is important, as Tomas-Carus et al. (Tomas-Carus et al., 2019) suggested that the CogTUG test with the counting numbers backward test may be more effective than the TUG test alone in classifying fallers and non-fallers among community-dwelling older adults, with particular relevance to the cognitive stop and cognitive error results. Thus, the findings of the present study should be considered in the development of fall prevention programs, and these programs should include DT paradigms. The DT results in the present study are in line with those of a 24-week study conducted by Eggenberger et al. (Eggenberger et al., 2015), which comprised two multimodal exercise programs that included different types of physical exercise and simultaneous cognitive training tasks; the authors observed that these programs significantly improved DT variables to a greater extent than did single interventions involving walking. The findings in the present study are also consistent with those of a 12-week study conducted by Yokoyama et al. (Yokoyama et al., 2015), which showed that a cognitive-motor DT intervention program induced more benefits than did a single intervention in terms of cognitive domains. The larger treatment effect in the variable “cognitive stops”, within EG2, may be explained by WBV providing additional benefits in the multimodal exercise program. In fact, the sensorimotor and neuromuscular stimulation, promoted by WBV along with the neurophysiological changes induced in DT training, can lead to improvements in cognitive function (Tait et al., 2017). At the 12-week follow-up evaluation, in this study, the DT effects were no longer evident, with some variables showing significant declines, particularly the DT performance time and the number of cognitive errors; these findings are contrary to those in the study by Eggenberger et al. (Eggenberger et al., 2015), in which the improvements in DT performance remained at the 1-year follow-up.

Regarding the outcome “number of falls”, both programs induced changes in the fall rate by decreasing the number of falls (EG1: −44.2%; EG2: −63.0%). No studies were found that evaluated the effect of a psychomotor intervention program in the fall rate. The 16-week study implemented by Freiberger et al. (Freiberger et al., 2007), which included a psychomotor intervention focusing mainly on body awareness and coordination, showed improved physical function performance at the post-intervention, but no reduction in the number of falls at the 12-month follow-up. Although a previous meta-analysis (Jepsen et al., 2017) observed that WBV training induced a reduction in the fall rate of 0.67 (95% CI 0.50 to 0.89, $p = 0.0006$), most of the studies included were performed in nursing homes, and compared with the present study, these studies included programs of different lengths or used higher frequencies (≥ 20 Hz). However, although lower vibration frequencies were applied in the present study, beneficial results were obtained without endangering the integrity of the skeletal muscle structures and joints, which can be affected by a higher vibration frequency (Gusi et al., 2006).

Future studies should further investigate the contribution of the WBV to cognitive function and its neurophysiological mechanisms in community-dwelling older adults. A strength of the present study is that it had methodological quality, given that the study design was an RCT and a long-term intervention was implemented; moreover, previously, these two intervention programs were barely studied. However, the present study also has some limitations. First, this study has a single-blinded rather than a double-blinded design. The small sample size and associated dropout rate may have limited the statistical power of the study and thus the ability to generalize the present findings. Nonetheless, the sample size met the minimum size calculated by G*Power in the power analysis, 15 participants per group, and other studies with the same frequency/week and length of the intervention presented identical dropout rates (Boa Sorte Silva et al., 2018). In the future, the number of falls at the follow-up evaluation should be recorded. Last, 82.4% of the participants in this study were women. Although this proportion is similar to those in other prevention fall programs, recruitment strategies must be adopted to reduce this inequality in sex (Barker et al., 2016).

5. Conclusions

This RCT study showed that the two multimodal exercise programs studied were well tolerated and were effective in improving cognitive and physical risk factors for falls, particularly RT, mobility, and DT performance. Moreover, the improvements induced in these risk factors were concomitant with a significant reduction in the number of falls in both EGs. Both multimodal exercise programs induced positive effects in mobility and DT performance (and in RT in EG2), with a medium clinical effect in EG1 and ranging from medium to large in EG2. These effects were no longer evident after the 12-week no-intervention follow-up period. Considering that falls are a major public health problem, these findings reveal the benefits of the two multimodal interventions in fall prevention programs. Moreover, this study demonstrated the importance of not discontinuing psychomotor intervention programs to prevent the deterioration of cognitive and physical function in community-dwelling older people at risk of falling, particularly when they are combined with WBV exercise.

Funding

This study was supported by the European Fund for regional development through Horizon 2020 - Portugal 2020 - Programa Operacional Regional do Alentejo (ALT20-03-0145-FEDER-000007) with respect to the "Ageing Safety in Alentejo - Understanding for action (ESACA)". Hugo Rosado holds an "Fundação para a Ciência e a Tecnologia" doctoral fellowship (SFRH/BD/147398/2019). Funders did not contribute to the design, analysis, or preparation of this manuscript.

Acknowledgments

The authors would like to thank all participants who participated in this study.

6. References

Barker, A. L., Talevski, J., Bohensky, M. A., Brand, C. A., Cameron, P. A., & Morello, R. T. (2016). Feasibility of Pilates exercise to decrease falls risk: a pilot randomized controlled trial in community-dwelling older people. *Clinical Rehabilitation*, *30*(10), 984-996. https://doi.org/10.1177/0269215515606197

Blackwood, J., Shubert, T., Fogarty, K., & Chase, C. (2016). The Impact of a Home-Based Computerized Cognitive Training Intervention on Fall Risk Measure Performance in Community Dwelling Older Adults, a Pilot Study. *The Journal of Nutrition, Health & Aging*, *20*(2), 138-145. https://doi.org/10.1007/s12603-015-0598-5

Boa Sorte Silva, N. C., Gill, D. P., Gregory, M. A., Bocti, J., & Petrella, R. J. (2018). Multiple-modality exercise and mind-motor training to improve mobility in older adults: A randomized controlled trial. *Experimental Gerontology*, *103*, 17-26. https://doi.org/10.1016/j.exger.2017.12.011

Borg, G. A. (1982). Psychophysical bases of perceived exertion. *Medicine and Science in Sports and Exercise*, *14*(5), 377-381. https://doi.org/10.1249/00005768-198205000-00012

Cohen, J. (1998). *Statistical power analysis for the behavioral sciences*.

Craig, C. L., Marshall, A. L., Sjostrom, M., Bauman, A. E., Booth, M. L., Ainsworth, B. E., Pratt, M., Ekelund, U., Yngve, A., Sallis, J. F., & Oja, P. (2003). International physical activity questionnaire: 12-country reliability and validity. *Medicine and Science in Sports and Exercise*, *35*(8), 1381-1395. https://doi.org/10.1249/01.MSS.0000078924.61453.FB

Deary, I. J., Liewald, D., & Nissan, J. (2011). A free, easy-to-use, computer-based simple and four-choice reaction time programme: the Deary-Liewald reaction time task. *Behavior Research Methods*, *43*(1), 258-268. https://doi.org/10.3758/s13428-010-0024-1

Donath, L., van Dieen, J., & Faude, O. (2016). Exercise-Based Fall Prevention in the Elderly: What About Agility? *Sports Medicine*, *46*(2), 143-149. https://doi.org/10.1007/s40279-015-0389-5

Eggenberger, P., Theill, N., Holenstein, S., Schumacher, V., & de Bruin, E. D. (2015). Multicomponent physical exercise with simultaneous cognitive training to enhance dual-task walking of older adults: a secondary analysis of a 6-month randomized controlled trial with 1-year follow-up. *Clinical Interventions in Aging*, *10*, 1711-1732. https://doi.org/10.2147/CIA.S91997

Finnegan, S., Seers, K., & Bruce, J. (2019). Long-term follow-up of exercise interventions aimed at preventing falls in older people living in the community: a systematic review and meta-analysis. *Physiotherapy*, *105*(2), 187-199. https://doi.org/10.1016/j.physio.2018.09.002

Focht, B. C., Knapp, D. J., Gavin, T. P., Raedeke, T. D., & Hickner, R. C. (2007). Affective and self-efficacy responses to acute aerobic exercise in sedentary older and younger adults. *Journal of Aging and Physical Activity*, *15*(2), 123-138. https://doi.org/10.1123/japa.15.2.123

Freiberger, E., Menz, H. B., Abu-Omar, K., & Rutten, A. (2007). Preventing falls in physically active community-dwelling older people: a comparison of two intervention techniques. *Gerontology*, *53*(5), 298-305. https://doi.org/10.1159/000103256

Fritz, C. O., Morris, P. E., & Richler, J. J. (2012). Effect size estimates: current use, calculations, and interpretation. *Journal of Experimental Psychology: General*, *141*(1), 2-18. https://doi.org/10.1037/a0024338

Gobbo, S., Bergamin, M., Sieverdes, J. C., Ermolao, A., & Zaccaria, M. (2014). Effects of exercise on dual-task ability and balance in older adults: a systematic review. *Archives of Gerontology and Geriatrics*, *58*(2), 177-187. https://doi.org/10.1016/j.archger.2013.10.001

Graveson, J., Bauermeister, S., McKeown, D., & Bunce, D. (2016). Intraindividual Reaction Time Variability, Falls, and Gait in Old Age: A Systematic Review. *Journals of Gerontology. Series B: Psychological Sciences and Social Sciences*, *71*(5), 857-864. https://doi.org/10.1093/geronb/gbv027

Gusi, N., Raimundo, A., & Leal, A. (2006). Low-frequency vibratory exercise reduces the risk of bone fracture more than walking: a randomized controlled trial. *BMC Musculoskeletal Disorders*, *7*(1), 92. https://doi.org/10.1186/1471-2474-7-92

Hernandez, D., & Rose, D. J. (2008). Predicting which older adults will or will not fall using the Fullerton Advanced Balance scale. *Archives of Physical Medicine and Rehabilitation*, *89*(12), 2309-2315. https://doi.org/10.1016/j.apmr.2008.05.020

Jepsen, D. B., Thomsen, K., Hansen, S., Jorgensen, N. R., Masud, T., & Ryg, J. (2017). Effect of whole-body vibration exercise in preventing falls and fractures: a systematic review and meta-analysis. *BMJ Open*, *7*(12), e018342. https://doi.org/10.1136/bmjopen-2017-018342

Joubert, C., & Chainay, H. (2018). Aging brain: the effect of combined cognitive and physical training on cognition as compared to cognitive and physical training alone - a systematic review. *Clinical Interventions in Aging*, *13*, 1267-1301. https://doi.org/10.2147/CIA.S165399

Kutsuna, T., Hiyama, Y., Kusaka, S., Kusumoto, Y., Tsuchiya, J., Umeda, M., & Takahashi, T. (2019). The effect of short-term health promotion intervention on motor function in community-dwelling older adults. *Aging Clinical and Experimental Research*, *31*(4), 475-481. https://doi.org/10.1007/s40520-018-0994-x

Lacroix, A., Kressig, R. W., Muehlbauer, T., Gschwind, Y. J., Pfenninger, B., Bruegger, O., & Granacher, U. (2016). Effects of a Supervised versus an Unsupervised Combined Balance and Strength Training Program on Balance and Muscle Power in Healthy Older Adults: A Randomized Controlled Trial. *Gerontology*, *62*(3), 275-288. https://doi.org/10.1159/000442087

Lajoie, Y., & Gallagher, S. P. (2004). Predicting falls within the elderly community: comparison of postural sway, reaction time, the Berg balance scale and the Activities-specific Balance Confidence (ABC) scale for comparing fallers and non-fallers. *Archives of Gerontology and Geriatrics*, *38*(1), 11-26. https://doi.org/10.1016/s0167-4943(03)00082-7

Linde, K., & Alfermann, D. (2014). Single versus combined cognitive and physical activity effects on fluid cognitive abilities of healthy older adults: a 4-month randomized controlled trial with follow-up. *Journal of Aging and Physical Activity*, *22*(3), 302-313. https://doi.org/10.1123/japa.2012-0149

Pereira, C., Rosado, H., Cruz-Ferreira, A., & Marmeleira, J. (2018). Effects of a 10-week multimodal exercise program on physical and cognitive function of nursing home residents: a psychomotor intervention pilot study. *Aging Clinical and Experimental Research*, *30*(5), 471-479. https://doi.org/10.1007/s40520-017-0803-y

Probst, M., Knapen, J., Poot, G., & Vancampfort, D. (2010). Psychomotor therapy and psychiatry: what’s in a name? *The Open Complementary Medicine Journal*, *2*(1), 105-113. https://doi.org/10.2174/1876391X01002010105

Regterschot, G. R., Van Heuvelen, M. J., Zeinstra, E. B., Fuermaier, A. B., Tucha, L., Koerts, J., Tucha, O., & Van Der Zee, E. A. (2014). Whole body vibration improves cognition in healthy young adults. *PloS One*, *9*(6), e100506. https://doi.org/10.1371/journal.pone.0100506

Rikli, R. E., & Jones, C. J. (2013). Development and validation of criterion-referenced clinically relevant fitness standards for maintaining physical independence in later years. *Gerontologist*, *53*(2), 255-267. https://doi.org/10.1093/geront/gns071

Schoene, D., Valenzuela, T., Lord, S. R., & de Bruin, E. D. (2014). The effect of interactive cognitive-motor training in reducing fall risk in older people: a systematic review. *BMC Geriatrics*, *14*, 107. https://doi.org/10.1186/1471-2318-14-107

Sherrington, C., Michaleff, Z. A., Fairhall, N., Paul, S. S., Tiedemann, A., Whitney, J., Cumming, R. G., Herbert, R. D., Close, J. C. T., & Lord, S. R. (2017). Exercise to prevent falls in older adults: an updated systematic review and meta-analysis. *British Journal of Sports Medicine*, *51*(24), 1750-1758. https://doi.org/10.1136/bjsports-2016-096547

Tait, J. L., Duckham, R. L., Milte, C. M., Main, L. C., & Daly, R. M. (2017). Influence of Sequential vs. Simultaneous Dual-Task Exercise Training on Cognitive Function in Older Adults. *Frontiers in Aging Neuroscience*, *9*, 368. https://doi.org/10.3389/fnagi.2017.00368

Taylor-Piliae, R. E., Peterson, R., & Mohler, M. J. (2017). Clinical and Community Strategies to Prevent Falls and Fall-Related Injuries Among Community-Dwelling Older Adults. *Nursing Clinics of North America*, *52*(3), 489-497. https://doi.org/10.1016/j.cnur.2017.04.004

Tomás, R., Lee, V., & Going, S. (2011). The Use of Vibration Exercise in Clinical Populations. *ACSM's Health & Fitness Journal*, *15*(6), 25-31. https://doi.org/10.1249/FIT.0b013e31823373e8

Tomas-Carus, P., Biehl-Printes, C., Pereira, C., Veiga, G., Costa, A., & Collado-Mateo, D. (2019). Dual task performance and history of falls in community-dwelling older adults. *Experimental Gerontology*, *120*, 35-39. https://doi.org/10.1016/j.exger.2019.02.015

Vaughan, S., Wallis, M., Polit, D., Steele, M., Shum, D., & Morris, N. (2014). The effects of multimodal exercise on cognitive and physical functioning and brain-derived neurotrophic factor in older women: a randomised controlled trial. *Age and Ageing*, *43*(5), 623-629. https://doi.org/10.1093/ageing/afu010

Word Health Organization. (2018a). *Ageing and health*. https://www.who.int/news-room/facts-in-pictures/detail/ageing

Word Health Organization. (2018b). *Falls*. https://www.who.int/news-room/fact-sheets/detail/falls

Yang, F., King, G. A., Dillon, L., & Su, X. (2015). Controlled whole-body vibration training reduces risk of falls among community-dwelling older adults. *Journal of Biomechanics*, *48*(12), 3206-3212. https://doi.org/10.1016/j.jbiomech.2015.06.029

Yokoyama, H., Okazaki, K., Imai, D., Yamashina, Y., Takeda, R., Naghavi, N., Ota, A., Hirasawa, Y., & Miyagawa, T. (2015). The effect of cognitive-motor dual-task training on cognitive function and plasma amyloid beta peptide 42/40 ratio in healthy elderly persons: a randomized controlled trial. *BMC Geriatrics*, *15*, 60. https://doi.org/10.1186/s12877-015-0058-4

Yoshihara, S., Kanno, N., Fukuda, H., Arisaka, O., Arita, M., Sekine, K., Yamaguchi, K., Tsuchida, A., Yamada, Y., Watanabe, T., Shimizu, T., Nishikawa, K., & Nishimuta, T. (2015). Caregiver treatment satisfaction is improved together with children's asthma control: Prospective study for budesonide monotherapy in school-aged children with uncontrolled asthma symptoms. *Allergology International*, *64*(4), 371-376. https://doi.org/10.1016/j.alit.2015.05.010

Zhu, X., Yin, S., Lang, M., He, R., & Li, J. (2016). The more the better? A meta-analysis on effects of combined cognitive and physical intervention on cognition in healthy older adults. *Ageing Research Reviews*, *31*, 67-79. https://doi.org/10.1016/j.arr.2016.07.003

Paper 2

Benefits of Two 24-Week Interactive Cognitive–Motor Programs on Body Composition, Lower-Body Strength, and Processing Speed in Community Dwellings at Risk of Falling: A Randomized Controlled Trial

Hugo Rosado[1,2]*, Catarina Pereira[1,2], Jorge Bravo[1,2], Joana Carvalho[3,4], Armando Raimundo[1,2]

[1] Departamento de Desporto e Saúde, Escola de Saúde e Desenvolvimento Humano, Universidade de Évora, Évora, Portugal.

[2] Comprehensive Health Research Centre (CHRC), Universidade de Évora, Évora, Portugal.

[3] Faculdade de Desporto, Universidade do Porto, Porto, Portugal.

[4] CIAFEL - Research Centre in Physical Activity, Health and Leisure, Universidade do Porto, Portugal

* Corresponding author: hrosado@uevora.pt

Abstract

Background: This 24-week randomized controlled trial study evaluated the effects of two interactive cognitive–motor programs on body composition, lower-body strength, and processing speed in community dwellings at risk of falling.

Methods: Forty-eight participants (75.0 ± 5.4 years) were allocated into EG1 (psychomotor intervention program), EG2 (combined program (psychomotor intervention + whole-body vibration)), and a control group.

Results: EG programs induced significant improvements in bone mass, lower-body strength, and processing speed ($p < 0.05$), with similar treatment effects on lower-body strength and processing speed and higher bone mineral content and density within EG2. The fall rate decreased in EG1 (44.2%) and EG2 (63%) ($p < 0.05$). After the 12-week no-intervention follow-up, improvements in lower-body strength were reversed in both EGs, but those in processing speed were maintained, mainly in EG2 ($p < 0.05$).

Conclusions: In conclusion, both programs were accepted and well tolerated. The combined program led to additional benefits in bone mass. Both programs positively impacted physical and cognitive risk factors for falls and injuries. They induced similar improvements in lower-body strength and processing speed, decreasing the fall rate. These findings suggest that both programs are successful for fall and injury prevention in the studied population.

Keywords: aging; falls; psychomotor intervention; bone mineral density; cognitive function; muscle strength

1. Introduction

Falls are common in older adults and are a significant cause of mortality or fall-related injuries such as fractures, leading to reduced mobility and independence (Ng et al., 2019). Given the increasing aging population, the occurrence of falls and healthcare-associated costs are projected to rise (Ng et al., 2019; Tricco et al., 2017). In fact, the aging process can lead to changes in some modifiable risk factors for falls. It is widely accepted that body composition changes, particularly a reduced muscle mass in the lower limbs and loss of bone mineral density (BMD), are major indicators of falls or fall-related fractures (Beck, 2015; Shepherd et al., 2017). In addition, a decrease in physical function, such as a loss of muscle strength, and cognitive performance, particularly a slower processing speed, can enhance the risk of falling, especially in those with a history of previous falls (Ambrose et al., 2013; Sprague et al., 2021). In this way, it is essential to promote specific interventions to prevent the negative consequences of falls.

It is well established in the literature that single (e.g., exercise alone such as resistance training) or different combinations of interventions (e.g., exercise alongside vitamin D supplementation, or balance plus strength training) may prevent falls in community-dwelling older adults (Di Lorito et al., 2021; Senderovich & Tsai, 2020; Tricco et al., 2017). However, the intervention type, frequency, duration, participant's mean adherence, or participant's satisfaction level may influence the intervention's effectiveness and should be investigated. Recent studies have shown an association between long-term exercise (at least 24 weeks, three times per week at a moderate intensity) and a reduction in the number of falls or fall-related fractures in community-dwelling older people (de Souto Barreto et al., 2019; Ng et al., 2019).

Beyond physical function, exercise training leads to enhancements in cognitive function, such as processing speed (Desjardins-Crepeau et al., 2016; Falck et al., 2019). The connectivity between physical activity/exercise and cognitive function is well established, and the potential mechanisms supporting the protective effects of exercise on cognitive abilities are described in the literature (Marmeleira, 2013). According to a previous study, this relationship can lead to hippocampal changes that promote neurogenesis and synaptogenesis processes through neuroplasticity. Concomitantly, positive effects of cognitive-based interventions (e.g., computerized cognitive training) on physical performance have been reported, leading to significant improvements in risk factors for falls, such as mobility, balance, and gait impairments (Marusic et al., 2018; Smith-Ray et al., 2015). However, an interactive cognitive–motor (ICM) intervention, promoting simultaneous cognitive and motor stimulation, may present better results in physical and cognitive functions, particularly in risk factors for falls, and should be preferred to a single intervention (Gavelin et al., 2021; Schoene et al., 2015).

In this way, a psychomotor intervention program tailored to older adults may present promising results for physical and cognitive functions (Freiberger et al., 2007; Kwag et al., 2021; Pereira et al., 2018), and can be considered an ICM intervention. Psychomotor therapy uses movement and corporality as the main resources to optimize physical, cognitive, affective, and perceptual skills through physical activity and functional body movements (Kwag et al., 2021), in which reaching high-intensity training or performing high-impact exercises are not concerns. However, the potential effects of this therapy on body composition and physical and cognitive functions are still poorly known given the lack of studies, and its potential to reduce the risk of falls should be further explored.

On the other hand, whole-body vibration (WBV) training may improve bone mass and reduce the incidence of falls, thus minimizing fracture risk in case of a fall [3]. Moreover, WBV promotes muscle contractions by mechanical stimulation/oscillation and could improve physical function performance, particularly muscle strength, a critical risk factor for falls (Beck, 2015; Sarabon et al., 2020). WBV can also improve some aspects of cognition (Boerema et al., 2018); nonetheless, little is known about the WBV effects on older adults' processing speed.

Given the potential benefits of both interventions, we hypothesized that a combined intervention, including a psychomotor intervention and WBV training, could emerge as an effective and novel intervention to reduce the risk factors for falls or fall-related fractures. Additionally, few ICM programs have included a no-intervention follow-up (Blasco-Lafarga et al., 2020; Boa Sorte Silva et al., 2018), so the potential positive effects on body composition and physical and cognitive functions over time remain unclear. Thus, this randomized controlled trial (RCT) aimed to evaluate the effects of two ICM programs (psychomotor intervention versus psychomotor intervention + WBV) on body composition, lower-body strength, and processing speed in community dwellings at risk of falling.

2. Methods

2.1. Study design and participants

This 24-week RCT followed a single-blinded design and was performed between March 2018 and January 2019, as described elsewhere (Rosado et al., 2021). Three groups were included: (1) experimental group 1 (EG1), which performed a psychomotor intervention program; (2) experimental group 2 (EG2), which underwent a combined program (psychomotor intervention program + WBV); and (3) the control group (CG), in which participants were asked to maintain their daily life routines. Participants were evaluated at baseline (m1), after 24 weeks of intervention (m2), and after a 12-week no-intervention follow-up (m3). After the follow-up evaluations, participants allocated in the CG were invited to participate in a fall prevention program. This RCT was reported according to the Consolidated Standard of Reporting Trials (CONSORT 2010) guidelines (http://www.consort-statement.org); accessed on 20 January 2021). In addition, a concise overview of the intervention programs was described according to the TIDieR checklist (https://www.equator-network.org/reporting-guidelines/tidier/), accessed on 20 January 2021). This study was registered at ClinicalTrials.gov (NCT03446352) on 26 February 2018.

The sample size was calculated using the online G*Power software, considering an effect size = 0.25 (Joubert & Chainay, 2018), alpha = 0.05, and statistical power of 95%. Hence, a minimum sample size of 45 participants was determined (15 participants for each group) to identify significant changes. The number of participants was increased to cover an expectable dropout rate. Thus, 61 community-dwelling Portuguese older adults were enrolled via verbal invitation and leaflets placed in community settings such as senior associations, recreation centers, and city halls.

Inclusion criteria required: (a) males or females aged 65 years or more; (b) score of ≥ 18 points (moderate or high physical functioning) on the Composite Physical Function scale (Rikli & Jones, 2013); and (c) a history of falls (≥ 1 fall) in the preceding six months or scoring 25 points or below (high risk of falling) on the Fullerton Advanced Balance scale (Hernandez & Rose, 2008). Exclusion criteria were as follows: (a) Cognitive impairment; (b) dependent mobility (walk without walking aids); (c) musculoskeletal (diagnosis of osteoporosis (T-score of −2.5 or below); recent lower-limb fracture; knee or hip prostheses), cardiovascular (pacemaker), and neurological (epilepsy) conditions that could compromise participants' well-being (Tomás et al., 2011); and (d) participation in a regular exercise program over the last six months (Focht et al., 2007).

Among 61 candidates, 56 volunteers met the inclusion criteria (47 women and 9 men), and 5 volunteers were excluded, as described in Figure 4. After baseline evaluation, participants were randomly assigned according to simple randomization procedures with sequential numbers (1:1:1 ratio), performed by an investigator with no clinical involvement in the trial. The online "Random Team Generator" (https://www.randomlists.com/team-generator), accessed on 2 April 2018) was used, and participants were allocated into three groups: EG1 (n = 18), EG2 (n = 19), and CG (n = 19).

All the participants gave written informed consent. Ethical approval for the study was provided by the institutional research ethics committee on human health and well-being (reference number 16012), following the guidelines of the Declaration of Helsinki.

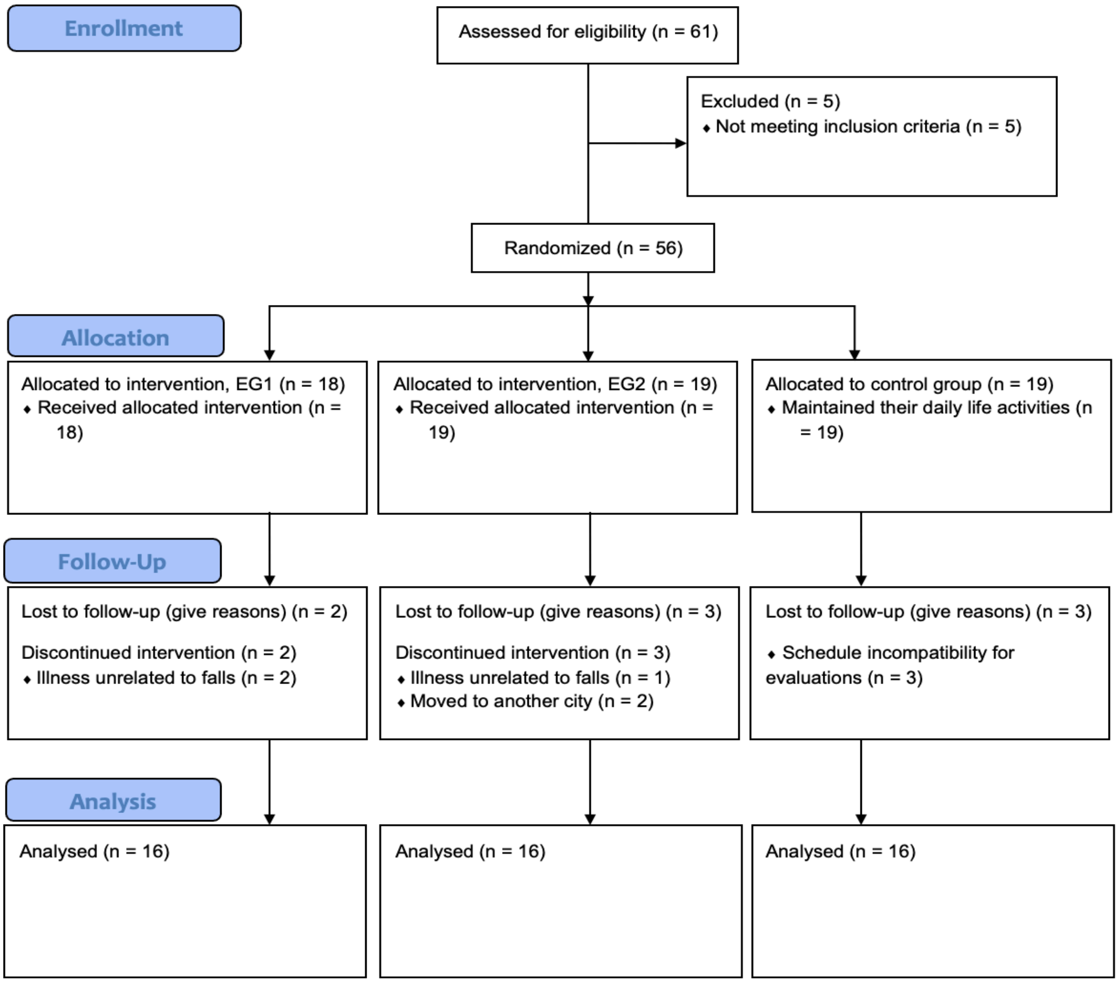

Figure 4. Flow diagram of the study participants.

2.2. Procedures

The same trained rater, who graduated in rehabilitation sciences, conducted the participants' assessments individually at the university laboratories. The evaluator was blinded to participants' allocation. Cognitive tests and questionnaire completion were performed in a room with minimal noise and a comfortable temperature. Physical function and body composition variables' assessments were undertaken in appropriate laboratories. Before each cognitive and physical assessment, participants were instructed with a verbal explanation, followed by a practice trial.

2.3. Outcome measures

Body composition was assessed by dual-energy X-ray absorptiometry (DXA—Hologic QDR, Hologic, Inc., Bedford, MA, USA), which is considered a reliable, accurate, and safe imaging modality to measure changes in body composition and bone (Shepherd et al., 2017). This assessment involved fat mass (%); lean body mass (kg); total bone mineral content (BMC) (g); total BMD (g/cm^2); T-scores (n) as reference values for healthy young adults; and Z-scores as reference values for age and gender (n). Daily quality assurance was performed through a Hologic Spine Phantom.

Lower-body strength and muscle resistance were measured by the 30-s Chair Stand Test (30CST), in accordance with the methodology proposed by Jones, Rikli, and Beam (Jones et al., 1999). The number of full and corrected stands in 30 s was recorded. Furthermore, the maximal strength of the knee extensors and flexors (60º/s; a range of motion of 90º) was assessed with an isokinetic dynamometer (Biodex System 3, Biodex Corp., Shirley, NY, USA), which was established as a reliable assessment device in community-dwelling older adults (Hartmann et al., 2009). After a practice trial, one test trial was performed, including a set of three concentric repetitions. The highest peak torque value (N·m) reached in the test was recorded for further analysis.

Processing speed was assessed by the Trail Making Test (TMT) A and B, according to the instructions proposed by Cavaco et al. (Cavaco et al., 2013). The time (s) to complete TMT-A and TMT-B was recorded as the number of errors.

Fall occurrence was assessed through an interview based on a script that comprises information about the date of each fall and the circumstances surrounding it (e.g., fall-related injuries, type, and location of fall). This oral interview was conducted to doublecheck for false-positive or false-negative responses. A fall was defined "*as an event which results in a person coming to rest inadvertently on the ground or floor or other lower level*" (World Health Organization, 2018). The self-reported number of falls was collected at baseline (retrospective falls over the previous six months) and post-intervention (prospective falls over the six intervention months).

2.3.1. Complementary Outcome Measures

To assess the exercise intensity, the Borg Rating of Perceived Exertion scale was used, based on effort levels ranging from 6 points (very, very light) to 20 points (very, very hard) (Borg, 1982). Participants' satisfaction level was assessed by using the Caregiver Treatment Satisfaction questionnaire, which ranged between 1 point (extremely dissatisfied) and 5 points (extremely satisfied) (Yoshihara et al., 2015). Sociodemographic characteristics (age, sex, and educational level) were collected by means of an interview based on a script. Standing height (m) and body mass (kg) were measured through a stadiometer (Seca 206, Hamburg, Germany) and an electronic scale (Seca 760, Hamburg, Germany), respectively, and body mass index (kg/m^2) was calculated. To assess the physical independence, the Composite Physical Function scale was used, which includes an ample range of functional abilities (Rikli & Jones, 2013); this 12-item self-report scale can range between 0 (worst) and 24 (best) points, and participants were categorized as "low functioning" (score: < 18), "moderate functioning" (score: 18 to 23), or "high functioning" (score: 24). Each participant's habitual physical activity was measured using the short version of the International Physical Activity Questionnaire (IPAQ) by means of the metabolic equivalent of task ([MET]-min/week), recording the time (min/day), the frequency (days/week), and MET intensity (i.e., walking: 3.3 MET; moderate: 4.0 MET; or vigorous: 8.0 MET). Physical activity was computed as the sum of metabolic expenditure spent on the three types of activity, each one calculated as time × frequency × MET intensity (Craig et al., 2003).

2.4. Interactive cognitive-motor programs

Both programs were performed three times per week (75 min/session) on alternate days, with up to 10 participants in each class. All supervised sessions were delivered by the same specialist, who has a master's degree in rehabilitation sciences, at the gerontopsychomotricity laboratory. Sessions were rescheduled for those who were absent for 3 consecutive sessions.

The ICM programs included cognitive and motor tasks (Gavelin et al., 2021). Adaptative, specific, and progressive tasks were performed over the intervention period. These tasks followed the American College of Sports Medicine recommendations (e.g., gradual intensity/difficulty increase: initial stage comprising 2 sets of 8 repetitions and final stage comprising 3 sets of 15 repetitions) (Garber et al., 2011). Physical exercises were executed using the participant's body weight or affordable equipment such as fitballs, resistance bands, rubber mats, or unstable surfaces. A moderate exercise intensity (~ 13 points) on the Borg RPE scale was a target in both programs.

2.4.1. Psychomotor intervention program

This program included the main principles of a psychomotor intervention tailored to older people (e.g., body-mediated activities such as body scheme awareness) and was focused on ICM stimulation. Each class started with a 5 min beginning ritual and a 10 min warm-up. This phase involved joint rotation (from neck to ankle) and a quick dual-task activity for neurophysiological activation (e.g., standing up and sitting down from the chair or pointing body parts according to arithmetic tasks). The main phase (50 min) consisted of different interactive activities (sensory/neuromotor exercises) that promote simultaneous cognitive and motor stimulation for alternate periods of approximately 15 min (i.e., the first 15 min comprised activities with greater cognitive demand, followed by 15 min with greater motor demand). The previous phase included neurocognitive activities (e.g., processing speed: select different animals/flowers based on relevant stimulus, as quickly as possible), motor activities (e.g., postural muscle and lower-limb exercises: dorsi-plantar flexion, such as standing on toes; knee extension/flexion, such as bodyweight squats), and dual-task paradigms (e.g., fitball wall squats simultaneously with a regressive countdown by 3 from 30 or while reciting their phone number backwards). During the 5 min cool-down phase, stretching exercises or relaxation methods using massage balls for body awareness development were performed. Lastly, at the 5 min finishing ritual, participants were asked to record their exercise intensity (RPE scale) and satisfaction levels (Caregiver Treatment Satisfaction questionnaire).

2.4.2. Combined exercise program

As a complement to the psychomotor intervention program, participants in the combined exercise program were instructed to individually perform a WBV program (initial stage: 3 min; final stage: 6 min) on a side-alternating vibration device (Galileo® Med35).

Participants were asked to stand up on the platform without shoes while holding the handlebar with bent knees (~ 30º of knee flexion) and an erect trunk position to prevent musculoskeletal injuries. The exercise volume was also increased gradually during the 24-week intervention (exercise time: 45–60 s; the number of series: 4–6; and frequency: 12.6–15 Hz). An amplitude of 3 mm and a 1 min seated rest between series were always per- formed.

2.5. Statistical analysis

All statistical analyses were conducted using the SPSS software package (version 24.0, IBM SPSS Inc.). According to the Shapiro–Wilk and the Levene test results, repeated measures ANOVA assumptions were not met. Thus, non-parametric statistics were performed. The Friedman test was used for within-group comparisons, and the Kruskal–Wallis test was used for between-group comparisons. Pairwise post hoc tests were also carried out when significant differences were found. Lastly, the Wilcoxon test was performed to compare paired fall data between the baseline and the post-intervention (i.e., number of falls).

Data are presented as means ± standard deviations or frequencies (%). The variation value was calculated between the baseline, post-intervention, and follow-up evaluations as Δ: moment_x - moment_{x-1}. For significant differences between the evaluation moments, the respective delta percentage was also computed by the following formula: (Δ%: $[(\text{moment}_x - \text{moment}_{x-1})/\text{moment}_{x-1}] \times 100$).

Effect size (ES) was determined for the within-group and between-group comparisons following the guidelines for non-parametric tests (Fritz et al., 2012). To quantify the practical meaningfulness of the treatment effect, the ES was computed as $r = (Z/ \sqrt{N})$ and classified based on Cohen's thresholds (small: 0.10; medium: 0.30; and large: 0.50) (Cohen, 1998).

In all analyses, a *p*-value of < 0.05 was considered statistically significant.

3. Results

Overall, 48 participants out of the 56 initially randomized completed the present study. Dropouts (dropout rate: 14.3%) were similarly distributed between groups, and participants who dropped out presented similar characteristics compared to participants who finished ICM programs (75 sessions each). Mean adherence was identical in both EGs (EG1: 82.3% vs. EG2: 84.3%), as were the exercise intensity (EG1: 12.9 ± 0.4 vs. EG2: 13.2 ± 0.3) and satisfaction level (EG1: 4.98 ± 0.3 vs. EG2: 4.99 ± 0.1). No adverse events from intervention programs were reported.

Table 7 summarizes participants' general characteristics at baseline, and no significant between-group differences were observed.

Table 7. General characteristics of the participants at baseline.

	EG1 Prevalence or mean ± SD	**EG2 Prevalence or mean ± SD**	**CG Prevalence or mean ± SD**	**p-value**
Age (years)	74.3 ± 5.4	74.7 ± 5.5	75.9 ± 5.7	0.750
Sex, female (%)	14 (87.5)	15 (93.8)	13 (81.3)	0.571
Educational level (years)	6.0 ± 2.6	6.1 ± 3.4	7.0 ± 5.1	0.992
BMI (kg/m^2)	29.1 ± 3.0	28.6 ± 4.3	28.0 ± 4.8	0.601
CPF (points)	21.5 ± 2.7	20.8 ± 2.2	21.4 ± 2.9	0.579
IPAQ (MET-min/week)	927.0 ± 557.9	953.4 ± 638.5	791.7 ± 482.2	0.803
Number of falls within the last six months (n)	1.13 ± 0.8	1.19 ± 1.0	1.13 ± 0.3	0.978

SD: standard deviation; EG1: experimental group 1 [psychomotor intervention program] (n = 16); EG2: experimental group 2 [psychomotor intervention program + WBV] (n = 16); GC: control group (n = 16); BMI: Body Mass Index; CPF: Composite Physical Function; IPAQ: International Physical Activity Questionnaire; Significant differences within groups, $p < 0.05$.

Likewise, no significant differences between groups were found at baseline regarding body composition, physical function, or cognitive function variables.

Table 8 presents the findings of our study regarding the body composition variables. Within-group comparisons evidenced significant improvements from baseline to post-intervention evaluations only in the EGs, mainly in EG2. Specifically, the results showed that the programs induced improvements in the following variables: "Total BMC" (Δm2−m1% EG2: 11.4%, $p < 0.001$), "Total BMD" (Δm2−m1% EG1: 2.1%, $p = 0.040$; Δm2−m1% EG2: 7.1%, $p < 0.001$), "T-score" (Δm2−m1% EG2: 46.0%, $p < 0.001$), and "Z-score" (Δm2−m1% EG2: 243%, $p < 0.001$). These results were not maintained at the follow-up evaluation, in which EG2 demonstrated a significant decreasing trend in the previous variables, namely, "Total BMC" (Δm3−m2%: −6.9%, $p = 0.002$), "Total BMD"

(Δm3−m2%: −5.0%, $p = 0.001$), “T-score” (Δm3−m2%: −72.2%, $p = 0.001$), and “Z-score” (Δm3−m2%: −53.2%, $p = 0.008$). The respective effect sizes from baseline to post-intervention were medium (0.32) in EG1 and large (0.56 to 0.59) in EG2, whereas those between post-intervention and the follow-up were large (0.57 to 0.62).

Table 8. Impact of the interactive cognitive–motor programs on body composition variables.

		Baseline (A) (Mean ± SD)	Post-intervention (B) (Mean ± SD)	Follow-up (C) (Mean ± SD)	*p*-value	Pairwise Comparison
Body composition						
Body weight (kg)						
	EG1	66.8 ± 9.7	67.5 ± 9.0	67.1 ± 9.1	0.494	--
	EG2	66.1 ± 10.4	65.7 ± 10.7	66.2 ± 11.2	0.223	--
	CG	67.9 ±11.9	68.3 ± 12.0	67.2 ± 11.9	0.085	--
Fat mass (%)						
	EG1	39.3 ± 4.7	39.8 ± 5.1	39.0 ± 4.9	0.185	--
	EG2	41.1 ± 6.1	40.6 ± 6.2	41.0 ± 6.3	0.269	--
	CG	38.8 ± 6.9	38.7 ± 6.4	38.4 ± 6.7	0.570	--
Lean body mass (kg)						
	EG1	41.1 ± 7.1	40.9 ± 7.3	41.5 ± 7.3	0.368	--
	EG2	38.6 ± 5.6	38.6 ± 5.7	38.7 ± 5.9	0.829	--
	CG	40.2 ± 7.3	40.3 ± 7.7	40.3 ± 7.6	0.829	--
Total BMC (g)						
	EG1	1923.4 ± 313.0	2024.9 ± 402.0	1934.3 ± 271.6	0.047	--
	EG2	1705.9 ± 322.3	1901.0 ± 392.8	1770.3 ± 404.6	< 0.001	B > A, C
	CG	1992.8 ± 443.0	1997.1 ± 485.0	2026.1 ± 461.7	0.939	--
Total BMD (g/cm^2)						
	EG1	1.050 ± 0.098	1.072 ± 0.097	1.045 ± 0.091	0.022	B > A
	EG2	0.974 ± 0.112	1.043 ± 0.124	0.990 ± 0.133	< 0.001	B > A, C
	CG	1.091 ± 0.141	1.084 ± 0.156	1.093 ± 0.146	0.570	--
T-score (n)*						
	EG1	-0.6 ± 1.2	-0.4 ± 1.1	-0.7 ± 1.1	0.062	--
	EG2	-1.6 ±1.2	-0.9 ± 1.2	-1.5 ± 1.3	< 0.001	B > A, C
	CG	-0.6 ± 1.5	-0.7 ± 1.6	-0.5 ± 1.6	0.225	--
Z-score (n)*						
	EG1	1.3 ± 1.1	1.5 ± 1.0	1.3 ± 0.9	0.101	--
	EG2	0.3 ± 1.3	1.1 ± 1.3	0.5 ± 1.4	< 0.001	B > A, C
	CG	1.4 ± 1.3	1.4 ± 1.4	1.5 ± 1.4	0.192	--

SD: standard deviation; EG1: experimental group 1 (psychomotor intervention program) (n = 16); EG2: experimental group 2 (psychomotor intervention program + WBV) (n = 16); CG: control group (n = 16); BMC: bone mineral content; BMD: bone mineral density; > significant differences within groups, $p < 0.05$; * these variables included a different number of participants per group due to limitations of reference population in DXA for gender and age in T-score(EG1: n = 14; EG2: n =15; CG: n =13) and Z-score (EG1: n = 13; EG2: n = 15; CG: n = 12).

Table 9 displays the analyses within and between groups for physical function concerning lower-body strength variables. Within-group comparisons between the baseline and post-intervention evaluations detected significant improvements in both EGs. In particular, the results showed that the programs induced improvements in the variable "30CST" (Δ%m2−m1EG1: 45.2%, $p < 0.001$; Δm2−m1% EG2: 42.9%, $p < 0.001$), representing an increase in the number repetitions. However, these improvements at the post-intervention were not maintained at the follow-up evaluation, with a considerable performance decrease in both EGs (Δm3−m2% EG1: −21.4%, $p = 0.001$; Δm3−m2% EG2: −21.6%, $p = 0.008$). Additionally, significant differences among groups were also found at the post-intervention in this variable between EG1 and the CG, as the participants in EG1 achieved ~ 6 more repetitions than those in the CG ($p < 0.001$), as well as between EG2 and the CG, in which participants in EG2 executed ~ 5 more repetitions than those in the CG ($p = 0.004$). The within-group ES from baseline to post-intervention in EG1 (0.62) and EG2 (0.60) was large and remained large between the post-intervention and the follow-up (EG1: 0.63; EG2: 0.58). The ES between groups was also large between EG1 and the CG (0.69) and between EG2 and the CG (0.56).

In regard to the maximal strength of the knee extensors and flexors variables, despite descriptive analysis suggesting an increase of 8.9% at post-intervention in the variable "Isokinetic peak torque (extension 60o)" in EG2, significant differences were only detected between the baseline and the follow-up evaluations in EG1 and the CG. A significant decrease between baseline and the follow-up was observed in the variable "Isokinetic peak torque (extension 60o)" in EG1 (Δm3−m1%: −8.6%, $p = 0.008$, r = 0.31) and the CG (Δm3−m1%: −9.2%, $p = 0.008$, r = 0.41) and in the variable "Isokinetic peak torque (flexion 60o)" in the CG (Δm3−m1%: −12.9%, $p = 0.040$, r = 0.51).

Table 9. Impact of the interactive cognitive–motor programs on physical function variables.

		Baseline (A) (Mean ± SD)	**Post-intervention (B) (Mean ± SD)**	**Follow-up (C) (Mean ± SD)**	***p*-value**	**Pairwise Comparison**
Lower-body strength 30CST (n)						
	EG1	12.4 ± 3.2	18.1 ± 3.1 [a]	14.2 ± 2.3	< 0.001	B > A, C
	EG2	11.9 ± 3.5	17.1 ± 4.2 [b]	13.4 ± 3.5	< 0.001	B > A, C
	CG	13.2 ± 3.3	12.3 ± 3.2	12.0 ± 3.3	0.325	--
Isokinetic peak torque (extension 60°) (N·m)						
	EG1	82.3 ± 26.3	82.3 ± 25.6	75.3 ± 23.6	0.008	A > C
	EG2	71.2 ± 27.8	77.5 ± 21.0	75.6 ± 25.6	0.144	--
	CG	75.6 ± 24.9	71.7 ± 22.9	68.7 ± 19.7	0.010	A > C
Isokinetic peak torque (flexion 60°) (N·m)						
	EG1	42.5 ± 13.7	45.0 ± 14.2	43.3 ± 16.5	0.646	--
	EG2	40.3 ± 10.3	40.8 ± 9.5	39.9 ± 10.5	0.829	--
	CG	43.7 ± 14.7	38.7 ± 12.3	38.0 ± 11.3	0.022	A > C

SD: standard deviation; 30CST: 30 s Chair Stand Test; EG1: experimental group 1 (psychomotor intervention program) (n = 16); EG2: experimental group 2 (psychomotor intervention program + WBV) (n = 16); CG: control group (n = 16); > significant differences within groups, $p < 0.05$; [a] significant differences between EG1 and CG, $p < 0.05$; [b] significant differences between EG2 and CG, $p < 0.05$.

Concerning cognitive function (Table 10), namely, the processing speed variables, significant within-group changes between the baseline and the post-intervention were observed in both EGs. The results revealed that the programs induced improvements in the variables “TMT-A time” (Δm2−m1% EG1: −20.8%, $p = 0.011$; Δm2−m1 % EG2: −24.0%, $p = 0.008$) and “TMT-B time” (Δm2−m1% EG1: −23.1%, $p < 0.001$; Δm2−m1% EG2: −22.9%, $p < 0.001$). The previously described values showed a better performance after the 24-week intervention by decreasing the time to complete the tasks. These improvements remained evident in both EGs between the baseline and the 12-week follow-up evaluations for the same variables “TMT-A time” (Δm3−m1% EG2: −20.0%, $p = 0.014$) and “TMT-B time” (Δm3−m1% EG1: −19.6%, $p = 0.001$; Δm3−m1% EG2: −17.0%, $p = 0.040$). The corresponding effect sizes (r) were large between the baseline and the post-intervention periods in both EGs (EG1: 0.55 to 0.62; EG2: 0.51 to 0.58), while those between baseline and the follow-up were large in EG1 (0.61) and medium in EG2 (0.43 to 0.45).

In terms of the fall occurrence, within-group comparisons from baseline to post-intervention periods showed a reduction in the number of falls of 44.2% in EG1 and 63% in EG2 (EG1: 1.13 ± 0.8 vs. 0.63 ± 0.7, $p = 0.021$; EG2: 1.19 ± 1.0 vs. 0.44 ± 0.7, $p = 0.007$), while the CG presented similar results and remained unchanged (1.13 ± 0.3 vs. 1.06 ± 1.0, $p = 0.763$).

Table 10. Impact of the interactive cognitive–motor programs on processing speed variables.

		Baseline (A) (Mean ± SD)	Post-intervention (B) (Mean ± SD)	Follow-up (C) (Mean ± SD)	*p*-value	Pairwise Comparison
Processing speed						
TMT-A time (s)						
	EG1	91.3 ± 31.6	72.3 ± 27.8	85.1 ± 35.5	0.010	A > B
	EG2	85.2 ± 36.4	64.7 ± 29.3	68.2 ± 31.1	0.003	A > B, C
	CG	80.4 ± 39.8	73.3 ± 34.6	72.1 ± 30.8	0.305	--
TMT-A errors (n)						
	EG1	0.6 ± 1.1	0.3 ± 0.6	0.5 ± 1.0	0.438	--
	EG2	0.4 ± 0.5	0.3 ± 0.6	0.3 ± 0.6	0.368	--
	CG	0.4 ± 0.6	0.3 ± 0.6	0.4 ± 0.7	0.595	--
TMT-B time (s)						
	EG1	254.9 ± 70.9	196.0 ± 81.2	204.9 ± 81.6	< 0.001	A > B, C
	EG2	224.0 ± 87.1	172.7 ± 76.9	186.0 ± 89.1	< 0.001	A > B, C
	CG	202.5 ± 80.1	200.1 ± 83.1	187.8 ± 75.7	0.105	--
TMT-B errors (n)						
	EG1	2.1 ± 1.4	1.4 ± 1.2	2.0 ± 1.4	0.109	--
	EG2	1.6 ± 1.3	0.9 ± 1.1	1.3 ± 1.3	0.217	--
	CG	1.9 ± 1.3	1.4 ± 1.0	1.8 ± 1.2	0.234	--

SD: standard deviation; TMT: Trail Making Test; EG1: experimental group 1 (psychomotor intervention program) (n = 16); EG2: experimental group 2 (psychomotor intervention program + WBV) (n = 16); CG: control group (n = 16); > significant differences within groups, $p < 0.05$.

4. Discussion

Overall, the present study results evidenced that both programs were accepted and well tolerated by participants. They effectively improved bone mass, which is essential to prevent fall-related injuries such as fractures. Despite an increase in BMD within EG1, EG2, which combined the psychomotor intervention and WBV training, led to additional benefits for more bone mass variables, namely, BMD, BMC, T-Score, and Z-score, with a large ES in all of these variables. Likewise, both programs effectively improved physical (lower-body strength) and cognitive (processing speed) risk factors for falls and injuries and decreased the fall rate. The improvements in these risk factors were clinically relevant, as they all had a large ES. After the no-intervention 12-week follow-up, the enhancements in bone mass induced by the programs were not maintained, particularly in EG2. Likewise, the physical benefits induced by both programs were reversed, unlike the cognitive function improvements, which were maintained, particularly within EG2. Our study is the second to evaluate the effects of a psychomotor intervention combined with WBV training and only the third study investigating the effects of a psychomotor intervention as a fall prevention program (Freiberger et al., 2007; Rosado et al., 2021).

Regarding the adherence rate and tolerability, a few ICM studies have been carried out over 24 weeks, three times per week, in community dwellings. Along these lines, compared to our EGs, the 24-week study conducted by Boa Sorte Silva et al. (Boa Sorte Silva et al., 2018) showed a lower mean adherence (83.3% vs. 70%). Predicting compensatory sessions in case of health problems may be an effective strategy for reducing absenteeism. Moreover, the exercise intensity of the RPE scale corresponded to the defined target (~ 13 points) and guaranteed that all participants performed all tasks during the intervention programs.

In regard to body composition, compared to the psychomotor intervention program, the combined intervention induced improvements in BMD and BMC, T-Score, and Z-score, with a larger ES in all variables. Thus, these improvements within EG2 were more visible at an osteogenic level than muscular strength and muscle mass levels, as described above, which could positively influence fracture risk. The vibration exposure could lead to a more effective stimulation of bone formation, increasing the BMD and BMC. Furthermore, these results suggest that adding only ~ 5 min per session of WBV training in a psychomotor intervention can lead to additional benefits. Given the lack of ICM studies focused on body composition changes, the comparison of our study with other studies is limited. Contrary to the present study, the 24-week study carried out by Marín-Cascales and colleagues (Marin-Cascales et al., 2017) found a significant decrease in total fat mass, both in the WBV group and in the multicomponent program group (aerobic and drop jumps exercises), in postmenopausal women. These authors also found no changes in total lean mass or BMD in either group. The findings of the previous study regarding total lean mass are consistent with our study findings. The best method to improve muscle mass or lean body mass is still unclear, and future investigations are needed since muscle weakness increases the risk of falling (Beck, 2015; Sarabon et al., 2020).

Furthermore, it is interesting to observe that our psychomotor intervention with low material effort also achieved significant improvements in BMD. Thus, our psychomotor intervention can also be recommended as an effective therapy to minimize bone loss. Concerning the improvements in BMC, our study evidenced superior improvements to the multicomponent 24-month program conducted by Englund and colleagues (Englund et al., 2005). In the previous study, their EG, which included strengthening, aerobic, balance, and coordination exercises, increased BMC by 3.5%, while our EG1 and EG2 increased it by 5.3% and 11.4%, respectively, despite only EG2 presenting significant improvements. Therefore, our EG2 could positively influence the prevention of bone demineralization. At the follow-up, these improvements were reversed, especially in EG2, suggesting the importance of non-cessation WBV training in body composition. These results were followed by normative data comparisons of T-score and Z-score variations, in which lower mean scores represent a lower bone density.

With respect to physical function, namely, lower-body strength, both programs induced similar improvements. This is an unexpected finding because WBV training has been referred to as an effective program for improving muscle strength, alone or combined with other programs (Sarabon et al., 2020). Therefore, it would be expected that an intervention that combines WBV and a psychomotor intervention, including strength stimulation, would provide additional benefits in muscle strength compared to the psychomotor intervention alone. At the post-intervention, both EGs significantly increased the number of repetitions performed in the "30CST" (EG1: 45.2%; EG2: 42.9%), with similar effect sizes. These results support the findings in previous studies, such as Desjardins-Crépeau et al.'s (Desjardins-Crepeau et al., 2016) study, in which only mixed aerobic and resistance training combined with cognitive training led to an increase of more than 45% in the number of repetitions. Additionally, compared to the 12-week study conducted by Hsien-Te Peng and colleagues (Peng et al., 2020), our EGs achieved a more accentuated increase in the number of repetitions than their ICM EG, which improved by 10.1% (21.8 ± 6.9 vs. 24.0 ± 6.4). For the maximal strength of the knee extensors and flexors, despite an increase of 8.9% in the variable "Isokinetic peak torque (extension 60o)" within EG2, it was not significant. However, these results are in accordance with other ICM studies that presented an increase of 10.9% in the knee extension force after 12 months of intervention (Sipila et al., 2021). The fact that both programs included mostly resistance strength exercises could help to explain these results. Therefore, these results suggest that ICM programs designed for fall prevention should consist of resistance strength exercises. However, for enhancements in maximal strength, both programs should focus more on muscle strength and power exercises, possibly through plate-loaded machines. The sessions' intensity level at the RPE scale should target values between 13 and 15 (Sipila et al., 2021). Nevertheless, the specificity of a psychomotor intervention, mainly oriented to corporeality and self-awareness, does not incorporate or reach these high intensities in a session.

After the 12-week follow-up, improvements induced by both programs in lower-body strength, particularly in the "30CST" variable, were reversed. These findings are similar to those from Blasco-Lafarga et al.'s study (Blasco-Lafarga et al., 2020), which developed an ICM program (strength + cardiovascular exercises under dual-task paradigms). These authors pointed out that the effects of detraining were more marked in muscle strength than in other physical function outcomes, with muscle strength being the physical function capability with more sensitivity to an intervention program and the respective detraining. Considering our intervention programs' specificity, the results highlight the need for detraining periods to be less than 12 weeks, which is in line with recommendations in Blasco-Lafarga and colleagues' study (Blasco-Lafarga et al., 2020). Another recommendation is to implement a home-based program including strength exercises, while the psychomotor intervention is not restarted.

Regarding the processing speed of our study participants, both EGs showed significant post-intervention improvements, with slightly larger effect sizes in EG1. Thus, the WBV training did not lead to additional benefits. Our results are consistent and superior to other ICM programs in community dwellings. After 24 weeks of an ICM intervention (resistance/balance training + computerized cognitive training), the participants (74.5 ±

3.8 years) of the study carried out by Sipila et al. (Sipila et al., 2021) performed the TMT-A and TMT-B tests in less than 3.4% and 8.3% of the time, respectively; compared to the present study, our EGs executed the TMT-A and TMT-B in at least 19% less time. The specificity of the computerized cognitive training, which was initially supervised and, after some sessions, carried out individually and unsupervised, may explain these differences. An unsupervised ICM intervention (exergames under different postural conditions) was also carried out in the 16-week study conducted by Schoene et al. (Schoene et al., 2015), and no significant improvements were observed in participants' (82.0 ± 7.0 years) performance in the TMT- A (37.1 ± 19.2 vs. 32.8 ± 12.2 s) and TMT-B variables (110.9 ± 60.0 vs. 107.7 ± 47.7 s). Finally, the 12-week study carried out by Desjardins-Crépeau et al. (Desjardins-Crepeau et al., 2016) focused on an interactive program (stretching and toning exercises + dual-task training program) that significantly improved the processing speed by 15.3% in the TMT-A test, whereas no significant differences in the TMT-B variable were detected. Likewise, the previous study was supervised, and participants (73.2 + 6.3 years) also performed computerized cognitive training.

Although prior studies have shown significant improvements in several domains of executive function, supervised ICM interventions, such as our programs, without resorting to computerized cognitive training can lead to additional improvements in information processing. Moreover, the diversity of group exercises proposed in our programs, as dual-task paradigms targeting the enhancement of specific cognitive domains and brain regions such as the prefrontal cortex, could help explain our study results. In this way, it is recommended that fall prevention programs have these characteristics. Thus, these findings must be interpreted with caution. Considering the effects of the programs' cessation, the processing speed improvement induced by both programs was maintained at the follow-up evaluation, especially within EG2. These findings are in line with other studies. In the study of Blasco-Lafarga and colleagues (Blasco-Lafarga et al., 2020), after 14 weeks of detraining, the executive function results showed a slight decrease. Therefore, cognitive function losses seem to be less sensitive to a detraining period. This is important because cognitive improvements, particularly in processing speed, directedly reduce the risk of falls and can attenuate the decline in physical function over ten years (Sprague et al., 2021).

Lastly, a significant reduction in fall occurrence was observed in both EGs at the post-intervention, especially within EG2, which showed fewer falls. Despite the WBV training's low frequency (15 Hz) within EG2 to ensure a safe intervention, the mechanical stimulation and higher muscle activation provided by WBV could lead to a larger protective effect of the combined program for falls. The psychomotor intervention for fall prevention conducted by Freiberger and colleagues (Freiberger et al., 2007) reported the fall occurrence over the previous six months at baseline and during the 12-month follow-up, and no significant differences were observed. Likewise, few ICM programs include the number of falls as the main outcome. The 16-week study carried out by Gschwind et al. (Gschwind et al., 2015), which included a virtual-reality intervention program, showed a decrease in the incidence of falls in EG (-68.0%). However, alongside the specificity of a virtual-reality intervention, the retrospective falls of the previous study were collected over the previous 12 months at baseline, so comparisons to our study should be interpreted with caution. One of the first studies to directly evaluate the effects of WBV training on falls also showed a significant decrease in the fall rate only in the combined 18-month program (multicomponent physical training + WBV). However, these results are difficult to compare to our study given the long-term intervention, exclusively postmenopausal women participants, and the higher frequency used (25–35 Hz) on the WBV (von Stengel et al., 2011).

Some considerations related to our study's findings should be made, such as the recommendation that older people at risk of falling actively engage in ICM programs and the recommendation to improve the ICM program by combining the psychomotor intervention with WBV training to potentialize the benefits in physical and cognitive risk factors for fall and fall-related injuries. In the absence of the WBV platform, the single psychomotor intervention is widely recommended since this ICM program has also been shown to induce benefits in fall and fall-related injury risk factors, namely, the processing speed, lower-body strength, and BMD.

Future studies should include more psychomotor measures potentially linked with falls, such as the body scheme or knowledge of body part impairments. Furthermore, physiological assessments, such as collecting the brain-derived neurotrophic factor levels or an electroencephalogram to evaluate more precisely the effects of a psychomotor intervention on brain neuroplasticity, can also be incorporated. Regarding the strengths of the present study, we highlight the RCT design, which included a follow-up, and the intervention length. Our study also has some limitations. First, this study followed a single-blinded design. Second, the dropout rate (14.3%) was high; however, it was lower than in other interactive cognitive–motor fall prevention programs (Schoene et al., 2015). According to the G*Power software, the sample size remained sufficient to detect significant changes, which allows the generalization of the findings to the target population. Third, participants were not randomly assigned by gender (i.e., first females, second males). Fourth, nutritional supplementation such as vitamin D intake was not controlled, allowing more efficient calcium absorption to potentialize the impact of both programs on bone mass; however, the impact of vitamin D supplementation on BMD in older adults is still inconclusive (Hill & Aspray, 2017). Lastly, despite the predominance of female participants in our study, it was less than that presented in other studies (Ng et al., 2019).

5. Conclusions

Our results suggest that both interactive cognitive–motor programs were accepted and were well tolerated by participants. They effectively improved bone mass, particularly the combined program, which evidenced additional benefits in BMC, BMD, T-Score, and Z-score. Both programs positively impacted physical and cognitive risk factors for falls and injuries. Moreover, they decreased the fall rate, suggesting successful fall and injury prevention programs in community dwellings at risk of falling. Both the psychomotor intervention program and the combined program were shown to enhance the lower-body strength and the processing speed, with similar treatment effects. After the 12-week no-intervention follow-up, the bone mass and lower-body strength improvements were reversed in EG2 and in both EGs, respectively. However, the improvements induced by both programs in processing speed remained after the detraining period, particularly in EG2. These findings highlight the potential benefits of a psychomotor intervention program as a fall prevention program. In addition, the study findings evidenced that only ~ 5 min of WBV training enhanced these benefits, mainly due to its protective effect on bone and fall-related fractures.

Funding

This work was supported by the European Fund for regional development through Horizon 2020-Portugal 2020, with respect to the "ESACA - Ageing Safety in Alentejo. Understanding for action - Project" (Grant ALT20-03-0145-FEDER-000007). In addition, this work was funded by national funds through the Foundation for Science and Technology, under the project UIDP/04923/2020, and by the doctoral fellowship (SFRH/BD/147398/2019). The funding source had no involvement in the conceptualization, analysis, or preparation of this manuscript.

Acknowledgments

The authors would like to thank all participants for their contribution to this study.

6. References

Ambrose, A. F., Paul, G., & Hausdorff, J. M. (2013). Risk factors for falls among older adults: a review of the literature. *Maturitas*, *75*(1), 51-61. https://doi.org/10.1016/j.maturitas.2013.02.009

Beck, B. R. (2015). Vibration Therapy to Prevent Bone Loss and Falls: Mechanisms and Efficacy. *Current Osteoporosis Reports*, *13*(6), 381-389. https://doi.org/10.1007/s11914-015-0294-8

Blasco-Lafarga, C., Cordellat, A., Forte, A., Roldan, A., & Monteagudo, P. (2020). Short and Long-Term Trainability in Older Adults: Training and Detraining Following Two Years of Multicomponent Cognitive-Physical Exercise Training. *International Journal of Environmental Research and Public Health*, *17*(16). https://doi.org/10.3390/ijerph17165984

Boa Sorte Silva, N. C., Gill, D. P., Owen, A. M., Liu-Ambrose, T., Hachinski, V., Shigematsu, R., & Petrella, R. J. (2018). Cognitive changes following multiple-modality exercise and mind-motor training in older adults with subjective cognitive complaints: The M4 study. *PloS One*, *13*(4), e0196356. https://doi.org/10.1371/journal.pone.0196356

Boerema, A. S., Heesterbeek, M., Boersma, S. A., Schoemaker, R., de Vries, E. F. J., van Heuvelen, M. J. G., & Van der Zee, E. A. (2018). Beneficial Effects of Whole Body Vibration on Brain Functions in Mice and Humans. *Dose-Response: A Publication of International Hormesis Society*, *16*(4), 1559325818811756. https://doi.org/10.1177/1559325818811756

Borg, G. A. (1982). Psychophysical bases of perceived exertion. *Medicine and Science in Sports and Exercise*, *14*(5), 377-381. https://doi.org/10.1249/00005768-198205000-00012

Cavaco, S., Goncalves, A., Pinto, C., Almeida, E., Gomes, F., Moreira, I., Fernandes, J., & Teixeira-Pinto, A. (2013). Trail Making Test: regression-based norms for the Portuguese population. *Archives of Clinical Neuropsychology*, *28*(2), 189-198. https://doi.org/10.1093/arclin/acs115

Cohen, J. (1998). *Statistical power analysis for the behavioral sciences*.

Craig, C. L., Marshall, A. L., Sjostrom, M., Bauman, A. E., Booth, M. L., Ainsworth, B. E., Pratt, M., Ekelund, U., Yngve, A., Sallis, J. F., & Oja, P. (2003). International physical activity questionnaire: 12-country reliability and validity. *Medicine and Science in Sports and Exercise*, *35*(8), 1381-1395. https://doi.org/10.1249/01.MSS.0000078924.61453.FB

de Souto Barreto, P., Rolland, Y., Vellas, B., & Maltais, M. (2019). Association of Long-term Exercise Training With Risk of Falls, Fractures, Hospitalizations, and Mortality in Older Adults: A Systematic Review and Meta-analysis. *JAMA Internal Medicine*, *179*(3), 394-405. https://doi.org/10.1001/jamainternmed.2018.5406

Desjardins-Crepeau, L., Berryman, N., Fraser, S. A., Vu, T. T., Kergoat, M. J., Li, K. Z., Bosquet, L., & Bherer, L. (2016). Effects of combined physical and cognitive training on fitness and neuropsychological outcomes in healthy older adults. *Clinical Interventions in Aging*, *11*, 1287-1299. https://doi.org/10.2147/cia.s115711

Di Lorito, C., Long, A., Byrne, A., Harwood, R. H., Gladman, J. R. F., Schneider, S., Logan, P., Bosco, A., & van der Wardt, V. (2021). Exercise interventions for older adults: A systematic review of meta-analyses. *Journal of Sport and Health Science*, *10*(1), 29-47. https://doi.org/10.1016/j.jshs.2020.06.003

Englund, U., Littbrand, H., Sondell, A., Pettersson, U., & Bucht, G. (2005). A 1-year combined weight-bearing training program is beneficial for bone mineral density and neuromuscular function in older women. *Osteoporosis International*, *16*(9), 1117-1123. https://doi.org/10.1007/s00198-004-1821-0

Falck, R. S., Davis, J. C., Best, J. R., Crockett, R. A., & Liu-Ambrose, T. (2019). Impact of exercise training on physical and cognitive function among older adults: a systematic review and meta-analysis. *Neurobiology of Aging*, *79*, 119-130. https://doi.org/10.1016/j.neurobiolaging.2019.03.007

Focht, B. C., Knapp, D. J., Gavin, T. P., Raedeke, T. D., & Hickner, R. C. (2007). Affective and self-efficacy responses to acute aerobic exercise in sedentary older and younger adults. *Journal of Aging and Physical Activity*, *15*(2), 123-138. https://doi.org/10.1123/japa.15.2.123

Freiberger, E., Menz, H. B., Abu-Omar, K., & Rutten, A. (2007). Preventing falls in physically active community-dwelling older people: a comparison of two intervention techniques. *Gerontology*, *53*(5), 298-305. https://doi.org/10.1159/000103256

Fritz, C. O., Morris, P. E., & Richler, J. J. (2012). Effect size estimates: current use, calculations, and interpretation. *Journal of Experimental Psychology: General*, *141*(1), 2-18. https://doi.org/10.1037/a0024338

Garber, C. E., Blissmer, B., Deschenes, M. R., Franklin, B. A., Lamonte, M. J., Lee, I. M., Nieman, D. C., Swain, D. P., & American College of Sports, M. (2011). American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. *Medicine and Science in Sports and Exercise*, *43*(7), 1334-1359. https://doi.org/10.1249/MSS.0b013e318213fefb

Gavelin, H. M., Dong, C., Minkov, R., Bahar-Fuchs, A., Ellis, K. A., Lautenschlager, N. T., Mellow, M. L., Wade, A. T., Smith, A. E., Finke, C., Krohn, S., & Lampit, A. (2021). Combined physical and cognitive training for older adults with and without cognitive impairment: A systematic review and network meta-analysis of randomized controlled trials. *Ageing Research Reviews*, *66*, 101232. https://doi.org/10.1016/j.arr.2020.101232

Gschwind, Y. J., Eichberg, S., Ejupi, A., de Rosario, H., Kroll, M., Marston, H. R., Drobics, M., Annegarn, J., Wieching, R., Lord, S. R., Aal, K., Vaziri, D., Woodbury, A., Fink, D., & Delbaere, K. (2015). ICT-based system to predict and prevent falls (iStoppFalls): results from an international multicenter randomized controlled trial. *European Review of Aging and Physical Activity*, *12*, 10. https://doi.org/10.1186/s11556-015-0155-6

Hartmann, A., Knols, R., Murer, K., & de Bruin, E. D. (2009). Reproducibility of an isokinetic strength-testing protocol of the knee and ankle in older adults. *Gerontology*, *55*(3), 259-268. https://doi.org/10.1159/000172832

Hernandez, D., & Rose, D. J. (2008). Predicting which older adults will or will not fall using the Fullerton Advanced Balance scale. *Archives of Physical Medicine and Rehabilitation*, *89*(12), 2309-2315. https://doi.org/10.1016/j.apmr.2008.05.020

Hill, T. R., & Aspray, T. J. (2017). The role of vitamin D in maintaining bone health in older people. *Therapeutic Advances in Musculoskeletal Disease*, *9*(4), 89-95. https://doi.org/10.1177/1759720X17692502

Jones, C. J., Rikli, R. E., & Beam, W. C. (1999). A 30-s chair-stand test as a measure of lower body strength in community-residing older adults. *Research Quarterly for Exercise and Sport*, *70*(2), 113-119. https://doi.org/10.1080/02701367.1999.10608028

Joubert, C., & Chainay, H. (2018). Aging brain: the effect of combined cognitive and physical training on cognition as compared to cognitive and physical training alone - a systematic review. *Clinical Interventions in Aging*, *13*, 1267-1301. https://doi.org/10.2147/CIA.S165399

Kwag, E., Stuckenschneider, T., Schneider, S., & Abeln, V. (2021). The effect of a psychomotor intervention on electroencephalography and neuropsychological performances in older adults with and without mild cognitive impairment. *Psychogeriatrics*, *21*(4), 528-539. https://doi.org/10.1111/psyg.12702

Marin-Cascales, E., Alcaraz, P. E., & Rubio-Arias, J. A. (2017). Effects of 24 Weeks of Whole Body Vibration Versus Multicomponent Training on Muscle Strength and Body Composition in Postmenopausal Women: A Randomized Controlled Trial. *Rejuvenation Research*, *20*(3), 193-201. https://doi.org/10.1089/rej.2016.1877

Marmeleira, J. (2013). An examination of the mechanisms underlying the effects of physical activity on brain and cognition. *European Review of Aging and Physical Activity*, *10*(2), 83-94. https://doi.org/10.1007/s11556-012-0105-5

Marusic, U., Verghese, J., & Mahoney, J. R. (2018). Cognitive-Based Interventions to Improve Mobility: A Systematic Review and Meta-analysis. *Journal of the American Medical Directors Association*, *19*(6), 484-491 e483. https://doi.org/10.1016/j.jamda.2018.02.002

Ng, C., Fairhall, N., Wallbank, G., Tiedemann, A., Michaleff, Z. A., & Sherrington, C. (2019). Exercise for falls prevention in community-dwelling older adults: trial and participant characteristics, interventions and bias in clinical trials from a systematic review. *BMJ Open Sport & Exercise Medicine*, *5*(1), e000663. https://doi.org/10.1136/bmjsem-2019-000663

Peng, H. T., Tien, C. W., Lin, P. S., Peng, H. Y., & Song, C. Y. (2020). Novel Mat Exergaming to Improve the Physical Performance, Cognitive Function, and Dual-Task Walking and Decrease the Fall Risk of Community-Dwelling Older Adults. *Frontiers in Psychology*, *11*, 1620. https://doi.org/10.3389/fpsyg.2020.01620

Pereira, C., Rosado, H., Cruz-Ferreira, A., & Marmeleira, J. (2018). Effects of a 10-week multimodal exercise program on physical and cognitive function of nursing home residents: a psychomotor intervention pilot study. *Aging Clinical and Experimental Research*, *30*(5), 471-479. https://doi.org/10.1007/s40520-017-0803-y

Rikli, R. E., & Jones, C. J. (2013). Development and validation of criterion-referenced clinically relevant fitness standards for maintaining physical independence in later years. *Gerontologist*, *53*(2), 255-267. https://doi.org/10.1093/geront/gns071

Rosado, H., Bravo, J., Raimundo, A., Carvalho, J., Marmeleira, J., & Pereira, C. (2021). Effects of two 24-week multimodal exercise programs on reaction time, mobility, and dual-task performance in community-dwelling older adults at risk of falling: a randomized controlled trial. *BMC Public Health*, *21*(Suppl 2), 408. https://doi.org/10.1186/s12889-021-10448-x

Sarabon, N., Kozinc, Z., Lofler, S., & Hofer, C. (2020). Resistance Exercise, Electrical Muscle Stimulation, and Whole-Body Vibration in Older Adults: Systematic Review and Meta-Analysis of Randomized Controlled Trials. *Journal of Clinical Medicine*, *9*(9). https://doi.org/10.3390/jcm9092902

Schoene, D., Valenzuela, T., Toson, B., Delbaere, K., Severino, C., Garcia, J., Davies, T. A., Russell, F., Smith, S. T., & Lord, S. R. (2015). Interactive Cognitive-Motor Step Training Improves Cognitive Risk Factors of Falling in Older Adults - A Randomized Controlled Trial. *PloS One*, *10*(12), e0145161. https://doi.org/10.1371/journal.pone.0145161

Senderovich, H., & Tsai, P. M. (2020). Do Exercises Prevent Falls Among Older Adults: Where Are We Now? A Systematic Review. *Journal of the American Medical Directors Association*, *21*(9), 1197-1206 e1192. https://doi.org/10.1016/j.jamda.2020.05.010

Shepherd, J. A., Ng, B. K., Sommer, M. J., & Heymsfield, S. B. (2017). Body composition by DXA. *Bone*, *104*, 101-105. https://doi.org/10.1016/j.bone.2017.06.010

Sipila, S., Tirkkonen, A., Savikangas, T., Hanninen, T., Laukkanen, P., Alen, M., Fielding, R. A., Kivipelto, M., Kulmala, J., Rantanen, T., Sihvonen, S. E., Sillanpaa, E., Stigsdotter Neely, A., & Tormakangas, T. (2021). Effects of physical and cognitive training on gait speed and cognition in older adults: A randomized controlled trial. *Scandinavian Journal of Medicine and Science in Sports*, *31*, 1518-1533. https://doi.org/10.1111/sms.13960

Smith-Ray, R. L., Hughes, S. L., Prohaska, T. R., Little, D. M., Jurivich, D. A., & Hedeker, D. (2015). Impact of Cognitive Training on Balance and Gait in Older Adults. *Journals of Gerontology. Series B: Psychological Sciences and Social Sciences*, *70*(3), 357-366. https://doi.org/10.1093/geronb/gbt097

Sprague, B. N., Phillips, C. B., & Ross, L. A. (2021). Cognitive Training Attenuates Decline in Physical Function Across 10 Years. *Journals of Gerontology. Series B: Psychological Sciences and Social Sciences*, *76*(6), 1114-1124. https://doi.org/10.1093/geronb/gbaa072

Tomás, R., Lee, V., & Going, S. (2011). The Use of Vibration Exercise in Clinical Populations. *ACSM's Health & Fitness Journal*, *15*(6), 25-31. https://doi.org/10.1249/FIT.0b013e31823373e8

Tricco, A. C., Thomas, S. M., Veroniki, A. A., Hamid, J. S., Cogo, E., Strifler, L., Khan, P. A., Robson, R., Sibley, K. M., MacDonald, H., Riva, J. J., Thavorn, K., Wilson, C., Holroyd-Leduc, J., Kerr, G. D., Feldman, F., Majumdar, S. R., Jaglal, S. B., Hui, W., & Straus, S. E. (2017). Comparisons of Interventions for Preventing Falls in Older Adults: A Systematic Review and Meta-analysis. *JAMA*, *318*(17), 1687-1699. https://doi.org/10.1001/jama.2017.15006

von Stengel, S., Kemmler, W., Engelke, K., & Kalender, W. A. (2011). Effects of whole body vibration on bone mineral density and falls: results of the randomized controlled ELVIS study with postmenopausal women. *Osteoporosis International*, *22*(1), 317-325. https://doi.org/10.1007/s00198-010-1215-4

World Health Organization. (2018). *Falls*. https://www.who.int/news-room/fact-sheets/detail/falls

Yoshihara, S., Kanno, N., Fukuda, H., Arisaka, O., Arita, M., Sekine, K., Yamaguchi, K., Tsuchida, A., Yamada, Y., Watanabe, T., Shimizu, T., Nishikawa, K., & Nishimuta, T. (2015). Caregiver treatment satisfaction is improved together with children's asthma control: Prospective study for budesonide monotherapy in school-aged children with uncontrolled asthma symptoms. *Allergology International*, *64*(4), 371-376. https://doi.org/10.1016/j.alit.2015.05.010

Paper 3

Can two multimodal psychomotor exercise programs improve attention, affordance perception, and balance in community dwellings at risk of falling? A randomized controlled trial

Hugo Rosado[1,2]*, Jorge Bravo[1,2], Armando Raimundo[1,2], Joana Carvalho[3,4], Gabriela Almeida[1,2], Catarina Pereira[1,2]

[1] Departamento de Desporto e Saúde, Escola de Saúde e Desenvolvimento Humano, Universidade de Évora, Évora, Portugal.

[2] Comprehensive Health Research Centre (CHRC), Universidade de Évora, Évora, Portugal.

[3] Faculdade de Desporto, Universidade do Porto, Porto, Portugal.

[4] CIAFEL - Research Centre in Physical Activity, Health and Leisure, Universidade do Porto, Portugal.

* Corresponding author: hrosado@uevora.pt

Abstract

Background: Falls are associated with cognitive and physical function deterioration. Attention decline, inaccurate affordance perception, and balance impairment are considered to be risk factors for falls. Furthermore, few studies have reported psychomotor intervention as a fall prevention program. This study aimed to investigate the effects of two multimodal programs on attention, perceptual and stepping-forward boundaries, and balance in community-dwelling older adults at risk of falling.

Methods: Fifty-one community-dwelling older adults were recruited to participate in a 24-week randomized controlled trial. Participants (75.4 ± 5.6 years) were randomly assigned to one of three groups: the 1) multimodal psychomotor program [EG1], 2) combined program (multimodal psychomotor program + whole-body vibration program) [EG2], and 3) control group. Participants were assessed at baseline, at post-intervention, and after a 12-week no-intervention follow-up period.

Results: The within-group comparisons showed significant improvements in attention and balance in EG1 and EG2 after the intervention ($p < 0.05$). The magnitudes of the treatment effects were similar in both EGs, ranging from medium to large. Decreases in the fall rate were also observed in EG1 (−44.2%) and EG2 (−63.0%) ($p < 0.05$). During the follow-up period, these improvements in attention were maintained, while those in balance were reversed in both EGs. No significant differences between groups were found.

Conclusions: These study results suggest that both multimodal exercise programs were effective for fall prevention and were well tolerated by the participants. Specifically, EG1 and EG2 showed identical improvements in attention, and EG2 presented a slightly larger enhancement in balance and a larger decrease in the fall rate. Our findings demonstrate the benefits of maintaining the psychomotor intervention program by itself or in combination with the whole-body vibration program to prevent cognitive and physical function deterioration.

Keywords: Older adults, Falls, Psychomotor intervention, Whole-body vibration, Exercise therapy and rehabilitation, Action boundary

1. Introduction

According to the United Nations, the number of older adults aged 65 years or over is increasing faster than all other age groups (United Nations, 2019). Following this trend, the aging process is related to an increase in falls, such that one-third of community-dwelling older adults aged 65 years or more, experience at least one fall each year, resulting in substantial economic costs (Fernandez et al., 2019). This evidence highlights the importance of developing effective strategies and programs to prevent fall occurrences and manage fall risk factors to maintain independence and quality of life (Fernandez et al., 2019; Wollesen et al., 2020).

Related to the aging process, a link has been established between cognitive decline and fall risk since cognitive function and motor maintenance share restricted neural resources (Robinson & Kiely, 2017). Within cognitive function abilities, attention is a specific element of executive functions (EF) (Nagamatsu et al., 2011). Evidence from neuroimaging studies focusing on structural or physiological changes (e.g., cerebral white matter and brain volume) suggests that a decline in EF is related to an increased fall risk (Nagamatsu et al., 2013; Nagamatsu et al., 2011). According to O'Halloran et al. (O'Halloran et al., 2011), brain changes promote a larger variability in sustained attention, which is strongly associated with fall risks. Additionally, the selective attention described as a fundamental EF has also been related to falls (Nagamatsu et al., 2013).

Similarly, age-associated locomotor skills deterioration can lead to inaccurate perceived action limits, whereby it is essential to recognize the respective action boundary (e.g., perceptual and stepping-forward boundary), especially in community-dwelling older adults (Almeida et al., 2019). Accordingly, affordances, that is, possibilities for action, are a concept involving the relationship between the action possibilities of the individual (e.g., maximum stepping-forward length) under a particular set in an environment (Gibson, 1977; Jeschke et al., 2020). However, recent literature has shown that older adults frequently overestimate their motor abilities, specifically their action boundary as a step length (Almeida et al., 2019). This is particularly relevant and especially true for fallers because those who overestimate their step length reveal more signs of motor deterioration, which can lead to an increase in fall risk (Almeida et al., 2019; Caffier et al., 2019). Moreover, perceptual overestimation can also potentially induce balance impairment and consequent falls (Caffier et al., 2019). Despite the previous findings, no experimental studies on fall prevention programs were found focusing on affordance perception, particularly the perceived and real action boundary, enhancing the need for further investigations.

Additionally, balance impairment is related to falls and is one of the most often used and recommended components for integration into fall prevention programs as well as one of the most effective at reducing the rate and risk of falling, especially when incorporated into multimodal exercise programs (Sherrington et al., 2019).

The body and brain adapt in response to consistent cognitive and physical stimuli (Robinson & Kiely, 2017). In this line, previous studies have proposed the concept of neuroplasticity over aging (Pereira et al., 2018), with the possibility for older people to improve their performance through single or combined cognitive-motor intervention programs. Nevertheless, the potential improvements in fall prevention programs depend on the type of tasks and training proposed (Sherrington et al., 2019; Wollesen et al., 2020). Single cognitive training programs such as computer-based cognitive training can positively induce improvements in motor control, specifically in locomotor coordination, reducing fall risk (Robinson & Kiely, 2017). Likewise, exercise alone (e.g., balance training and functional exercises) is also considered effective at reducing the rate of falls (23%) and the number of fallers (15%) (Sherrington et al., 2019). However, the current literature suggests that a combined intervention focusing on cognitive and motor exercise challenges may promote additional benefits (Kao et al., 2018; Raichlen et al., 2020). Despite this, few studies concerning this cognitive-motor interactive training on risk factors for falls have been carried out (Wang et al., 2015), highlighting the need for further investigations, particularly on community-dwelling older adults.

In this line, evidence supports the use of psychomotor interventions focusing on the body and movement as a means for expression to enhance the cognitive, motor, and relational aspects of psychomotor aging (Probst et al., 2010). Specifically, a psychomotor intervention may induce improvements in the age-related deterioration of the previous processes (Pereira et al., 2018). However, there is a lack of studies focusing on psychomotor intervention as a fall prevention program (Freiberger et al., 2007). Likewise, whole-body vibration (WBV) has been shown to be effective in improving balance in older adults through neurophysiological mechanisms (i.e., the mechanical vibration conducted to the body, in association with the respective biological effects), reducing the risk and incidence of falls (Bemben et al., 2018; Orr, 2015). This method may also lead to an enhancement of EF (Regterschot et al., 2014). However, to our knowledge, an intervention program that combines both methods has not yet been studied, particularly on fall prevention programs. Thus, the objective of this study was to investigate the effects of two multimodal programs on attention, perceptual and stepping-forward boundaries, and balance in community-dwelling older adults at risk of falling.

2. Methods

2.1. Trial design

The present study was designed as a 24-week randomized controlled trial (RCT), single-blinded, with a three-arm parallel assignment. Community-dwelling older adults from Évora (Portugal) were allocated into three groups (allocation ratio 1:1:1): experimental group 1 (EG1) was assigned a multimodal psychomotor program; experimental group 2 (EG2) was assigned a combined program (multimodal psychomotor program + WBV); and the control group (CG) was asked to maintain their daily life activities. After the study finished, those in the CG were offered an identical fall prevention program. This trial was conducted between March 2018 and January 2019, and it was previously registered at ClinicalTrials.gov (NCT03446352). Also, this study was reported in accordance with the CONSORT guidelines for RCTs (http://www.consort-statement.org).

2.2. Participants

Participants were male and female community-dwelling older adults recruited in community settings as the local senior university and recreational centers via pamphlets. In each community setting, verbal communication was used to present our study and for answers to any possible doubts. The older adults who expressed interest to participate were scheduled for the baseline evaluation.

A minimum sample size of 45 participants was required (15 participants per group) to detect a treatment difference, calculated by the online G*Power software, under the following parameters: $\alpha = 0.05$ and power = 0.95. Accounting for an expected dropout rate of 20%, a minimum of 60 participants were recruited for this study.

The inclusion criteria comprised the following: a) age ≥ 65 years old; b) classified with moderate or high physical independence according to the Composite Physical Function (CPF) scale (≥ 18 points) (Rikli & Jones, 2013); c) participants who had experienced at least one fall in the previous six months or were identified with a high risk of falling according to the result in the Fullerton Advanced Balance (FAB) scale (≤ 25 points)

(Hernandez & Rose, 2008). Exclusion criteria comprised: a) cognitive impairment; b) walking dependently (e.g., with mobility aids); c) musculoskeletal, cardiovascular, and neurological conditions (Tomás et al., 2011); and d) attending physical and/or cognitive structured exercise programs preceding six months (Focht et al., 2007).

Initially, sixty-one older adults were assessed for eligibility and agreed to participate in the study as described in Figure 5. Five participants did not fulfill the inclusion criteria, which remained a total of fifty-six participants (47 women and 9 men). For participants who were enrolled in this study, simple randomization was performed according to the "Random Team Generator" (https://www.randomlists.com/team-generator) into EG1 (n = 18), EG2 (n = 19), and CG (n = 19). An investigator with no clinical involvement in the trial performed the randomization.

All the study participants were volunteers and gave their written informed consent. This study was approved by the University of Évora Ethics Committee - Health and Well Being (reference number 16012) and conducted in accordance with the Declaration of Helsinki.

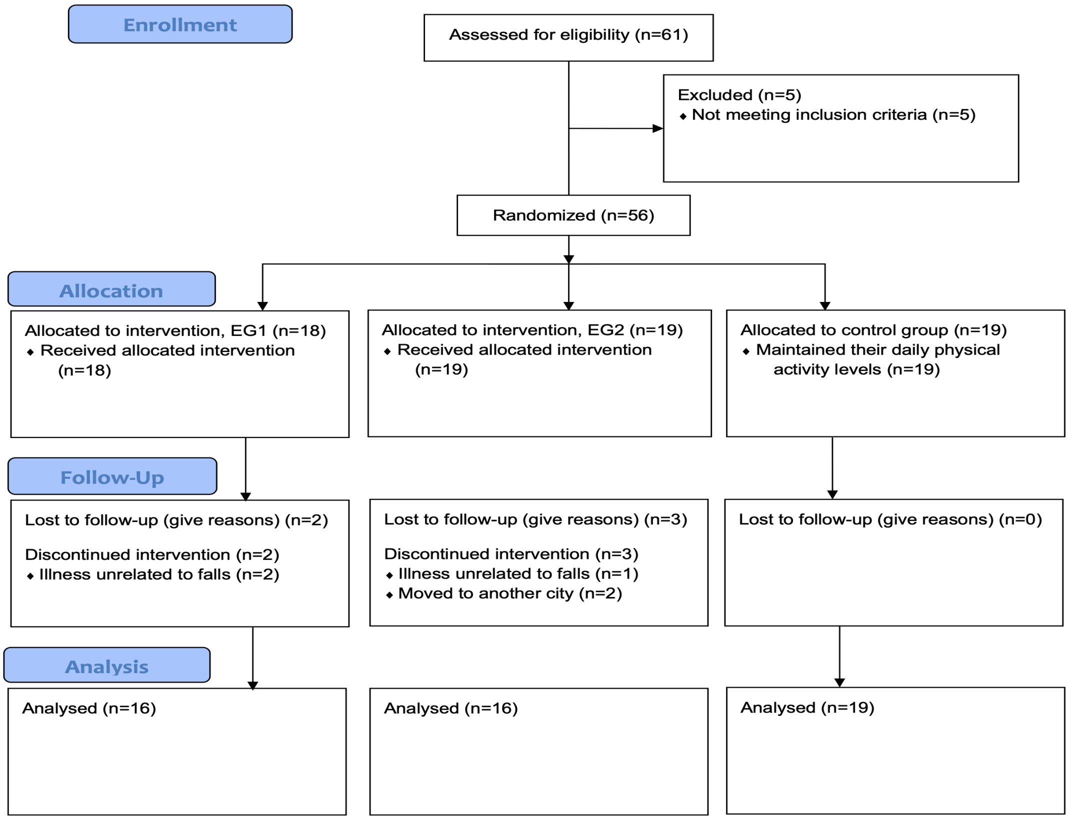

Figure 5. Flow diagram.

2.3. Procedures

A trained evaluator in the rehabilitation sciences field individually assessed all participants at baseline, at post-intervention (24 weeks), and after a 12-week no-intervention follow-up. The evaluator was blinded to participants' allocation. Cognitive and other measures assessed by questionnaires were performed in a laboratory silent room. Affordance perception, physical function and body composition assessments were performed in a laboratory hall. All assessments were preceded by the protocoled explanation and/or demonstration performed by the evaluator.

Data collection was performed at the University of Évora laboratories.

2.4. Outcome measures

2.4.1. Attention

Selective and sustained attention was assessed by the d2 Test of Attention, which was demonstrated to be a valid and reliable measurement in older people (Brickenkamp, 2007). Participants had 20 s in each of the 14 lines of the test to identify and mark the letter "d" with two dashes (above or below the letter), as quickly as possible. Measures of performance comprised items processed (n); items recognized correctly (n); total efficacy (n), which indicates the relationship between speed and thoroughness in the task; concentration index (n), which reflects the ability to concentrate; fluctuation rate (n), which indicates the consistency in the task execution; and percentage of errors (%).

2.4.2. Affordance perception

The perceptual and stepping-forward boundary was assessed by the stepping-forward affordance perception test, established as a valid, accurate, and reliable tool for fall risk assessment in community-dwelling older adults (Almeida et al., 2019). The estimated stepping-forward and real stepping-forward distances were collected as described by Almeida et al. (Almeida et al., 2019). In addition, the absolute error (|real-estimated distances|) and the error tendency measuring the magnitude and direction error (overestimation: real < estimated distances; or underestimation: real > estimated distances), (over- or underestimation) were also computed.

2.4.3. Balance

Multidimensional balance was assessed by the FAB scale, which is considered a valid and reliable instrument designed to assess independently living older adults. This scale comprises 10 individual tests, such that each one ranged from 0 (worst) to 4 points (best), and the "Total FAB scale" (sum of the test scores) ranged from 0 (worst) to 40 points (best) (Hernandez & Rose, 2008).

2.4.4. Falls

The occurrence of falls, respective circumstances (e.g., type/place of fall), and consequent injuries were assessed by means of an interview following a 13-item script, although only the occurrence of falls was used in this manuscript. A fall was defined in accordance with the definition proposed by the World Health Organization "as *an event which results in a person coming to rest inadvertently on the ground or floor or other lower level*" (World Health Organization, 2018). The number of fall occurrences in the previous 6 months was recorded retrospectively at baseline and at post-intervention.

2.4.5. Secondary outcomes measures

Each session exercise intensity was assessed by the Borg Rating of Perceived Exertion scale, ranging from "very, very light" (6 points) to "very, very hard" (20 points), measured (Borg, 1982). Satisfaction level achieved through each exercise session was assessed by the Caregiver Treatment Satisfaction (CTS) questionnaire, ranging from "extremely dissatisfied" (1 point) to "extremely satisfied" (5 points) (Yoshihara et al., 2015). Sociodemographic characteristics were assessed through an interview based on a script. Body mass index was calculated by dividing weight by height squared (kg/m^2), in which the participant´s height (m) was measured shoeless in a stadiometer (Seca 206, Hamburg, Germany), and the weight (kg) was measured using an electronic scale (Seca 760, Hamburg, Germany). Physical independence was assessed by the CPF scale, ranging from 0 (worst) to 24 points (best) (Rikli & Jones, 2013). Based on the previous 12-item CPF scale score, participants were classified as low functioning (< 18 points), moderate functioning (18 - 23 points), and high functioning (24 points). Finally, physical activity (the sum of walking, moderated and vigorous physical activity) was assessed by the International Physical Activity Questionnaire (IPAQ) using the metabolic equivalent of task ([MET]-min/week), calculated as activity duration*frequency per week*MET intensity (Craig et al., 2003).

2.5. Multimodal exercise programs

Participants randomly engaged in one of the two EGs (3x/week on non-consecutive days; 75 min/session). Each EG was divided into two classes, without differences, with up to 10 participants. A master's degree therapist in psychomotor therapy planned and directed both EG sessions under the supervision of a university Sports Sciences professor. The therapist who planned and operationalized both exercise intervention programs did not participate in the assessments. When the EGs participants were absent for 3 consecutive sessions, the missed sessions were rescheduled to maintain the established attendance level (≥ 80%).

EG1 assigned a multimodal psychomotor program, with 75-minute sessions, that privileged the body and movement as mediators. This program integrated simultaneous neurocognitive (focusing on executive function training) and motor (focusing on physical fitness performance) stimulation through several exercises designed to promote general physiological and specific neurophysiological stress in the involved mechanisms. EG2 assigned a combined program (multimodal psychomotor program + WBV program; starting with 72 + 3 min/session and ending with 69 + 6 min/session, respectively). The time allocated to the WBV program was proportionally withdrawn from each phase of the multimodal psychomotor program. Regarding the WBV program performance, the participants stood shoeless on the side-alternating vibratory platform (Galileo® Med35) in a semi-squat position. The exercise time ranging from 45 to 60 (s), the number of series ranging from 4 to 6, and the frequency ranging from 12.6 to 15 Hz progressively increased over intervention. The amplitude (3 mm) and resting time between series (60 s) remained equal throughout the intervention.

The complexity and intensity of both programs increased with sessions (planned for moderate intensity: until approximately 13 points at RPE scale). Each session was divided into 5 phases: beginning ritual (~ 5 min), warm-up (~ 10 min), main section (~ 50 min), cool down (~ 5 min), and a finishing ritual (~ 5 min). After a neuromuscular activation warm-up, the main section was implemented, comprising multimodal exercises. In this phase, neurocognitive-, motor-, and sensorial-specific exercises promoting simultaneous cognitive (e.g., attention - to assign different commands to different actions), perceptual (e.g., motor planning - to imagine geometric figures on the floor and then execute the movement), and motor (e.g., balance - body sport balance disc and fitball exercises to change the base of support) stimulation were performed on identical alternated periods

(10 - 15 min). During the cool-down, relaxation techniques and exercises involving body awareness/scheme were performed. Finally, at the finishing ritual, participants recorded intensity and satisfaction levels through the RPE scale and CTS questionnaire, respectively.

2.6. Data analysis

To ensure participant confidentiality and anonymity, a code was attributed to each participant. Data were analyzed using the SPSS software (v. 24.0, IBM SPSS Inc.). The significance level for all the statistical analyses was established at $p < 0.05$.

Descriptive data are expressed in terms of the mean and standard deviation (SD) for quantitative variables and frequency (%) for categorical variables. Differences (Δ) between each evaluation moment (baseline, post-intervention, and follow-up) were calculated for all variables by the formula $\Delta = \text{moment}_x - \text{moment}_{x-1}$, and the proportional changes were computed such as $\Delta\% = [(\text{moment}_x - \text{moment}_{x-1})/\text{moment}_{x-1}] \times 100$).

The Kolmogorov-Smirnov test and Levene homogeneity of variances test were used to evaluate the normality of the data distribution. Since much of the data were not normally distributed, non-parametric tests were performed, namely, the Friedman test for comparisons within groups followed by the related pairwise post hoc test and the Kruskal-Wallis test for comparisons between groups followed by the independent pairwise post hoc test. In the case of two related samples, the Wilcoxon test was carried out for within-group comparisons. Additionally, to perform comparisons regarding qualitative variables (error tendency variables), Cochran's Q test was used for within-group comparisons, and the chi-squared test was used for between-group comparisons.

The magnitude of the treatment effect was determined following the instructions for non-parametric tests (Fritz et al., 2012) and according to Cohen's method, in which the effect size (ES) was computed as $r = (Z/\sqrt{N})$. Standardized classification for small (0.10), medium (0.30), and large (0.50) effects was used (Cohen, 1998).

3. Results

Table 11 provides the participants' characteristics at baseline and no significant differences between groups were found.

Table 11. Participant's characteristics at baseline.

	EG1 Prevalence or Mean ± SD	**EG2 Prevalence or Mean ± SD**	**CG Prevalence or Mean ± SD**	***p*-value**
Age (years)	74.3 ± 5.4	74.7 ± 5.5	76.8 ± 5.8	0.407
Sex, female (%)	14 (87.5)	15 (93.8)	13 (68.4)	0.124
Educational level (years)	6.0 ± 2.6	6.1 ± 3.4	7.0 ± 5.3	0.997
Body mass index (kg/m^2)	29.1 ± 3.0	28.6 ± 4.3	28.1 ± 4.4	0.648
Physical independence (points)	21.5 ± 2.7	20.8 ± 2.2	21.5 ± 2.8	0.554
Physical activity (MET-min/week)	927.0 ± 557.9	953.4 ± 638.5	740.4 ± 520.9	0.611
Number of falls within the last six months (n)	1.13 ± 0.8	1.19 ± 1.0	1.11 ± 0.3	0.993

SD: standard deviation; EG1: experimental group attending the multimodal psychomotor program (n = 16); EG2: experimental group attending the combined program: multimodal psychomotor program + WBV (n = 16); GC: control group (n = 19). Significant differences between groups, $p < 0.05$.

A total of fifty-one participants completed this RCT study. Those who dropped out of the study (n = 5) had similar characteristics compared to participants who completed the multimodal exercise programs. Regarding the attendance sessions, both EGs met the established attendance level, with similar results on the 75 sessions (EG1: 82.3% vs. EG2: 84.3%). Regarding the tolerability and satisfaction level of the multimodal exercise programs, both EGs had identical results, as shown by the RPE scale (EG1: 12.9 ± 0.4 vs. EG2: 13.2 ± 0.3) and CTS questionnaire (EG1: 4.98 ± 0.3 vs. EG2: 4.99 ± 0.1), respectively.

Table 12 presents the results for cognitive function, namely, selective and sustained variables. At baseline, all groups presented similar results, and no statistically significant differences were found between groups in cognitive variables. On post-intervention evaluation and on follow-up evaluation, between-group comparison did not detect significant differences between the three study groups in these variables.

The within-group comparisons showed significant improvements between the baseline and post-intervention evaluations in both EGs, particularly in the variables "Items processed", "Items recognized correctly", "Total efficacy", and "Concentration index". Specifically, both EGs increased the total number of items processed in the variable "Items processed" (Δ% EG1: 14.7%, $p = 0.014$; Δ% EG2: 14.4%, $p = 0.006$), improved the efficacy of performing the task in the variable "Total efficacy" (Δ% EG1: 17.2%, p = 0.006; Δ% EG2: 16.3%, p = 0.001), and increased the concentration in the variable "Concentration index" (Δ% EG1: 17.8%, p = 0.003; Δ% EG2: 19.0%, p = 0.001). Significant improvements were also found by correctly identifying more "d" letters with 2 dashes in the variable "Items recognized correctly" (Δ% EG2: 18.3%, p = 0.001). Similarly, the post hoc test pairwise comparisons revealed significant differences in the same variable, "Items recognized correctly" (Δ% EG1: 13.9%, p = 0.022). Furthermore, significant improvements between the baseline and the follow-up evaluations were found in the variables described above, namely, in "Items processed" (Δ% EG1: 13.4%, p = 0.040; Δ% EG2: 13.3%, p = 0.003), in "Items recognized correctly" (Δ% EG2: 16.8%, p = 0.001), in "Total efficacy" (Δ% EG1: 15.2%, p = 0.018; Δ% EG2: 14.0%, p = 0.002), and in "Concentration index" (Δ% EG1: 14.4%, p = 0.031; Δ% EG2: 18.5%, p = 0.002). In addition, the post hoc test pairwise comparisons showed significant differences in the variable "Fluctuation rate" in the CG (Δ%: −20.8%, p = 0.043). Regarding the ES within-groups between the baseline and the post-intervention evaluations, from the previous variables, it ranged from 0.47 (medium) to 0.54 (large), in EG1, and from 0.48 (medium) to 0.51 (large), in EG2, while between the baseline and the follow-up evaluation ranged from 0.43 (medium) to 0.52 (large), in EG1 and was medium (0.48), in EG2.

Table 12. Impact of the multimodal exercise programs in selective and sustained attention variables.

		Baseline (A) (Mean ± SD)	**Post-intervention (B) (Mean ± SD)**	**Follow-up (C) (Mean ± SD)**	**p-value[a]**	**Pairwise Comparison**
Selective and sustained attention						
Items processed (n)						
	EG1	254.8 ± 68.0	292.3 ± 86.9	288.8 ± 82.9	0.009	A < B, C
	EG2	265.1 ± 78.2	303.3 ± 82.8	300.4 ± 91.5	0.001	A < B, C
	CG	244.8 ± 75.5	250.0 ± 81.2	249.9 ± 78.1	0.854	--
	p-value[b]	0.855	0.204	0.210		
Items recognized correctly (n)						
	EG1	96.6 ± 27.2	110.0 ± 37.3	108.9 ± 35.5	0.047	--
	EG2	101.8 ± 36.2	120.4 ± 33.9	118.8 ± 36.9	< 0.001	A < B, C
	CG	95.5 ± 34.8	95.0 ± 39.8	99.8 ± 36.2	0.076	--
	p-value[b]	0.893	0.160	0.295		
Total efficacy (n)						
	EG1	236.3 ± 70.3	276.9 ± 90.5	272.2 ± 85.7	0.003	A < B, C
	EG2	251.2 ± 81.2	292.2 ± 84.3	286.4 ± 92.1	< 0.001	A < B, C
	CG	227.3 ± 73.9	228.6 ± 84.9	234.3 ± 80.2	0.076	--
	p-value[b]	0.801	0.136	0.312		
Concentration index (n)						
	EG1	90.0 ± 32.1	105.9 ± 40.6	103.0 ± 38.0	0.002	A < B, C
	EG2	97.8 ± 38.2	116.3 ± 36.3	115.8 ± 39.3	< 0.001	A < B, C
	CG	89.9 ± 38.1	88.3 ± 44.7	96.1 ± 39.1	0.141	--
	p-value[b]	0.858	0.143	0.293		
Fluctuation rate (n)						
	EG1	11.1 ± 2.6	12.6 ± 3.3	11.1 ± 3.5	0.207	--
	EG2	12.7 ± 6.0	10.3 ± 2.6	10.4 ± 3.1	0.637	--
	CG	12.9 ± 4.9	11.8 ± 4.6	10.2 ± 3.2	0.047	--
	p-value[b]	0.262	0.182	0.575		
Percentage of errors (%)						
	EG1	7.8 ± 6.9	6.2 ± 5.6	6.6 ± 5.5	0.895	--
	EG2	6.0 ± 5.3	4.2 ± 3.8	5.3 ± 5.8	0.611	--

	CG	7.7 ± 6.0	10.4 ± 9.3	7.6 ± 7.3	0.141	--
	p-value[b]	0.549	0.068	0.423		

SD: standard deviation; EG1: experimental group attending the multimodal psychomotor program (n = 16); EG2: experimental group attending the combined program: multimodal psychomotor program + WBV (n = 16); CG: control group (n = 19); [a] within-group comparisons; [b] between-group comparisons. <: significant differences within groups, $p < 0.05$.

Table 13 shows the results for the affordance perception and physical function - multidimensional balance - variables. At baseline, all groups presented similar results, and no statistically significant differences were found between groups on the perceptual and stepping-forward boundary variables or on multidimensional balance. On post-intervention evaluation and on follow-up evaluation, between-group comparison did not detect significant differences between the three study groups in these variables.

As seen in Table 13, the within-group comparison showed no significant differences between the three evaluation data on perceptual and stepping-forward boundary variables, except in the variable "Error tendency". Cochran's Q test revealed significant differences in the variable "Error tendency" in both EGs at the follow-up evaluation, in which an increase in the number of participants overestimating the perceived stepping-forward boundary was observed.

The within-group multidimensional balance variable comparison showed significant improvements between baseline and post-intervention in both EGs. As shown in Table 13, after the 24-week intervention, EG1 improved by approximately 4.4 more points (Δ% = 16.2%, $p < 0.001$). Similar results in the same variable had EG2, which improved by approximately 4.8 more points (Δ% = 17.4%, $p < 0.001$). Additionally, differences between the post-intervention and follow-up evaluations were also observed in this variable, in which both EGs showed a worse score in the follow-up evaluation than in the post-intervention evaluation (Δ% EG1: −7.9%, $p = 0.018$; Δ% EG2: −7.7%, $p = 0.011$). The respective ES between the baseline and post-intervention evaluations was large in EG1 (r: 0.60) and EG2 (r: 0.62). Between the post-intervention and follow-up evaluations, the ES was also large (r: 0.59) in both EGs, representing a considerable decrease in performance.

Table 13. Impact of the multimodal exercise programs in the affordance perception and balance variables.

		Baseline (A) Prevalence or Mean ± SD	**Post-intervention (B) Prevalence or Mean ± SD**	**Follow-up (C) Prevalence or Mean ± SD**	**p-value[a]**	**Pairwise Comparison**
Perceptual and stepping-forward boundary						
Estimated stepping-forward (cm)						
	EG1	53.1 ± 10.4	53.5 ± 14.0	54.1 ± 12.1	0.779	--
	EG2	56.3 ± 12.6	58.4 ± 9.5	60.2 ± 13.3	0.051	--
	CG	61.3 ± 13.5	58.5 ± 11.8	55.6 ± 13.4	0.340	--
	p-value[b]	0.069	0.178	0.454		
Real stepping-forward (cm)						
	EG1	60.6 ± 17.8	64.8 ± 15.3	62.9 ± 14.0	0.156	--
	EG2	65.7 ± 10.9	67.3 ± 11.7	66.5 ± 15.0	0.432	--
	CG	69.5 ± 16.5	64.4 ± 19.4	61.7 ± 18.4	0.157	--
	p-value[b]	0.339	0.878	0.734		
Absolute Error (cm)						
	EG1	10.4 ± 8.0	11.4 ± 8.5	11.0 ± 8.7	0.528	--
	EG2	9.4 ± 6.5	10.3 ± 6.0	9.2 ± 7.1	0.939	--
	CG	8.8 ± 7.5	9.9 ± 7.1	10.0 ± 6.4	0.555	--
	p-value[b]	0.644	0.928	0.852		
Error tendency (%)						
Overestimation	EG1	12.5	6.3	31.3	0.039	--
Underestimation		87.5	93.8	68.8		--
Overestimation	EG2	0	12.5	31.3	0.042	--
Underestimation		100	87.5	68.8		--
Overestimation	CG	15.8	31.6	31.6	0.276	--
Underestimation		84.2	68.4	68.4		--
	p-value[b]	0.199	0.199	0.223		
Multidimensional balance (points)						
	EG1	27.1 ± 4.9	31.5 ± 3.7	29.0 ± 4.7	< 0.001	B > A, C
	EG2	27.6 ± 5.1	32.4 ± 4.1	29.9 ± 4.9	< 0.001	B > A, C
	CG	29.7 ± 3.2	29.5 ± 3.7	28.9 ± 3.5	0.351	--

p-value[b]	0.248	0.054	0.751

SD: standard deviation; EG1: experimental group attending the multimodal psychomotor program (n = 16); EG2: experimental group attending the combined program: multimodal psychomotor program + WBV (n = 16); CG: control group (n = 19); [a] within-group comparisons; [b] between-group comparisons. <: significant differences within groups, $p < 0.05$.

Last, concerning the number of falls, at baseline, all groups presented similar results, and no statistically significant differences were found between groups in the number of falls. The within-group comparison analysis indicated significant improvements by reducing the number of falls between the baseline and post-intervention evaluations (fall number EG1: 1.13 ± 0.8 vs. 0.63 ± 0.7, $p = 0.021$; fall number EG2: 1.19 ± 1.0 vs. 0.44 ± 0.7, $p = 0.008$). In turn, no differences were observed in the CG (1.11 ± 0.3 vs. 0.95 ± 1.0, $p = 0.405$).

4. Discussion

The present study aimed to investigate the effects of two multimodal exercise programs on attention, affordance perception, and balance in community-dwelling older adults at risk of falling. First, both the multimodal psychomotor program and the combined program (multimodal psychomotor program + WBV program) were demonstrated to be effective for fall prevention and were well tolerated. Second, results suggested that both programs induced significant improvements in cognitive and physical risk factors for falls, particularly in regards to attention and multidimensional balance, with similar treatment effect magnitudes. These results complement recent literature knowledge suggesting that combined programs may potentialize the benefits of interventions designed for older adults (Kao et al., 2018), particularly in regards to risk factors for falls (Raichlen et al., 2020; Wang et al., 2015). In particular, our findings showed similar improvements in attention in both EGs and a slightly larger enhancement in balance in EG2. The improvements found in the present study were also observed concerning the number of falls, with a significant decrease in the fall rate in EG1 and especially in EG2, which showed a larger decrease. Furthermore, after a 12-week no-intervention follow-up period, these improvements in both EGs were maintained in attention and were reversed on balance.

The adherence rate in our EGs study (83.3%) was in line with other fall prevention programs (Sherrington et al., 2019). In the same way, the EGs participants in the present study reported similar levels on the Borg Rating of Perceived Exertion scale (moderate intensity) compared to those reported in a previous study (Linde & Alfermann, 2014). Likewise, the satisfaction level shown in EG1 (4.98 ± 0.3) and EG2 (4.99 ± 0.1) in the current study was identical to the results reported in Linde and Alfermann (Linde & Alfermann, 2014).

For cognitive function, the within-group comparisons showed that both multimodal exercise programs induced improvements in selective and sustained attention variables, with an ES ranging from medium to large. Few studies have used the d2 Test of Attention in community-dwelling older adults. In this line, the 16-week study of Linde and Alferman (Linde & Alfermann, 2014) showed improvements in the concentration index in the physical, cognitive, and combined (physical + cognitive) groups compared to the CG. However, the cognitive group had a larger ES (0.88) than the combined (0.64) or physical (0.51) groups. Although few studies have shown cognitive benefits of a WBV program (Regterschot et al., 2014), no additional benefits were found in EG2. The improvements in attention variables in our multimodal exercise programs could be explained by the fact that combined interventions promoting simultaneous dual task activities (cognitive + motor tasks) may promote additional benefits (Raichlen et al., 2020), and could provide changes in the prefrontal cortex, which is considered an area age-sensitive to changes in several cognitive domains such as attention (Fraser et al., 2017). Also, combined interventions could lead to a reduction in attention demand (Jehu et al., 2018). The findings at the 12-week follow-up period of the present study are consistent with the 12-week follow-up study of Jehu, Paquet and Lajoie (Jehu et al., 2018), in which the physical and combined (physical + cognitive) groups improved EF, reducing the attention demand, and sustained these enhancements at the follow-up. Additionally, our study findings showed that the variable “total efficacy” was the only variable that remained with a large ES within EG1. However, contrary to the 12-week follow-up study of Linde and Alfermann (Linde & Alfermann, 2014), in which only the physical group retained improvements in the concentration index, our study’s EGs maintained their results in selective and sustained attention.

Concerning the affordance perception variables, the within-group comparisons at the follow-up evaluation showed an increase in the overestimation values (error tendency) only in the EGs. Starting with the error tendency results, at baseline, all groups underestimated more the perception-action ability, especially EG2, which could work as a protective mechanism for falls (Almeida et al., 2019). However, 12 weeks of detraining was sufficient for a decrease in the perception-action ability, inducing a significant increase in the overestimation values. The fact that the participants performed the stepping-forward affordance perception test in a controlled environment, with no potential risk of falling and more confidence, may also have influenced the results. Given the lack of experimental studies on these matters, step length overestimation in older adults has been reported in other cross-sectional studies (Caffier et al., 2019). Caffier et al. (Caffier et al., 2019) reported significant differences in the step length estimation error (overestimation) in older adults with and without a risk of falling. Given the importance of an accurate perception-action ability, especially in an overestimated performance, future studies should incorporate exercises focusing on anticipatory motor planning. The rationale for this recommendation is based on the fact that older adults prepared an action with a larger anticipation to achieve the same accuracy than younger groups, in addition to greater prefrontal cortical activation (Berchicci et al., 2012). Likewise, possible recommendations for future investigations include a larger long-term fall prevention program (e.g., 12 months) focusing even more on affordances and perception-action ability and motor imagery training. In this line, a recent systematic review suggested that the use of motor imagery training, which appeals to the imagination of an action without the respective motor execution, may improve risk factors for falls, such as balance and mobility in older adults (Nicholson et al., 2019).

For physical function, both multimodal exercise programs induced improvements in multidimensional balance, with a large ES. Although both EGs presented a similar ES, the combined exercise program presented a slightly larger ES. Few studies have reported the effects of a WBV program in addition to an exercise program in community-dwelling older adults. The present study findings are in line with the 8-week study of Pollock et al. (Pollock et al., 2012), although the setting was designed for frail older adults. In the Pollock et al. study (Pollock et al., 2012), the addition of a WBV program to balance and strength training resulted in similar enhancements in balance in both groups (exercise alone vs. exercise + WBV). A recent 4-week study also detected significant improvements in balance in a combined program (WBV + unstable shoes) compared to a CG that received WBV with standard shoes (Sobhani et al., 2018). These improvements in balance were found in both groups at post-intervention for the FAB scale score (combined program: 30.7 vs 35.2 points; CG: 31.9 vs. 35.6 points) and were maintained after a 4-week follow-up, only in the combined program (35.2 vs. 35.1 points) (Sobhani et al., 2018). Contrary to the follow-up results of previous studies, in which the balance results remained unchanged after a 4-week follow-up (Sobhani et al., 2018) or a 24-week follow-up (Pollock et al., 2012), the improvements in balance in the present study were no longer evident in both EGs after 12 weeks of detraining. The ES in both EGs remained large, revealing a decrease in performance.

Regarding the number of falls, both EGs showed a decrease in the fall rate post-intervention (EG1: −44.2%; EG2: −63.0%). Although no significant differences were found between groups, the combined exercise program induced a higher decrease in the fall rate. In agreement with the results of the present study, cognitive-motor interference training has been demonstrated to be effective for preventing falls in older adults (Wang et al., 2015). As mentioned before, few studies have focused on psychomotor intervention as a fall prevention program. The fall rate in the psychomotor intervention group of the

Freiberger et al. study (Freiberger et al., 2007) was observed at the 12-month follow-up, and no significant reduction in falls was found. In addition, the improvements in cognitive and physical risk factors for falls in EG2 in our study and the neurophysiological mechanisms induced by WBV training may have promoted additional benefits in the fall rate. In fact, WBV training as a single intervention can lead to a reduction in fall incidence in 12-week intervention programs (Tseng et al., 2016). However, the low frequency applied by the WBV program in the current study is in line with other studies (Tseng et al., 2016; Yang et al., 2015). In addition, higher-frequency vibration training (> 40 Hz) can lead to reduced immediate neuromuscular performance (Tseng et al., 2016).

The present study has strengths and limitations. The strengths include an RCT design with a long-term intervention comprising two multimodal exercise programs barely studied in fall prevention programs. To the best of our knowledge, this is also the first RCT focusing on the perceptual and stepping-forward boundary as a risk factor for falls in community-dwelling older adults. Current limitations include a single-blinded design and the dropout rate in the EGs (9.8%), although the present study showed a smaller dropout rate than other studies (Linde & Alfermann, 2014), and the remaining sample fulfilled the minimal sample size defined by the G*Power software. Even so, the decrease in sample size may have limited the statistical power of the study. Although descriptive data related to between-group comparisons were not contradictory to within comparisons, no significant differences were found as regards inferential comparisons between groups, namely at post-intervention. Despite the predominance of women in the present study (82.4%), these values are in line with other studies that reported approximately 80% of women in their survey (Sobhani et al., 2018). Last, it would have been interesting to assess measures such as the Activities-specific Balance Confidence Scale to evaluate other parameters that could influence the outcomes and recorded the number of falls at the follow-up evaluation.

5. Conclusions

The results of this RCT study suggest that the multimodal psychomotor program and the combined program (multimodal psychomotor program + WBV program) were effective and well tolerated in community-dwelling older adults at risk of falling. Both multimodal exercise programs induced improvements in risk factors for falls, particularly in attention and balance, with similar treatment effect magnitudes, ranging from medium to large in EG1 and EG2. Specifically, both EGs revealed identical improvements in attention, and the combined program presented a slightly larger enhancement in balance. Additionally, both EGs showed a decrease in the fall rate post-intervention, especially the combined program. After 12 weeks of detraining, the positive effects evidenced in both EGs were sustained in attention but reversed in balance. Our findings advocate the benefits of maintaining the multimodal psychomotor program as a single or combined intervention with WBV to prevent cognitive and physical function decline. Furthermore, given the increase in the aging trend, this study reveals two promising approaches to use as a fall prevention program in community-dwelling older adults, which can reduce the expensive health and social and economic costs from falls.

Funding

This study and publication costs were funded by the European Fund for regional development through Horizon 2020 - Portugal 2020 - Programa Operacional Regional do Alentejo (ALT20-03-0145-FEDER-000007) with respect to the “Ageing Safety in Alentejo - Understanding for action (ESACA)”. Hugo Rosado holds an “Fundação para a Ciência e a Tecnologia” doctoral fellowship (SFRH/BD/147398/2019). Funders did not contribute to the design, analysis, or preparation of this manuscript.

Acknowledgments

The authors would like to thank all participants who take part in this study.

6. References

Almeida, G., Bravo, J., Folgado, H., Rosado, H., Mendes, F., & Pereira, C. (2019). Reliability and construct validity of the stepping-forward affordance perception test for fall risk assessment in community-dwelling older adults. *PloS One*, *14*(11), e0225118. https://doi.org/10.1371/journal.pone.0225118

Bemben, D., Stark, C., Taiar, R., & Bernardo-Filho, M. (2018). Relevance of Whole-Body Vibration Exercises on Muscle Strength/Power and Bone of Elderly Individuals. *Dose-Response: A Publication of International Hormesis Society*, *16*(4), 1559325818813066. https://doi.org/10.1177/1559325818813066

Berchicci, M., Lucci, G., Pesce, C., Spinelli, D., & Di Russo, F. (2012). Prefrontal hyperactivity in older people during motor planning. *Neuroimage*, *62*(3), 1750-1760. https://doi.org/10.1016/j.neuroimage.2012.06.031

Borg, G. A. (1982). Psychophysical bases of perceived exertion. *Medicine and Science in Sports and Exercise*, *14*(5), 377-381. https://doi.org/10.1249/00005768-198205000-00012

Brickenkamp. (2007). *d2 Test of attention*. CEGOC-TEA.

Caffier, D., Luyat, M., Cremoux, S., Gillet, C., Ido, G., Barbier, F., & Naveteur, J. (2019). Do Older People Accurately Estimate the Length of Their First Step during Gait Initiation? *Experimental Aging Research*, *45*(4), 357-371. https://doi.org/10.1080/0361073X.2019.1627495

Cohen, J. (1998). *Statistical power analysis for the behavioral sciences*.

Craig, C. L., Marshall, A. L., Sjostrom, M., Bauman, A. E., Booth, M. L., Ainsworth, B. E., Pratt, M., Ekelund, U., Yngve, A., Sallis, J. F., & Oja, P. (2003). International physical activity questionnaire: 12-country reliability and validity. *Medicine and Science in Sports and Exercise*, *35*(8), 1381-1395. https://doi.org/10.1249/01.MSS.0000078924.61453.FB

Fernandez, N. B., Hars, M., Trombetti, A., & Vuilleumier, P. (2019). Age-related changes in attention control and their relationship with gait performance in older adults with high risk of falls. *Neuroimage*, *189*, 551-559. https://doi.org/10.1016/j.neuroimage.2019.01.030

Focht, B. C., Knapp, D. J., Gavin, T. P., Raedeke, T. D., & Hickner, R. C. (2007). Affective and self-efficacy responses to acute aerobic exercise in sedentary older and younger adults. *Journal of Aging and Physical Activity*, *15*(2), 123-138. https://doi.org/10.1123/japa.15.2.123

Fraser, S. A., Li, K. Z. H., Berryman, N., Desjardins-Crepeau, L., Lussier, M., Vadaga, K., Lehr, L., Vu, T. T. M., Bosquet, L., & Bherer, L. (2017). Does Combined Physical and Cognitive Training Improve Dual-Task Balance and Gait Outcomes in Sedentary Older Adults? *Frontiers in Human Neuroscience, 10*. https://doi.org/10.3389/fnhum.2016.00688

Freiberger, E., Menz, H. B., Abu-Omar, K., & Rutten, A. (2007). Preventing falls in physically active community-dwelling older people: a comparison of two intervention techniques. *Gerontology*, *53*(5), 298-305. https://doi.org/10.1159/000103256

Fritz, C. O., Morris, P. E., & Richler, J. J. (2012). Effect size estimates: current use, calculations, and interpretation. *Journal of Experimental Psychology: General*, *141*(1), 2-18. https://doi.org/10.1037/a0024338

Gibson, J. (1977). *The theory of affordances, In" Perceiving, Acting and Knowing".* (Erlbaum, Ed.). RE Shaw and J. Bransford.

Hernandez, D., & Rose, D. J. (2008). Predicting which older adults will or will not fall using the Fullerton Advanced Balance scale. *Archives of Physical Medicine and Rehabilitation*, *89*(12), 2309-2315. https://doi.org/10.1016/j.apmr.2008.05.020

Jehu, D. A. M., Paquet, N., & Lajoie, Y. (2018). Balance and Mobility Training With or Without Simultaneous Cognitive Training Reduces Attention Demand But Does Not Improve Obstacle Clearance in Older Adults. *Motor Control*, *22*(3), 275-294. https://doi.org/10.1123/mc.2017-0024

Jeschke, A. M., de Lange, A. M. M., Withagen, R., & Caljouw, S. R. (2020). Crossing the Gap: Older Adults Do Not Create Less Challenging Stepping Stone Configurations Than Young Adults. *Frontiers in Psychology*, *11*, 1657. https://doi.org/10.3389/fpsyg.2020.01657

Kao, C. C., Chiu, H. L., Liu, D., Chan, P. T., Tseng, I. J., Chen, R., Niu, S. F., & Chou, K. R. (2018). Effect of interactive cognitive motor training on gait and balance among older adults: A randomized controlled trial. *International Journal of Nursing Studies*, *82*, 121-128. https://doi.org/10.1016/j.ijnurstu.2018.03.015

Linde, K., & Alfermann, D. (2014). Single versus combined cognitive and physical activity effects on fluid cognitive abilities of healthy older adults: a 4-month randomized controlled trial with follow-up. *Journal of Aging and Physical Activity*, *22*(3), 302-313. https://doi.org/10.1123/japa.2012-0149

Nagamatsu, L. S., Boyd, L. A., Hsu, C. L., Handy, T. C., & Liu-Ambrose, T. (2013). Overall reductions in functional brain activation are associated with falls in older adults: an fMRI study. *Frontiers in Aging Neuroscience*, *5*, 91. https://doi.org/10.3389/fnagi.2013.00091

Nagamatsu, L. S., Hsu, C. L., Handy, T. C., & Liu-Ambrose, T. (2011). Functional neural correlates of reduced physiological falls risk. *Behavioral and Brain Functions*, *7*, 37. https://doi.org/10.1186/1744-9081-7-37

Nicholson, V., Watts, N., Chani, Y., & Keogh, J. W. (2019). Motor imagery training improves balance and mobility outcomes in older adults: a systematic review. *Journal of Physiotherapy*, *65*(4), 200-207. https://doi.org/10.1016/j.jphys.2019.08.007

O'Halloran, A. M., Penard, N., Galli, A., Fan, C. W., Robertson, I. H., & Kenny, R. A. (2011). Falls and falls efficacy: the role of sustained attention in older adults. *BMC Geriatrics*, *11*, 85. https://doi.org/10.1186/1471-2318-11-85

Orr, R. (2015). The effect of whole body vibration exposure on balance and functional mobility in older adults: a systematic review and meta-analysis. *Maturitas*, *80*(4), 342-358. https://doi.org/10.1016/j.maturitas.2014.12.020

Pereira, C., Rosado, H., Cruz-Ferreira, A., & Marmeleira, J. (2018). Effects of a 10-week multimodal exercise program on physical and cognitive function of nursing home residents: a psychomotor intervention pilot study. *Aging Clinical and Experimental Research*, *30*(5), 471-479. https://doi.org/10.1007/s40520-017-0803-y

Pollock, R. D., Martin, F. C., & Newham, D. J. (2012). Whole-body vibration in addition to strength and balance exercise for falls-related functional mobility of frail older adults: a single-blind randomized controlled trial. *Clinical Rehabilitation*, *26*(10), 915-923. https://doi.org/10.1177/0269215511435688

Probst, M., Knapen, J., Poot, G., & Vancampfort, D. (2010). Psychomotor Therapy and Psychiatry: What's in a Name? *The Open Complementary Medicine Journal*, *2*(1), 105-113. https://doi.org/10.2174/1876391X010020010105

Raichlen, D. A., Bharadwaj, P. K., Nguyen, L. A., Franchetti, M. K., Zigman, E. K., Solorio, A. R., & Alexander, G. E. (2020). Effects of simultaneous cognitive and aerobic exercise training on dual-task walking performance in healthy older adults: results from a pilot randomized controlled trial. *BMC Geriatrics*, *20*(1), 83. https://doi.org/10.1186/s12877-020-1484-5

Regterschot, G. R., Van Heuvelen, M. J., Zeinstra, E. B., Fuermaier, A. B., Tucha, L., Koerts, J., Tucha, O., & Van Der Zee, E. A. (2014). Whole body vibration improves cognition in healthy young adults. *PloS One*, *9*(6), e100506. https://doi.org/10.1371/journal.pone.0100506

Rikli, R. E., & Jones, C. J. (2013). Development and validation of criterion-referenced clinically relevant fitness standards for maintaining physical independence in later years. *Gerontologist*, *53*(2), 255-267. https://doi.org/10.1093/geront/gns071

Robinson, J. E., & Kiely, J. (2017). Preventing falls in older adults: Can improving cognitive capacity help? *Cogent Psychology*, *4*(1). https://doi.org/10.1080/23311908.2017.1405866

Sherrington, C., Fairhall, N. J., Wallbank, G. K., Tiedemann, A., Michaleff, Z. A., Howard, K., Clemson, L., Hopewell, S., & Lamb, S. E. (2019). Exercise for preventing falls in older people living in the community. *Cochrane Database of Systematic Reviews*, *1*(1), CD012424. https://doi.org/10.1002/14651858.CD012424.pub2

Sobhani, S., Sinaei, E., Motealleh, A., Hooshyar, F., Kashkooli, N. S., & Yoosefinejad, A. K. (2018). Combined effects of whole body vibration and unstable shoes on balance measures in older adults: A randomized clinical trial. *Archives of Gerontology and Geriatrics*, *78*, 30-37. https://doi.org/10.1016/j.archger.2018.05.016

Tomás, R., Lee, V., & Going, S. (2011). The Use of Vibration Exercise in Clinical Populations. *ACSM's Health & Fitness Journal*, *15*(6), 25-31. https://doi.org/10.1249/FIT.0b013e31823373e8

Tseng, S. Y., Hsu, P. S., Lai, C. L., Liao, W. C., Lee, M. C., & Wang, C. H. (2016). Effect of Two Frequencies of Whole-Body Vibration Training on Balance and Flexibility of the

Elderly: A Randomized Controlled Trial. *American Journal of Physical Medicine and Rehabilitation*, *95*(10), 730-737. https://doi.org/10.1097/PHM.0000000000000477

United Nations. (2019). *Ageing*. https://www.un.org/en/sections/issues-depth/ageing/

Wang, X., Pi, Y., Chen, P., Liu, Y., Wang, R., & Chan, C. (2015). Cognitive motor interference for preventing falls in older adults: a systematic review and meta-analysis of randomised controlled trials. *Age and Ageing*, *44*(2), 205-212. https://doi.org/10.1093/ageing/afu175

Wollesen, B., Wildbredt, A., van Schooten, K. S., Lim, M. L., & Delbaere, K. (2020). The effects of cognitive-motor training interventions on executive functions in older people: a systematic review and meta-analysis. *European Review of Aging and Physical Activity*, *17*, 9. https://doi.org/10.1186/s11556-020-00240-y

World Health Organization. (2018). *Falls*. https://www.who.int/news-room/fact-sheets/detail/falls

Yang, F., King, G. A., Dillon, L., & Su, X. (2015). Controlled whole-body vibration training reduces risk of falls among community-dwelling older adults. *Journal of Biomechanics*, *48*(12), 3206-3212. https://doi.org/10.1016/j.jbiomech.2015.06.029

Yoshihara, S., Kanno, N., Fukuda, H., Arisaka, O., Arita, M., Sekine, K., Yamaguchi, K., Tsuchida, A., Yamada, Y., Watanabe, T., Shimizu, T., Nishikawa, K., & Nishimuta, T. (2015). Caregiver treatment satisfaction is improved together with children's asthma control: Prospective study for budesonide monotherapy in school-aged children with uncontrolled asthma symptoms. *Allergology International*, *64*(4), 371-376. https://doi.org/10.1016/j.alit.2015.05.010

CHAPTER 5

General Discussion

General Discussion

This investigation's main goal was to analyze the effect of two intervention programs on fall risk factors in community-dwelling older people who had fallen or were at high risk of falling. The results of the experimental study evidenced that both programs were accepted and tolerated by participants. Furthermore, the psychomotor intervention and the combined program effectively prevented falls by decreasing fall risk factors. Indeed, both interventions positively impacted cognitive and physical function and body composition risk factors for falls and fall-related injuries. Moreover, both programs decreased the incidence of falls, especially the combined intervention (psychomotor intervention: −44.2%; combined intervention: −63.0%).

The study findings evidenced that, both programs significantly enhanced processing speed, selective and sustained attention, dual-task performance, mobility, lower-body strength, balance, and bone mineral density, reported in the literature as the main risk factors for falls. Furthermore, the combined intervention also significantly improved reaction time and bone mineral content, which are also relevant risk factors for falls. The changes induced by the programs help explain the decrease in the incidence of falls, particularly in the combined program. These findings showed that both programs were effective and recommended for fall prevention in community-dwelling older adults. Accordingly, these programs can establish a solution that will not only reduce the fall-related consequences in older adults' personal life but also contribute to decreasing the economic and social costs associated with falls in older adults (Florence et al., 2018).

After the no-intervention 12-week follow-up (detraining), both program groups' cognitive improvements were maintained in the selective and sustained attention and executive functions. In addition, the processing speed was also maintained in the combined intervention group. Contrarily, the enhancements in physical function were no longer evident in both program groups, namely in mobility, lower-body strength, and balance. Likewise, the dual-task performance results were reversed in the psychomotor intervention program group, and the total BMC and BMD results were reversed in the combined program group. However, the CG maintained their results. These observations showed that it is essential to remain in the programs since their cessation is associated with an accelerated loss of their beneficial effects, particularly in risk factors for falls related to physical function (Blasco-Lafarga et al., 2020) and body composition, which can nullify the impact of the programs to prevent the incidence of falls.

To the best of our knowledge, this is only the second investigation to analyze the effects of a psychomotor intervention program as a fall prevention program and the first to combine a psychomotor intervention with WBV. The interventions' clinical effects were similar, ranging from medium to large in both programs, between baseline and post-intervention (psychomotor intervention program: 0.41-0.62; combined program: 0.43-0.62), as well between post-intervention and follow-up (psychomotor intervention program: 0.41-0.63; combined program: 0.41-0.59). According to the results, and as described above, it is recommended to privilege the combined program to prevent falls. However, performing WBV training implies a vibratory platform acquisition, which has a considerable economic cost and may be unaffordable in community interventions. Therefore, the psychomotor intervention program is considered an effective alternative solution for fall prevention due to its beneficial and positive impact on the main risk factor for falls (Freiberger et al., 2007).

In summary, Chapters 1 and 3 presented the main conceptual framework that launched and supported the experimental study, which is included in Chapter 5. In this way, were introduced concepts and fundamentals such as the risk factors for falls, the additional benefits of combined interventions reported in the literature, or the effects that a psychomotor intervention program or WBV training potentially may have as fall prevention programs.

The study presented in Chapter 4 confirmed Hypothesis 1. The SF-APT was accurate, reliable, and valid for fall risk assessment. This instrument helped to fill a gap in fall risk assessment, particularly in the perception of affordances (i.e., action boundaries: perception vs. action) assessment in community-dwelling older adults. This is relevant, given that the aging-associated misperception of affordances could increase the risk of falling (Pereira et al., 2020). Therefore, the SF-APT was used in the RCT study to assess this fall risk factor.

The results reported in Chapter 5 confirmed most of the hypotheses related to the experimental study (i.e., Hypotheses 2, 3, 4, 5, 6, 7, 8, and 9). In addition, hypothesis 2 was confirmed. As discussed above, both programs showed to positively impact the risk factors for falls and to be effective interventions to prevent falls in community-dwelling older adults. Hypothesis 3 was partially confirmed. If, on the one hand, the combined intervention presented a larger decrease in fall rate compared to the psychomotor intervention program, on the other hand, no significant differences between these programs were found in the number of falls. Nevertheless, the larger decrease in fall rate shown in the combined intervention is in line with other studies, which evidence the positive effects of WBV training in decreasing fall incidence (Jepsen et al., 2017). However, more studies are needed to generalize these findings, which should be interpreted cautiously.

Hypotheses 4 and 5 were partly confirmed. Besides enhancements in the other cognitive abilities, the combined intervention led to additional improvements in reaction time compared to the psychomotor intervention. However, it was only in one variable (CRT DT). Moreover, the interventions' clinical effects between both programs in cognitive function were similar (psychomotor intervention program: 0.47-0.62; combined program: 0.43-0.58). This does not contradict recent literature that suggested a positive impact of WBV on cognitive function (Wen et al., 2023), although several characteristics can influence cognitive results. For instance, the WBV training program (e.g., exercise time, the number of series, frequency, or amplitude) or the cognitive tasks performed in the intervention programs (e.g., task complexity or amount of time of each task) (Gritschmeier, 2021). However, the fact that most studies investigated the cognitive impact of WBV with mice or young adults (Arenales Arauz et al., 2023) limits this discussion. In this way, more research is required to understand better the impact of neurophysiological changes promoted by WBV on cognitive function, specifically in community dwellings.

Hypothesis 6 was not confirmed. Globally, both programs presented a similar magnitude of the treatment effect (psychomotor intervention program: 0.51-0.62; combined program: 0.47-0.62). Despite the WBV training's positive effects described in the literature (Awan et al., 2017) in mobility, lower-body strength, and balance, the neurophysiological changes induced by our WBV training were insufficient to promote larger gains compared to the psychomotor intervention. The psychomotor intervention, like other cognitive-motor interventions (Teraz et al., 2022), could enhance physical function. Moreover, and as described above, the frequency used in WBV can influence potential results. Our WBV program didn't reach a high frequency due to the need to protect the lower limb joints. Likewise, the literature supports that frequencies of 20 Hz were more appropriate to neuromuscular responses in older persons than those of 40 Hz (Tseng et al., 2021).

Hypothesis 7 was confirmed. Besides BMD improvements showing a higher treatment effect, the combined program led to additional benefits in BMC compared to the psychomotor intervention program. These enhancements can be considered a protective mechanism against fall-related fractures. Despite these promising findings, considering that our intervention had only a 24-week length, the WBV impact on bone mass is still debatable in the literature (Jepsen et al., 2017). Therefore, our findings should be interpreted with caution.

Hypothesis 8 was confirmed. Both programs led to similar results in action boundaries, such no improvements were observed. As described before, and to our knowledge, this was the first investigation to include the perceptual and stepping-forward boundary as risk factors for falls in community-dwelling older adults, which complicated the comparison of the results. More psychomotor intervention programs or other cognitive-motor programs are needed, focusing on the perceptual misestimation between perception and action.

Finally, Hypothesis 9 was confirmed. Only 12 weeks of detraining were sufficient to revert the physical function improvements induced by both programs. In addition, the bone mass enhancement results were no longer evident at the follow-up evaluation, particularly in the combined program. On the other hand, cognitive improvements were maintained in both program groups. Contrary to cognitive function, physical function is considered more sensitive to changes. The systematic review conducted by Modaberi and colleagues (Modaberi et al., 2021) pointed out that the detraining effects could already be significant after four weeks after the cessation of fall prevention programs, even if the programs were specifically focused on balance tasks.

Moreover, the detraining also had a negative impact on the perceived stepping-forward boundary, with an increase in participants overestimating their perceived action boundaries. These results led participants to a high risk of falling, following the "Dynamic performance-exposure algorithm for falling risk assessment and prevention of falls in community-dwelling older adults" developed by Pereira and colleagues (Pereira et al., 2022). Therefore, our investigation reinforces the importance of ongoing psychomotor interventions to decrease fall risk factors.

References

Arenales Arauz, Y. L., van der Zee, E. A., Kamsma, Y. P. T., & van Heuvelen, M. J. G. (2023). Short-term effects of side-alternating Whole-Body Vibration on cognitive function of young adults. *PloS One*, *18*(1), e0280063. https://doi.org/10.1371/journal.pone.0280063

Awan, R. I., N., K., & S., P. (2017). The Effect of WBV on Balance, Mobility and Strength in Aging Adults: A Systematic Review. *Biological Systems: Open Access*, *6*(1). https://doi.org/10.4172/2329-6577.1000179

Blasco-Lafarga, C., Cordellat, A., Forte, A., Roldan, A., & Monteagudo, P. (2020). Short and Long-Term Trainability in Older Adults: Training and Detraining Following Two Years of Multicomponent Cognitive-Physical Exercise Training. *International Journal of Environmental Research and Public Health*, *17*(16). https://doi.org/10.3390/ijerph17165984

Florence, C. S., Bergen, G., Atherly, A., Burns, E., Stevens, J., & Drake, C. (2018). Medical Costs of Fatal and Nonfatal Falls in Older Adults. *Journal of the American Geriatrics Society*, *66*(4), 693-698. https://doi.org/10.1111/jgs.15304

Freiberger, E., Menz, H. B., Abu-Omar, K., & Rutten, A. (2007). Preventing falls in physically active community-dwelling older people: a comparison of two intervention techniques. *Gerontology*, *53*(5), 298-305. https://doi.org/10.1159/000103256

Gritschmeier, F. (2021). *Effects of whole body vibration on cognition* University of Regensburg]. Germany. https://epub.uni-regensburg.de/53479/

Jepsen, D. B., Thomsen, K., Hansen, S., Jorgensen, N. R., Masud, T., & Ryg, J. (2017). Effect of whole-body vibration exercise in preventing falls and fractures: a systematic review and meta-analysis. *BMJ Open*, *7*(12), e018342. https://doi.org/10.1136/bmjopen-2017-018342

Modaberi, S., Saemi, E., Federolf, P. A., & van Andel, S. (2021). A Systematic Review on Detraining Effects after Balance and Fall Prevention Interventions. *Journal of Clinical Medicine*, *10*(20). https://doi.org/10.3390/jcm10204656

Pereira, C., Bravo, J., Veiga, G., Marmeleira, J., Mendes, F., & Almeida, G. (2020). Stepping-forward affordance perception test cut-offs: Red-flags to identify community-dwelling older adults at high risk of falling and of recurrent falling. *PloS One*, *15*(10), e0239837. https://doi.org/10.1371/journal.pone.0239837

Pereira, C., Rosado, H., Almeida, G., & Bravo, J. (2022). Dynamic performance-exposure algorithm for falling risk assessment and prevention of falls in community-dwelling older adults. *Geriatric Nursing (New York, N.Y.)*, *47*, 135-144. https://doi.org/10.1016/j.gerinurse.2022.07.004

Teraz, K., Slosar, L., Paravlic, A. H., de Bruin, E. D., & Marusic, U. (2022). Impact of Motor-Cognitive Interventions on Selected Gait and Balance Outcomes in Older Adults: A Systematic Review and Meta-Analysis of Randomized Controlled Trials. *Frontiers in Psychology*, *13*, 837710. https://doi.org/10.3389/fpsyg.2022.837710

Tseng, S. Y., Ko, C. P., Tseng, C. Y., Huang, W. C., Lai, C. L., & Wang, C. H. (2021). Is 20 Hz Whole-Body Vibration Training Better for Older Individuals than 40 Hz? *International Journal of Environmental Research and Public Health*, *18*(22). https://doi.org/10.3390/ijerph182211942

Wen, J., Leng, L., Hu, M., Hou, X., & Huang, J. (2023). Effects of whole-body vibration training on cognitive function: A systematic review. *Frontiers in Human Neuroscience*, *17*, 854515. https://doi.org/10.3389/fnhum.2023.854515

CHAPTER 6

Conclusions

Conclusions

Concerning the main findings of the present investigation, it is possible to conclude that:

The literature review observed that interventions performing simultaneously cognitive and motor stimulation can lead to additional benefits compared to single interventions and demonstrate a good potential to reduce risk factors for falls. A psychomotor intervention can include these characteristics and can potentialize interactive cognitive-motor stimulation.

The SF-APT was demonstrated to be an accurate, reliable, and valid instrument for fall risk assessment. This instrument considers the perceived action boundaries in community-dwelling older people.

Regarding the experimental study, the psychomotor intervention program and the combined program were accepted and well tolerated by participants. The combined program led to a larger decrease in the incidence of falls.

Both programs were effective in preventing falls, by decreasing the fall risk factors. Specifically, both programs induced enhancements in processing speed, selective and sustained attention, dual-task performance, mobility, lower-body strength, balance, and bone mineral density, after 24 weeks of intervention. In addition, the combined program showed additional improvements in reaction time and bone mineral content. The magnitude of the treatment effect in both programs was similar, ranging from medium to large.

Globally, after a 12-week no-intervention follow-up, the improvements induced by the programs in cognitive function were maintained in both program groups, whereas the physical function improvements were reversed. In addition, bone mass gains were no longer evident after the detraining in the combined program.

The psychomotor intervention program demonstrated the potential to be used as a fall prevention program. Furthermore, for additional benefits, especially in bone mass, it's recommended to add WBV training as a complement to the psychomotor intervention program.

Practical Implications / Suggestions for Future Research

The present investigation has several practical implications, namely:

- Concerning the validation of the SF-APT, it allows therapists and other health professionals to use a key tool to provide information about perceived action boundaries that is friendly and easy to administer. This tool is useful for assessing older adult fall risk and shows potential to be used in other contexts.
- Demonstrated the effectiveness of a psychomotor intervention program as a fall prevention program.
- Demonstrated the effectiveness of a psychomotor intervention program by improving physical and cognitive function and body composition.
- Demonstrated that adding WBV training to the psychomotor intervention program induced additional benefits.
- The intervention programs increased physical activity and reduced sedentarism.
- The intervention programs promoted social interaction, which counteracted the social isolation frequently experienced by older adults.
- The publication of a book with activities performed in the intervention programs, directed to therapists and other health professionals who work with community dwellings.
- The presentation of several oral communications and posters at international congresses, conferences, and annual meetings. These presentations helped to share our data and main conclusions with the community.

The scientific articles included in the experimental study already had suggestions for future research. Nonetheless, we add or highlight the following ones:

- Since falls also occur in different directions, future studies should ponder to develop and validate an instrument to assess the perceived action boundaries through the sidesteps.
- Future studies should use other outcome measures to determine additional psychomotor intervention effects, such as the knowledge of body parts/body awareness or motor coordination (e.g., Geronto-Psychomotor Examination). Impairments in these parameters can increase the risk of falling.

- To assess the electrical brain activity through an electroencephalogram to determine the effect of psychomotor intervention programs (e.g., baseline vs. post-intervention) on cerebral functionality.
- In line with the previous proposal, it would be relevant to assess the brain-derived neurotrophic factor levels to evaluate more precisely the effects of a psychomotor intervention program on brain neuroplasticity.
- Lastly, it would be interesting to perform some psychomotor intervention sessions outdoors, particularly in green spaces.

Appendices

RCT: General methods

1. Study design

This 24-week RCT followed a single-blinded design and was performed between March 2018 and January 2019. Three groups were included: experimental group 1 (EG1), which performed a psychomotor intervention program; experimental group 2 (EG2), which underwent a combined program (psychomotor intervention program + WBV); and the control group (CG), in which participants were asked to maintain their daily life routines (waiting list).

This study followed the CONSORT guidelines for RCTs (http://www.consort-statement.org). The protocol was registered in ClinicalTrials.gov (NCT03446352).

2. Participants

The participants were community-dwelling older adults and were recruited via pamphlets distributed in strategic locations and verbal communication (recreational and senior centers). A total of 56 participants met the inclusion criteria (47 women and 9 men) and were randomly assigned to three groups, with an allocation ratio of 1:1:1.

3. Procedures

Participants were assessed individually at baseline, after 24 weeks of intervention, and after a 12-week no-intervention follow-up by the same trained evaluator. Data collection was performed at the University of Évora laboratories. After the follow-up evaluations, the CG participants were offered the opportunity to participate in a fall prevention program.

4. Outcome measures

Outcome measures	Assessment
Cognitive function	
Reaction time	Deary-Liewald reaction time test;
Dual-task performance	Deary-Liewald reaction time test; Cognitive Timed up and go test;
Processing speed	Trail Making Test (Parts A & B);
Attention	d2 Test of Attention;
Physical function	
Mobility	Timed up and go test;
Lower-body strength	Isokinetic dynamometer; 30-s Chair Stand Test;
Balance	Fullerton Advanced Balance scale;
Affordance perception	Stepping-forward affordance perception test;
Body composition	DXA;
Fall occurrence	An interview based on a script;
Secondary outcome measures	**Assessment**
Sociodemographic characteristics	An interview based on a script;
Exercise intensity	Borg Rating of Perceived Exertion scale;
Participants' satisfaction level	Caregiver Treatment Satisfaction questionnaire;
Body mass index (kg/m^2)	Weight (kg): Electronic scale (Seca 760, Hamburg, Germany); Height (m): Stadiometer (Seca 206, Hamburg, Germany);
Physical independence	The 12-item Composite Physical Function scale;
Metabolic expenditure ([MET]-min/ week)	International Physical Activity Questionnaire;

5. Intervention programs

Both programs were performed three times per week (75 min/session) on alternate days, with up to 10 participants in each class. All supervised sessions were delivered by the same specialist, who has a master's degree in psychomotricity, at the gerontopsychomotricity laboratory.

The activities performed were intended to be challenging, innovative, and pleasant in a social context, to involve and maintain participants' interest in both programs. Adaptative, specific, and progressive tasks were performed over the intervention period. Likewise, the complexity and intensity of both programs increased with sessions. Participants who were absent for 3 consecutive sessions were followed by phone, and the respective sessions were rescheduled.

5.1. Psychomotor intervention program

This program included the main principles of a psychomotor intervention tailored to older people (body and movement as intervention mediators). It was focused on promoting simultaneous cognitive and motor stimulation (ICM activities) on alternate periods of ~ 15 minutes.

Specifically, each session was divided into five phases: initial dialog (~ 5 min), global activation (~ 10min), main phase (~ 50min), cool-down (~ 5min), and a final dialog (~ 5min). Several activities performed in this program comprising the global activation, main phase, and cool-down phases are described in a published book (https://doi.org/10.24902/uevora.34).

5.2. Whole-body vibration program

The WBV program was performed individually on the side-alternating vibratory platform (Galileo Med35). The participants stood shoeless on the platform, in a semi-squat position. It followed a planned and structured training method:

Week	Sets (n)	Exercise time (s)	Frequency (Hz)	Amplitude (mm)	Time of rest (s)
1	4	45	12.6	3	60
2	4	60	12.6	3	60
3	5	60	12.6	3	60
4	5	60	12.6	3	60
5-10	6	60	13.8	3	60
11-24	6	60	15	3	60