

Universidade de Évora - Instituto de Investigação e Formação Avançada

Programa de Doutoramento em Motricidade Humana

Tese de Doutoramento

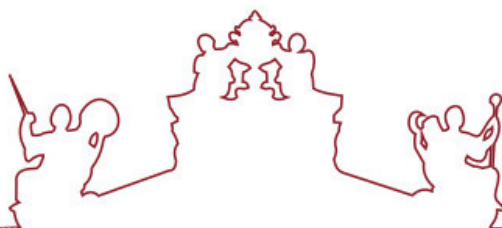
**Reforma ativa: Efeitos da aplicação de um programa de
treino na estimulação do sistema sensório motor**

Carolina Alexandra Alípio Mourata do Cabo

Orientador(es) | Jose Alberto Parraca
Orlando de Jesus Fernandes
Mário André da Cunha Espada

Évora 2026





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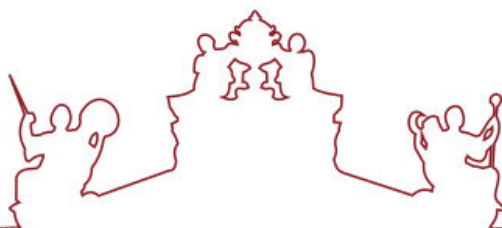
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A tese de doutoramento foi objeto de apreciação e discussão pública pelo seguinte júri nomeado pelo Diretor do Instituto de Investigação e Formação Avançada:

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(Arguente)
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(Arguente)

"O caminho faz-se caminhando"
— **Fernando Pessoa**



Agradecimentos

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Abreviaturas

AF – Atividade física

AP – Ântero-posterior

CDC – Centros de controlo e prevenção de doenças

CI – Implantes cocleares

CMA – Câmara municipal de Almada

CoM – Centro de massa

CoP – Centro de pressão

CRF – Aptidão cardiorrespiratória

30s-CST – Teste 30 segundos sentar e levantar

DCV – Doenças cardiovasculares

DF – Graus de liberdade

DFA – Análise flutuação detrendida

DM2 – Diabetes mellitus tipo 2

DP – Desvio padrão

DT – Dupla tarefa

DXA – Absorciometria por dupla energia

EnAP – Entropia aproximada

ES – Effect size (Tamanho do efeito)

ETGUG – Teste levantar, caminhar e voltar a sentar expandido

EUA – Estados unidos da América

FF – Flexão do antebraço

FITT – Frequência, intensidade, tempo e tipo

GC – Grupo de controlo

GE – Grupo experimental

GI – Grupo de intervenção

GSR – Razão de estabilidade da marcha

HADS – Escala hospitalar de ansiedade e depressão

HGS – Teste de força de preensão manual

ICC – Coeficiente de correlação intraclass

IIFA – Instituto de investigação e formação avançada

IMC – Índice de massa corporal

IMUs – Dispositivos inerciais



IPAQ – Questionário internacional de atividade física

LyE – Expoente de lyapunov

m – Metros

M – Média

MA – Município de Almada

maxAP_OA – Oscilação ântero-posterior máxima com olhos abertos

maxML_OF – Oscilação mediolateral máxima com olhos fechados

maxR_OA – Oscilação radial máxima com olhos abertos

mdML_OA – Distância média mediolateral com olhos abertos

mdML_OF – Distância média mediolateral com olhos fechados

meanSpd – Rapidez média escalar

mean_V – Velocidade vetorial média

mHealth – Aplicações de saúde móvel

ML – Mediolateral

MoCA – Avaliação cognitiva de montreal

MSEG – Grupo de exercício de força muscular

η^2p – eta quadrado parcial

NAF – Nível de atividade física

NC – Sem queixas de desequilíbrio

NE – Sem exercício

NEADL – Índice Nottingham de atividades da vida diária estendidas.

OA – Olhos abertos

OF – Olhos fechados

OMS – Organização mundial de saúde

PACES – Escala de prazer com atividade física

PASE – Escala de atividade física para idosos

PRT – Treino resistido progressivo

QV – Qualidade de vida

QVRS – Qualidade de vida relacionada com a saúde

R^2 – Coeficiente de determinação

rangeAP_OA – Amplitude da distância ântero-posterior com olhos abertos

rangeML_OF – Amplitude da distância mediolateral com olhos fechados

rangeRatio_OA – Acoplamento direcional com olhos abertos

rangeRatio_OF – Acoplamento direcional com olhos fechados



RBB – Alcançar atrás das costas
RBBR – Alcançar atrás das costas à direita
RBBL – Alcançar atrás das costas à esquerda
RCTs – Ensaios clínicos randomizados e controlados
rep – repetições
rms – Raiz quadrática média
s – segundos
SF-36 – Questionário de bem-estar e saúde geral
SNS – Serviço nacional de saúde
SR – Sentar e alcançar
SSWL – Sentar e levantar com inclinação
SSL – Sentar e levantar sem inclinação
SR-WBV – Vibração corporal total por ressonância rstocástica
SV – Vibração alternada lateral
swayLen – Área de oscilação por segundo
sway_Deg – Direção da oscilação
TC – Tai chi
TGA – Assimetria temporal da marcha
TIC – Tecnologias de informação e comunicação
TSM – Treino sensório motor
TUG –Levantar, caminhar e voltar a sentar
VL – Vasto lateral
VMO – Vasto medial oblíquo
VO₂max – Consumo máximo de oxigénio
VV – Vibração vertical
WC – Com queixas de desequilíbrio
WoS – Web of science



Resumo

Contexto: O processo de envelhecimento é um fenómeno contínuo e irreversível, caracterizado pela diminuição progressiva das funções físicas, cognitivas e psicossociais do ser humano (Wong et al., 2019). Estas alterações comprometem a autonomia funcional e aumentam o risco de doenças associadas à inatividade física. Face a este cenário, torna-se essencial o desenvolvimento de programas de exercício físico que promovam o envelhecimento ativo, a funcionalidade e a qualidade de vida.

Objetivo: O presente estudo teve como objetivo desenvolver e avaliar os efeitos de um programa de treino sensório-motor, designado “Reforma Ativa”, com a duração de 24 semanas, em indivíduos com idades compreendidas entre os 55 e os 80 anos, analisando o seu impacto na coordenação, adaptação motora, controlo postural, força muscular, flexibilidade, variabilidade da marcha, qualidade de vida relacionada com a saúde e nível de atividade física.

Métodos: Foi conduzido um ensaio clínico randomizado e controlado, com grupos paralelos, envolvendo a avaliação pré e pós-intervenção das seguintes variáveis: composição corporal (altura e peso), aptidão física (força, flexibilidade, agilidade, controlo postural e marcha), qualidade de vida relacionada com a saúde e nível de atividade física. O programa foi aplicado durante seis meses, com duas sessões semanais de 45 minutos cada, as avaliações ocorreram antes e após a intervenção. A estrutura do treino integrou seis circuitos, cada um composto por oito exercícios físicos, renovados mensalmente. A dificuldade dos exercícios aumentou progressivamente, com adaptações individuais para garantir a participação segura de todos os elementos.

Resultados: Os resultados obtidos demonstraram melhorias significativas nas variáveis analisadas, nomeadamente ao nível da força muscular, equilíbrio, controlo postural, flexibilidade e mobilidade funcional, bem como tendências positivas na qualidade de vida e no nível de atividade física. Com base nestes resultados, foi desenvolvida uma representação gráfica em formato de roseta, integrando todos os exercícios aplicados ao longo dos seis meses de intervenção, estruturados segundo os princípios do treino sensório-motor, destinada a apoiar técnicos e fisiologistas do exercício na implementação prática do programa.

Conclusão: A aplicação do programa “Reforma Ativa” revelou-se eficaz na melhoria das capacidades físicas e funcionais dos adultos mais velhos, contribuindo para o bem-estar e para a prevenção de declínios associados à inatividade. Recomenda-se a implementação



do programa em serviços de saúde, instituições sociais e municípios, como estratégia de promoção da saúde pública e de incentivo ao envelhecimento ativo. As atividades propostas demonstram potencial para integrar políticas locais de promoção da atividade física, reforçando o papel do exercício como ferramenta preventiva e terapêutica no contexto do envelhecimento.

Palavras-chave: envelhecimento; qualidade de vida; sensório motor; treino; variabilidade da marcha



Abstract: Active Retirement: Effects of applying a training program on stimulating the sensorimotor system.

Background: The ageing process is a continuous and irreversible phenomenon characterized by the progressive decline of physical, cognitive, and psychosocial functions in humans (Wong et al., 2019). These changes compromise functional autonomy and increase the risk of diseases associated with physical inactivity. In this context, it is essential to develop exercise programs that promote active ageing, functionality, and quality of life.

Objective: The present study aimed to develop and evaluate the effects of a 24-week sensorimotor training program, entitled “Reforma Ativa”, in individuals aged between 55 and 80 years, analyzing its impact on coordination, motor adaptation, postural control, muscle strength, flexibility, gait variability, health-related quality of life, and physical activity levels.

Methods: A randomized and controlled clinical trial with parallel groups was conducted, including pre- and post-intervention assessments of the following variables: body composition (height and weight), physical fitness (strength, flexibility, agility, postural control, and gait), health-related quality of life, and physical activity level. The program was implemented over six months, with two 45-minute sessions per week, followed by one year of monitoring. The training structure included six circuits, each consisting of eight physical exercises, renewed every four weeks. Exercise difficulty increased progressively, with individual adaptations to ensure safe participation for all.

Results: The results demonstrated significant improvements in all assessed variables, particularly in muscle strength, balance, postural control, flexibility, and functional mobility, as well as positive trends in health-related quality of life and level of physical activity. Based on these results, a graphical representation in the form of a rosette was developed, integrating all exercises implemented throughout the six-month intervention, structured according to the principles of sensorimotor training, to support exercise professionals and physiologists in the practical application of the program.

Conclusion: The implementation of the “Active Reform” program proved effective in improving the physical and functional capacities of older adults, contributing to well-being and preventing declines associated with inactivity. It is recommended that the program be implemented in healthcare services, social institutions, and municipalities as a public health strategy to promote active ageing. The proposed activities show potential



to be integrated into local physical activity promotion policies, reinforcing the role of exercise as a preventive and therapeutic tool in the context of ageing.

Keywords: aging; quality of life; sensorimotor; training; gait variability.



Capítulo 1 | Introdução

1.1. O envelhecimento

O envelhecimento é um processo natural e progressivo, associado a alterações neuromusculares, sensoriais e biomecânicas que afetam a marcha, o equilíbrio e a autonomia funcional. A perda de força muscular, a diminuição da mobilidade e o déficit de equilíbrio contribuem para o aumento da dependência e do risco de quedas em adultos mais velhos (Bacha et al., 2016; Suzuki et al., 2019). Alterações no padrão da marcha, como maior oscilação postural, base de suporte alargada e aumento da variabilidade, são frequentemente observadas nesta população (Ready, 2019).

As quedas constituem um problema de saúde pública, sendo a segunda principal causa de morte acidental a nível mundial em indivíduos com mais de 65 anos, com impacto significativo na funcionalidade, independência e qualidade de vida (McGarrigle et al., 2020). A sua ocorrência resulta da interação entre fatores intrínsecos, como alterações fisiológicas associadas ao envelhecimento, e fatores extrínsecos, como condições ambientais e sociais (Sampaio et al., 2017). Assim, a avaliação sistemática da força muscular, da amplitude de movimento, da marcha e do equilíbrio assume um papel central na prevenção deste fenómeno.

Embora o treino sensório motor tenha demonstrado efeitos positivos no equilíbrio e na segurança durante a marcha, permanece pouco claro o seu impacto direto sobre os parâmetros biomecânicos da marcha em adultos mais velhos (Rezende et al., 2012). Neste contexto, o presente projeto procura analisar a influência do treino sensório motor em indivíduos entre os 55 e os 80 anos sobre o padrão da marcha, contribuindo para a clarificação desta lacuna científica.

O envelhecimento está também associado a um declínio da qualidade de vida, frequentemente agravado pela inatividade física e pelo aparecimento de doenças crónicas. O recurso a tecnologias móveis, como smartphones equipados com sensores, surge como uma oportunidade para monitorizar parâmetros funcionais, apoiar a prevenção de quedas e promover uma gestão mais autónoma da saúde, embora a sua implementação ainda seja limitada no contexto da população idosa (Rasche et al., 2018; Zaleski et al., 2023).

1.2. Prática de exercício físico ao longo do envelhecimento

A prática regular de exercício físico é reconhecida como um fator determinante para a manutenção da autonomia funcional, do equilíbrio e da qualidade de vida em



adultos mais velhos. Em Portugal, o Serviço Nacional de Saúde (SNS) recomenda a realização de atividade física (AF) moderada, com especial enfoque no fortalecimento muscular e nos exercícios de equilíbrio, como estratégia para promover um envelhecimento ativo (SNS, 2018).

Apesar destes benefícios amplamente documentados, os estilos de vida contemporâneos favorecem o sedentarismo, sendo a inatividade física particularmente prevalente na população idosa portuguesa (Bento et al., 2023). A inatividade constitui um dos principais fatores de risco modificáveis para a mortalidade, estando associada a maior fragilidade, declínio funcional, doenças crónicas e risco acrescido de quedas (Fletcher et al., 2018; McGarrigle et al., 2020).

A AF engloba qualquer movimento corporal que aumente o gasto energético, enquanto o exercício físico se caracteriza por ser estruturado, planeado e orientado para a melhoria da condição física (Caspersen et al., 1985). Programas de exercício que integram treino de força, equilíbrio e coordenação sensório motora demonstram ser particularmente eficazes na redução do risco de quedas e na melhoria da mobilidade funcional (Rodrigues, Monteiro, et al., 2024).

A correta execução dos movimentos é essencial para maximizar os benefícios do treino e prevenir lesões, representando um desafio para a avaliação clínica e funcional. Neste sentido, os sensores portáteis e dispositivos inerciais (IMUs) emergem como ferramentas promissoras para a análise objetiva do movimento, permitindo uma avaliação não invasiva da marcha, do equilíbrio e do desempenho funcional em contextos clínicos e comunitários (Lin, 2025; Prisco et al., 2024).

Durante a pandemia de COVID-19, o uso de aplicações móveis e intervenções digitais ganhou relevância como alternativa às sessões presenciais, revelando potencial para promover a AF de forma acessível e económica em populações mais velhas (McGarrigle et al., 2020).

1.3. Treino sensório motor

O treino sensório motor baseia-se na integração das informações sensoriais provenientes dos sistemas propriocetivo, visual e vestibular, permitindo ao sistema nervoso central regular o movimento, a postura e o equilíbrio. A propriocepção, definida como a perceção da posição e do movimento corporal no espaço, desempenha um papel fundamental na estabilidade articular e no controlo motor (Santos et al., 2019).



O controlo da marcha resulta da interação entre programas motores centrais e mecanismos de feedback sensorial, permitindo a adaptação contínua às exigências ambientais. A integração multissensorial é essencial para a regulação da velocidade, do comprimento da passada e da estabilidade dinâmica durante a locomoção (Suzuki et al., 2019).

Intervenções baseadas na sincronização sensório motora, recorrendo a estímulos auditivos ou visuais, têm demonstrado efeitos positivos em diversas populações clínicas e no envelhecimento. Contudo, evidências recentes sugerem que estímulos com variabilidade temporal, mais próximos da variabilidade natural da marcha, podem ser mais eficazes na promoção da adaptabilidade motora do que estímulos rítmicos rígidos (Ready, 2019).

A variabilidade da marcha, longe de representar erro, constitui um marcador de saúde do sistema motor. A perda desta variabilidade e da complexidade temporal está associada ao envelhecimento e a patologias neurológicas, refletindo uma menor capacidade de adaptação às exigências do ambiente (Sherrington et al. 2020; Riemann & Lephart 2002).

1.4. Controlo postural

O controlo postural depende da integração dinâmica dos sistemas visual, vestibular e somatossensorial, permitindo a manutenção da estabilidade em relação à gravidade. A oscilação postural resulta da ação contínua de mecanismos de feedback neural que compensam perturbações internas e externas (Massion, 1994).

A análise do centro de pressão (CoP) constitui um dos principais indicadores biomecânicos da estabilidade postural. Abordagens não lineares, como a análise fractal, permitem caracterizar a complexidade temporal das oscilações posturais, oferecendo informação sobre a adaptabilidade do sistema de controlo motor (Wayne et al., 2013).

O envelhecimento está associado a uma redução da complexidade do CoP e a uma maior dependência do feedback visual, comprometendo a capacidade de adaptação a ambientes instáveis e aumentando o risco de quedas (Lipsitz & Goldberger, 1992).

1.5. Marcha

A marcha humana é um processo complexo que resulta da coordenação entre sistemas neuromuscular, esquelético e sensorial. Alterações na marcha são frequentes em



adultos mais velhos e estão associadas à redução da qualidade de vida, aumento do risco de quedas e declínio cognitivo (Baker, 2018).

A variabilidade e a complexidade dos padrões de marcha refletem a flexibilidade do sistema motor. A perda desta complexidade está associada ao envelhecimento e a doenças neurológicas, enquanto padrões saudáveis de variabilidade favorecem a adaptação a ambientes imprevisíveis (Likens et al., 2021; Vaz et al., 2020).

Abordagens não lineares permitem avaliar a estabilidade dinâmica da marcha e identificar indivíduos com maior risco de queda. Além disso, estímulos externos estruturados, como sinais auditivos com propriedades fractais, têm demonstrado potencial para restaurar padrões de marcha mais adaptativos (João R. Vaz et al., 2020).

1.6. Aplicações móveis

Os smartphones, equipados com sensores inerciais, representam uma solução acessível e portátil para a recolha de dados biomecânicos relacionados com a marcha e o equilíbrio. A utilização de aplicações móveis na área da saúde (mHealth) tem crescido, permitindo avaliações quantitativas em contextos clínicos, comunitários e educativos (Sampaio et al., 2017).

Apesar do potencial destas tecnologias, a sua adoção por adultos mais velhos enfrenta desafios relacionados com literacia digital, acesso a dispositivos e limitações cognitivas ou sensoriais. Ainda assim, quando adequadamente adaptadas, as aplicações móveis podem apoiar a promoção da AF, a prevenção de quedas e a monitorização funcional (Deniz-Garcia et al., 2023).

Entre as aplicações disponíveis, o Phyphox destaca-se pela utilização integrada de múltiplos sensores e pela possibilidade de visualização e exportação de dados em tempo real, constituindo uma ferramenta relevante para avaliação e investigação do movimento humano (Sampaio et al., 2017; Malacrida, 2021a).

1.7. Proposta de intervenção, materiais e metodologia para avaliar a intervenção definida

A investigação iniciou-se com a contextualização da investigação, incluindo a motivação, a relevância e os objetivos do estudo. Para tal, foi efetuada uma análise bibliográfica dos vários conceitos a analisar, bem como uma revisão da literatura e um enquadramento teórico, que foi estabelecido nesta fase inicial para suportar o estudo (incluindo a intervenção, a sua duração e os materiais propostos para a realização das



avaliações e baterias de testes a incorporar). Esta fase terminou com uma análise bibliométrica das tendências do sedentarismo, que resultou na publicação de dois artigos, um primeiro que procurou avaliar a evolução dos documentos relacionados com a forma como um estilo de vida sedentário influencia o processo de envelhecimento (apêndice 4) e um segundo artigo onde procurámos avaliar a evolução dos documentos relacionados com a influência da AF e da capacidade funcional ao longo do processo de envelhecimento (apêndice 5).

Para a recolha de dados desta amostra ((inscritos em atividades da Câmara municipal de Almada (CMA))), foi solicitada uma autorização formal aos colaboradores da CMA através de uma reunião presencial, seguida de um pedido de autorização formal ao diretor do departamento do desporto. As avaliações e a intervenção decorreram no Complexo municipal dos desportos “cidade de Almada”. Inicialmente, fizemos uma primeira ronda de testes ao equipamento, envolvendo a recolha de dados junto dos participantes. Esta fase teve como objetivo avaliar a viabilidade de implementação do equipamento no terreno, bem como a calendarização da intervenção de forma a não interromper o fluxo de trabalho dos técnicos que ajudaram durante a aplicação do projeto. Avaliámos que equipamentos funcionavam eficazmente e quais os que não funcionavam, permitindo-nos tomar decisões informadas sobre o que incluir ou excluir. Este processo ajudou na transição do planeamento teórico para a aplicação prática, assegurando que apenas as ferramentas mais eficazes tenham sido utilizadas no estudo.

Foi efetuado um ensaio controlado aleatório de grupos paralelos, incluindo uma fase de intervenção de 6 meses. Para ambos os grupos (controlo e experimental), foram realizadas avaliações na linha de base (antes de iniciar a intervenção) e após o fim da intervenção. Cada participante do grupo de intervenção (GI) recebeu uma intervenção, enquanto cada participante do grupo de controlo (GC) apenas realizou as avaliações antes e após a intervenção, e as suas tarefas diárias. Após o estudo, foi oferecido o mesmo número de aulas de treino sensório motor aos participantes do GC, no entanto não houve disponibilidade da CMA para a continuidade do projeto.

1.8. Considerações éticas

Este projeto foi aprovado pela Comissão de Ética da Universidade de Évora (número de aprovação: 21040). O estudo foi registado no Clinical Trials.gov PRRS *Protocol Registration and Results System* (Número de Registo: NCT05398354;



[https://www.clinicaltrials.gov/ct2/show/NCT05398354?term=NCT05398354&draw=2](https://www.clinicaltrials.gov/ct2/show/NCT05398354?term=NCT05398354&draw=2&rank=1)
&rank=1 (accedido em 12 de junho de 2022).

1.9. Cronograma do estudo

A investigação decorreu de acordo com o seguinte calendário:

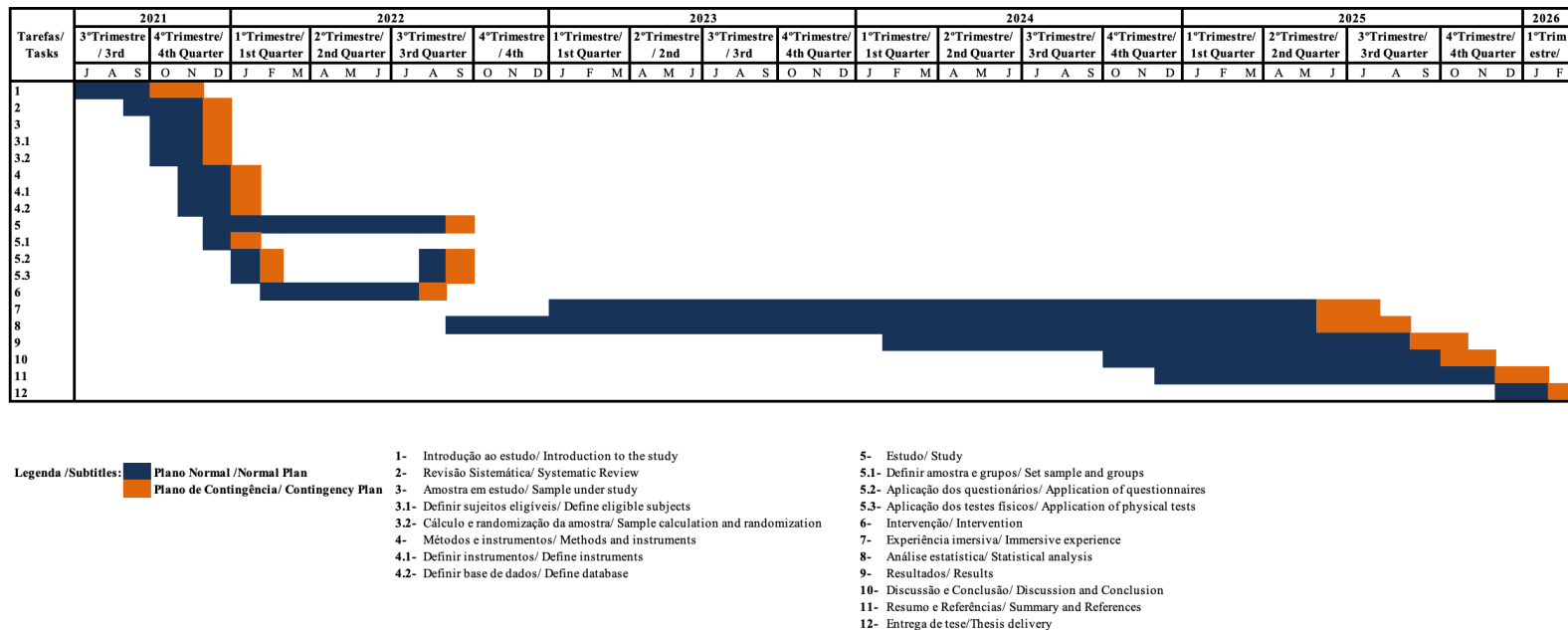


Figura 1- Cronograma.

1.10. Principais conclusões

O que é que já se sabe sobre o tema?

- O processo de envelhecimento é contínuo e irreversível, estando associado ao declínio das funções físicas e cognitivas, o que compromete a autonomia e a qualidade de vida dos indivíduos.
- A prática regular de exercício físico, devidamente estruturado e adaptado, é reconhecida como uma das estratégias mais eficazes para retardar os efeitos negativos do envelhecimento e prevenir doenças associadas à inatividade.
- Os programas de treino que combinam componentes motores, sensoriais e cognitivos apresentam benefícios adicionais, nomeadamente na melhoria da coordenação, do equilíbrio e da mobilidade funcional.
- Fatores de impacto negativo como o sedentarismo, hábitos de vida inadequados (consumo de tabaco e álcool), bem como a ausência de políticas de intervenção estruturadas para a população idosa, dificultam a adesão a programas regulares de AF.



- Já existem evidências que demonstram que a intervenção precoce e sustentada em indivíduos em idade pré-reforma ou reforma contribui para reduzir a dependência funcional e melhorar o bem-estar geral.

O que acrescenta este projeto?

- Identificação de fatores-chave: o projeto permitiu identificar variáveis determinantes para a adesão e eficácia de programas de treino em indivíduos entre os 55 e os 80 anos, destacando a importância da progressão ajustada, da diversidade de exercícios e da adaptação às necessidades individuais.
- Desenvolvimento de um programa formal de exercício: foi criado o programa “Reforma Ativa”, com estrutura metodológica clara (24 semanas de intervenção inicial, seguidas de acompanhamento), baseado em circuitos progressivos que podem ser replicados em diferentes contextos.
- Melhoria da saúde e desempenho: os resultados mostraram benefícios significativos na composição corporal, força, flexibilidade, agilidade, controlo postural e marcha, assim como melhorias na qualidade de vida relacionada com a saúde (QVRS) e nos níveis de atividade física (NAF).
- Recomendações baseadas em evidência: este projeto contribui para a criação de um manual de treino dirigido a técnicos e fisiologistas do exercício, bem como de uma plataforma online com treinos semanais, disponibilizando ferramentas práticas e de fácil acesso que poderão ser implementadas em serviços de saúde, programas sociais e municípios.
- Promoção da qualidade de vida: este projeto reforça a importância da AF enquanto estratégia central de saúde pública, sugerindo a integração de programas como o “Reforma Ativa” em políticas locais e nacionais, de forma a promover um envelhecimento mais saudável, ativo e autónomo.

1.11. Racional da tese e articulação dos artigos

O processo de envelhecimento está associado a um declínio progressivo da capacidade funcional, do equilíbrio e da marcha, comprometendo a autonomia, a qualidade de vida e aumentando o risco de quedas. Apesar do reconhecimento da AF como uma estratégia fundamental para um envelhecimento saudável, persistem lacunas na implementação de programas estruturados, acessíveis e baseados em evidência científica, especialmente dirigidos a adultos entre os 55 e os 80 anos.



Paralelamente, observa-se uma escassez de estudos que integrem o treino sensório motor com a análise da marcha e do controlo postural, recorrendo simultaneamente a tecnologias móveis de baixo custo que permitam a avaliação e monitorização em contextos reais. A maioria das investigações permanece confinada ao laboratório, limitando a sua aplicabilidade clínica e comunitária.

Neste contexto, a presente tese teve como objetivo geral desenvolver, implementar e avaliar um programa estruturado de treino sensório motor, analisando o seu impacto na capacidade funcional, controlo postural, marcha, níveis de AF e qualidade de vida relacionada com a saúde em adultos com idades compreendidas entre os 55 e os 80 anos.

A investigação foi organizada em vários estudos interligados. Inicialmente, foram conduzidos estudos de revisão da literatura, seguidos de estudos de revisão bibliométricos com o intuito de mapear as tendências científicas relacionadas com o sedentarismo, a AF e a capacidade funcional ao longo do envelhecimento. Estes estudos forneceram a base conceptual para o desenvolvimento do programa de intervenção. Posteriormente, foi implementado um ensaio controlado aleatorizado para avaliar os efeitos do treino sensório motor, recorrendo a avaliações funcionais e à utilização de sensores inerciais integrados em smartphones.

No seu conjunto, os estudos que compõem esta tese contribuem para o avanço do conhecimento científico na área do envelhecimento ativo e apresentam soluções práticas e replicáveis, nomeadamente através do programa “Reforma Ativa”, do desenvolvimento de ferramentas digitais e da proposta de integração destas intervenções em contextos comunitários e de saúde pública.

1.12. Lista de artigos

Esta tese de doutoramento baseia-se em dez estudos que foram desenvolvidos no período de 2020-2026 (em curso) no Instituto de investigação e formação avançada (IIFA), Faculdade de desporto e saúde, Universidade de Évora, Portugal.

Os estudos criados são:

Tabela 1- Lista de artigos científicos para a tese de doutoramento.

Estudos	Jornal e status	Quartile e fator de impacto
1. Physical training programs improve sensorimotor skills in older adults: Systematic Review with relevance to COVID-19	 Publicado: https://doi.org/10.25242/8868144920242686	Sem IF



2. The Influence of Postural Control on the Risk of Falls in the Elderly: Systematic Review



Q2
IF 1.4

Em revisão.

3. Evolution of research related to how a sedentary lifestyle influences the aging process: a bibliometric review



Q1
IF 1.9

Publicado: <https://doi.org/10.1007/s10389-024-02327-7>

4. Evolution of documents related to the influence of physical activity and functional capacity throughout the aging process: a bibliometric review



Q1
IF 5.2

Publicado: <https://doi.org/10.3389/fphys.2024.1427038>

5. Protocolo do Estudo “An Active Retirement Programme, a Randomized Controlled Trial of a Sensorimotor Training Programme for Older Adults: A Study Protocol”



Q2
IF 2.4

Publicado: <https://doi.org/10.3390/healthcare11010086>

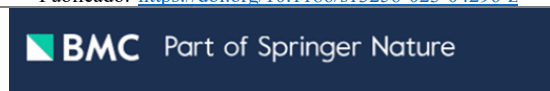
6. Assessment of spatiotemporal characteristics of gait, through the Phyphox® app: a case series



Q3
IF 2.6

Publicado: <https://doi.org/10.1186/s13256-023-04296-z>

7. The Impact of Sensorimotor Training on Physical Fitness in Older Women with Diabetes: A Pilot Study



Q1
IF 3.8

BMC Geriatrics

Publicado: <https://doi.org/10.1186/s12877-025-06591-4>

8. Evaluating the Effects of Sensorimotor Training on the Physical Capacities of Older People



Q1
IF 2.6

Publicado: <https://doi.org/10.3390/ejihpe15040050>

9. Effectiveness of different physical activity programs in improving older adults' physical capacities: a randomized controlled trial



Q2
IF 3.4

Publicado: <https://doi.org/10.3389/fphys.2025.1540776>



10. The Role of Physical Exercise in Enhancing Health, Quality of Life and Joy Among Older Adults

scientific reports

Q1
IF 3.9

Publicado: <https://doi.org/10.1038/s41598-025-26683-w>

11. Effects of Sensorimotor Training on postural sway during quiet standing in healthy older adults: A randomized controlled trial.



Q2
IF 1.3

Publicado: <https://doi.org/10.1007/s11332-026-01686-w>

12. Analysis of postural control through non-linear methods in older adults: A randomized controlled trial.



Q2
IF 2.4

Aceite para publicação.

O quadro lógico do projeto inspira-se nos princípios de inferência forte descritos por Platt (1964) e na estruturação progressiva do raciocínio científico proposta por Crick (1990), sendo representado através de um diagrama em árvore que organiza os artigos desenvolvidos ao longo da tese.

7. RCTs resultados dos questionários no papel do exercício físico na melhoria da saúde, na qualidade de vida e bem-estar em adultos mais velhos.

8. RCTs resultados do controlo postural através da análise linear.

9. RCTs resultados do controlo postural através da análise não linear.

6. RCTs resultados das capacidades físicas através do treino de diferentes programas de atividade física.

5. RCTs resultados das capacidades físicas através do treino sensório motor.

4. Estudos de caso.

3. Protocolo do estudo.

2. Revisões Bibliométricas.

1. Revisões da Literatura.

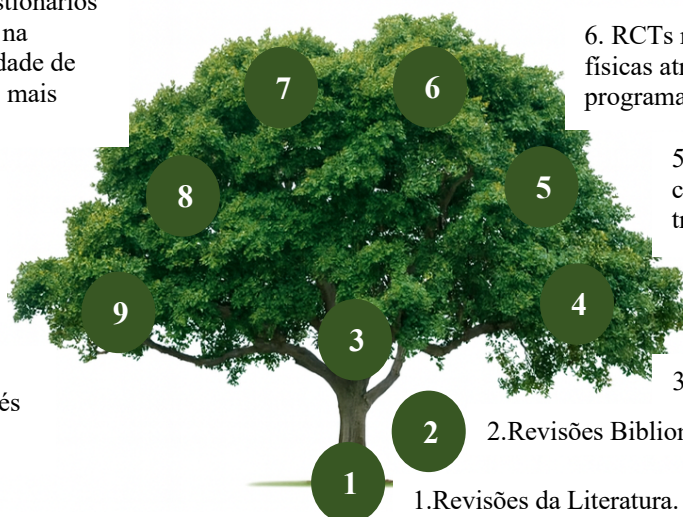


Figura 2- Estrutura da tese.

A metáfora da árvore representa não apenas a organização estrutural da tese, mas também o crescimento progressivo do conhecimento ao longo do processo investigativo.



1.13. Divulgação do trabalho de tese

Para o público em geral e outros grupos pertinentes, o acesso aos resultados do estudo pode ser facilitado através da publicação em revistas científicas. Esta abordagem de divulgação garante que os resultados do estudo são acessíveis a um público mais vasto, contribuindo para uma base de conhecimentos científicos e profissionais mais alargada. Para a divulgação do trabalho de tese, todos os artigos foram submetidos a revistas especializadas.

Para divulgar os resultados deste trabalho de doutoramento, houve participação em congressos como membro de um conselho científico, bem como através de apresentações orais e posters. Adicionalmente, a lecionação de aulas de doutoramento sobre os processos de desenvolvimento do projeto e da tese também ajudou a mostrar o trabalho desenvolvido nesta investigação. Além disso, o apoio à orientação de uma mestranda da Universidade de Évora, na área do treino em adultos mais velhos, colocará em prática todos os conhecimentos adquiridos ao longo deste processo. As certificações deste trabalho de divulgação encontram-se no Apêndice 1.

Por fim, a estratégia de comunicação para a divulgação dos resultados aos participantes e aos profissionais da CMA assenta na partilha transparente e completa da informação recolhida, dos resultados obtidos e das principais conclusões. Neste âmbito, foi já realizada uma reunião com o diretor do Departamento de Desporto da CMA e com os técnicos superiores responsáveis pelo projeto, logo após a conclusão da intervenção. Está igualmente prevista uma segunda reunião, a realizar após a publicação desta tese e dos artigos submetidos, que reunirá todos os responsáveis da CMA que contribuíram para o desenvolvimento e concretização deste projeto.



Capítulo 2 | Contexto

2.1. Envelhecimento: pesquisas na literatura

O envelhecimento demográfico constitui um dos principais desafios do século XXI, refletindo-se no aumento contínuo da proporção de indivíduos a nível mundial e nacional, com projeções que indicam uma duplicação da população com 65 anos ou mais até 2050. Esta transformação demográfica tem implicações significativas na saúde pública, particularmente devido ao aumento da prevalência de doenças crónicas, incapacidade funcional e necessidade de cuidados de longa duração (World Health Organization, 2020). Apesar da vasta produção científica nesta área, grande parte dos estudos permanece centrada na caracterização epidemiológica do envelhecimento, sendo menos frequentes investigações longitudinais capazes de compreender a evolução funcional ao longo do tempo.

O envelhecimento é um processo natural e heterogéneo, caracterizado por um declínio progressivo das funções fisiológicas, cuja velocidade varia consideravelmente entre indivíduos em função de fatores genéticos, ambientais e comportamentais. A literatura tem descrito este fenómeno através do conceito de “fenótipo do envelhecimento”, que integra alterações morfológicas, funcionais e cognitivas associadas ao aumento da vulnerabilidade a doenças crónicas (López-Otín et al., 2013; Izquierdo et al., 2025). Contudo, embora este enquadramento conceptual seja amplamente aceite, muitos estudos permanecem focados em marcadores isolados do envelhecimento, limitando uma compreensão integrada das interações entre sistemas fisiológicos (World Health Organization & Regional Office for Europe, 2021).

Para além das alterações biológicas, o envelhecimento envolve importantes dimensões psicossociais e funcionais. A diminuição da força muscular, da mobilidade e do equilíbrio está associada ao aumento do risco de quedas, perda de autonomia e redução da qualidade de vida (Wang et al., 2025; Noto, 2023). Paralelamente, fatores psicossociais como medo de cair, solidão, depressão e baixa autoeficácia contribuem para níveis mais elevados de sedentarismo e declínio funcional (Cabo et al., 2022). Apesar de estes fatores serem frequentemente identificados na literatura, muitos estudos analisam-nos de forma independente, existindo ainda necessidade de abordagens integradoras que considerem simultaneamente determinantes biológicos, comportamentais e contextuais do envelhecimento funcional.



Adicionalmente, condições como sarcopenia e fragilidade têm sido reconhecidas como marcadores centrais do declínio funcional associado à idade, sendo influenciadas tanto pelo envelhecimento fisiológico como por estilos de vida sedentários e inadequação nutricional (Larsson et al., 2019). Embora os benefícios do exercício físico sejam consistentemente relatados como estratégia preventiva, observa-se que uma parte significativa das investigações recorre a intervenções de curta duração ou a desenhos transversais, limitando a compreensão dos efeitos sustentados ao longo do tempo e a transferência dos resultados para programas comunitários estruturados.

Neste contexto, o conceito de envelhecimento saudável, definido como a manutenção da capacidade funcional ao longo da vida, reforça a necessidade de desenvolver intervenções baseadas em evidência que promovam simultaneamente a funcionalidade física, a participação social e o bem-estar psicológico (World Health Organization, 2020). Ainda assim, permanece evidente a lacuna de estudos que integrem programas estruturados de intervenção sensório motora com avaliação funcional multidimensional e acompanhamento longitudinal, aspecto que fundamenta a relevância da presente investigação.

2.2. Influência do sedentarismo no processo de envelhecimento

O envelhecimento é um processo progressivo caracterizado por alterações fisiológicas e funcionais que aumentam a vulnerabilidade a doenças crónicas e incapacidade funcional. Embora biologicamente inevitável, a evidência demonstra que fatores comportamentais, particularmente os níveis de AF e o tempo despendido em comportamentos sedentários, desempenham um papel determinante na modulação da trajetória do envelhecimento (Izquierdo et al., 2025). Ainda assim, uma parte significativa da literatura concentra-se na associação entre AF e saúde, permanecendo relativamente menor a atenção dada ao impacto independente do sedentarismo enquanto fator de risco específico.

A prática regular de AF está consistentemente associada ao aumento da longevidade, melhoria da qualidade de vida e redução do risco de doenças cardiovasculares (DCV), metabólicas e neurodegenerativas (Anderson & Durstine, 2019). Níveis elevados de aptidão cardiorrespiratória (CRF) têm sido identificados como fortes preditores de redução da mortalidade, frequentemente superando fatores de risco tradicionais como hipertensão, tabagismo ou diabetes mellitus tipo 2 (DM2) (Ross et al., 2016). Contudo, apesar da robustez destas evidências, estudos populacionais indicam que



mais de um quarto da população mundial não cumpre as recomendações mínimas de AF, situação particularmente relevante na população idosa, onde a adesão a programas estruturados permanece reduzida (Bull et al., 2020).

Para além da insuficiência de AF, o sedentarismo — definido como comportamentos de vigília com gasto energético ≤ 1.5 METs — tem emergido como um fator de risco independente para declínio funcional e mortalidade precoce (Mansoubi et al., 2015; Park et al., 2020). A literatura demonstra que períodos prolongados em posição sentada estão associados a alterações metabólicas adversas, incluindo menor sensibilidade à insulina, disfunção endotelial e perfis lipídicos desfavoráveis, contribuindo para o aumento do risco cardiometabólico mesmo em indivíduos fisicamente ativos (Goyal & Rakhra, 2024; Teno et al., 2024). Apesar destas descobertas consistentes, muitos estudos continuam a analisar AF e sedentarismo como dimensões opostas do mesmo comportamento, limitando a compreensão do seu impacto independente e combinado no envelhecimento funcional.

Mudanças sociais e tecnológicas, como a digitalização do trabalho e o aumento do tempo de ecrã, têm contribuído para a crescente prevalência de comportamentos sedentários ao longo do ciclo de vida. Em resposta, organismos internacionais reforçam a promoção de estilos de vida ativos como estratégia central de saúde pública, recomendando não apenas o cumprimento das metas semanais de exercício, mas também a redução do tempo sedentário diário (World Health Organization, 2020). No entanto, a tradução destas recomendações em intervenções sustentadas na comunidade permanece um desafio, especialmente em populações idosas com limitações funcionais ou baixa motivação para a prática de exercício estruturado.

Para além dos efeitos físicos, a evidência sugere que a AF regular contribui para a preservação da função cognitiva, promovendo neuroplasticidade, aumento de fatores neurotróficos e redução de processos inflamatórios associados ao envelhecimento cerebral (Bae et al., 2020; Erickson et al., 2011). Apesar destes resultados promissores, muitos estudos apresentam desenhos transversais ou intervenções de curta duração, limitando a compreensão dos efeitos acumulativos e sustentados da redução do sedentarismo e do aumento da AF ao longo do envelhecimento. Estas limitações reforçam a necessidade de investigações que integrem intervenções estruturadas, monitorização objetiva do comportamento motor e avaliação longitudinal dos efeitos funcionais e cognitivos.



Em conjunto, a evidência demonstra que, embora o envelhecimento esteja associado a declínios fisiológicos progressivos, a magnitude dessas alterações é fortemente modulada por fatores comportamentais, particularmente os níveis de AF e os padrões de sedentarismo. Contudo, apesar do consenso sobre os benefícios do exercício, persistem lacunas relevantes na compreensão de como intervenções estruturadas, monitorizadas de forma objetiva e implementadas a médio e longo prazo, podem otimizar a capacidade funcional e prevenir o declínio associado ao envelhecimento. Neste contexto, torna-se essencial investigar estratégias de intervenção que integrem avaliação funcional, monitorização tecnológica e programas de exercício multicomponente dirigidos à população idosa.

2.3. Influência da atividade física e da capacidade funcional ao longo do processo de envelhecimento

A AF e o exercício estruturado são amplamente reconhecidos como intervenções centrais na prevenção e gestão de síndromes geriátricas, contribuindo para a preservação da função muscular, aptidão cardiorrespiratória, equilíbrio e capacidade funcional global (Alodhialah et al., 2025). Evidência acumulada indica que a prática regular de AF de intensidade moderada, aproximadamente 150 minutos semanais, está associada à redução do risco de doenças crónicas, declínio cognitivo e mortalidade, bem como à melhoria do bem-estar emocional e da participação social (Hung et al., 2023; McPhee et al., 2016). Contudo, apesar da consistência destes resultados, muitos estudos baseiam-se em intervenções de curta duração ou em avaliações autorreportadas de AF, limitando a compreensão dos efeitos sustentados a médio e longo prazo e a precisão da monitorização comportamental.

Os determinantes da saúde e da longevidade resultam da interação dinâmica entre fatores genéticos, ambientais e comportamentais, frequentemente mediada por mecanismos epigenéticos influenciados pelo estilo de vida e pelas exposições ao longo do ciclo de vida (Barrès & Zierath, 2016; Cao-Lei et al., 2016). Neste contexto, embora existam determinantes não modificáveis do envelhecimento, fatores comportamentais, particularmente a AF, desempenham um papel central na modulação da capacidade funcional e podem atenuar parcialmente os efeitos adversos associados à predisposição genética e às alterações fisiológicas relacionadas com a idade.

A Organização mundial de saúde (OMS) enquadra o envelhecimento saudável como o resultado da interação entre capacidade intrínseca e ambiente, enfatizando a



autonomia funcional como indicador central de saúde em idades avançadas (Beard et al., 2016; World Health Organization, 2020). A evidência atual sugere que a prática regular de AF contribui positivamente para múltiplos domínios da capacidade intrínseca, incluindo mobilidade, cognição e vitalidade, estando associada à redução da mortalidade e à manutenção da independência funcional (Ramírez-Vélez et al., 2023; Sánchez-Sánchez et al., 2024). No entanto, persistem desafios relevantes relacionados com a adesão a programas de exercício, particularmente em populações envelhecidas e com níveis socioeconómicos mais baixos, o que limita o impacto populacional destas intervenções.

Apesar dos benefícios amplamente documentados, a participação em AF permanece insuficiente em vários países europeus, sendo Portugal um dos contextos com maior prevalência de sedentarismo (Alvarez-Lourido et al., 2023). Esta realidade reforça a necessidade de desenvolver estratégias de intervenção que combinem programas de exercício baseados em evidência, monitorização contínua e abordagens personalizadas capazes de aumentar a adesão e a eficácia das intervenções ao longo do tempo.

2.3.1. Treino multicomponente e personalização

O envelhecimento está associado a alterações fisiológicas progressivas, incluindo diminuição do consumo máximo de oxigénio (VO_{2max}), perda de massa e potência muscular, menor eficiência neuromuscular e alterações propriocetivas, fatores que contribuem para a redução da mobilidade e aumento do risco de quedas (Dhahbi et al., 2025). Estas mudanças justificam a necessidade de programas de exercício individualizados, ajustados ao estado funcional, às comorbilidades e ao perfil de risco de cada indivíduo. Embora a literatura demonstre benefícios consistentes do exercício em adultos mais velhos, observa-se heterogeneidade significativa nos protocolos utilizados, dificultando a definição de modelos de intervenção padronizados e comparáveis.

O treino resistido progressivo (PRT) é amplamente considerado um componente essencial das intervenções em populações envelhecidas, demonstrando eficácia na melhoria da força e potência muscular, na prevenção da sarcopenia e na preservação da autonomia funcional (Cruz-Jentoft et al., 2019; Izquierdo et al., 2025). Adicionalmente, o treino de potência muscular tem ganho destaque como um dos principais preditores de independência funcional e prevenção de quedas, evidenciando a importância de incluir exercícios executados a velocidades elevadas e com cargas adaptadas (Cadore & Izquierdo, 2018).



O treino de equilíbrio e proprioceptivo constitui igualmente um componente crítico, particularmente quando integrado em programas que combinam estímulos estáticos, dinâmicos e tarefas cognitivas simultâneas, promovendo adaptações sensório motoras relevantes para a mobilidade funcional segura (Sadaqa et al., 2023). Neste sentido, programas multicomponentes que integram treino de força, potência, resistência cardiorrespiratória, mobilidade e equilíbrio têm demonstrado maior eficácia na melhoria da capacidade funcional global e na redução do risco de quedas do que intervenções baseadas em componentes isolados (Sherrington et al., 2020). Contudo, a literatura evidencia que muitos programas carecem de monitorização individualizada da progressão e de avaliação sistemática da resposta funcional ao treino, constituindo uma limitação relevante na implementação clínica e comunitária destas intervenções.

2.3.2. Benefícios clínicos e cognitivos

Para além dos efeitos na capacidade funcional, a AF e o exercício estruturado exercem impactos significativos nos domínios clínico, cognitivo e psicossocial. A prática regular de exercício contribui para a redução da inflamação sistémica, melhoria da sensibilidade à insulina, regulação da pressão arterial e aumento da capacidade cardiorrespiratória, desempenhando um papel relevante na prevenção e controlo de doenças cardiometabólicas e musculoesqueléticas (Goyal & Rakhra, 2024). Apesar destes benefícios consistentes, a maioria dos estudos clínicos apresenta períodos de seguimento relativamente curtos, limitando a compreensão do efeito cumulativo das intervenções ao longo do envelhecimento.

No domínio cognitivo, o exercício físico está associado à melhoria de funções executivas, memória e velocidade de processamento, possivelmente mediada por mecanismos de neuroplasticidade, angiogénese e aumento de fatores neurotróficos (Dhahbi et al., 2025). Intervenções que combinam estímulos motores e cognitivos, como treino de dupla tarefa (DT) ou exercícios sensório motores, parecem apresentar benefícios adicionais, sugerindo que abordagens integradas podem ser particularmente relevantes para a preservação da funcionalidade em idades avançadas (Rieker et al., 2022).

Adicionalmente, a participação em programas de exercício está associada à redução de sintomas depressivos, ansiedade e isolamento social, bem como à melhoria da qualidade de vida relacionada com a saúde e da autoeficácia, fatores determinantes para a adesão a longo prazo (Ruiz-Comellas et al., 2022). Ainda assim, permanece limitada a evidência sobre estratégias eficazes para manter a participação contínua em programas de



exercício após o término das intervenções supervisionadas, constituindo uma lacuna relevante na literatura.

2.3.3. Perspetiva em saúde pública

Do ponto de vista da saúde pública, o envelhecimento populacional e a elevada prevalência de inatividade física representam desafios significativos para a sustentabilidade dos sistemas de saúde. A evidência demonstra que a promoção da AF constitui uma das estratégias mais custo-efetivas para reduzir hospitalizações, dependência funcional e mortalidade prematura (World Health Organization, 2020). Contudo, apesar das recomendações internacionais e da existência de programas comunitários, a implementação em larga escala permanece desigual entre regiões e grupos socioeconómicos.

Programas comunitários multicomponentes têm demonstrado eficácia na melhoria da funcionalidade e na redução do risco de quedas, mas muitos carecem de estratégias sistemáticas de monitorização, avaliação de impacto e integração com cuidados de saúde primários, limitando a sua sustentabilidade (Hopewell et al., 2018). Paralelamente, a literatura destaca a importância de reduzir o comportamento sedentário, não apenas aumentar os níveis de AF, evidenciando que interrupções frequentes do tempo sentado podem produzir benefícios metabólicos relevantes, particularmente em populações idosas com risco cardiometabólico elevado (Keadle et al., 2017).

A promoção de ambientes facilitadores do movimento, o desenvolvimento de soluções digitais acessíveis e a criação de programas domiciliários supervisionados surgem como estratégias promissoras para reduzir desigualdades no acesso à prática de exercício (Maresova et al., 2023). Assim, o exercício físico deve ser enquadrado não apenas como intervenção clínica individual, mas como componente estruturante das políticas públicas de envelhecimento ativo, com potencial impacto na qualidade de vida das populações envelhecidas e na sustentabilidade dos sistemas de saúde (Marquez et al., 2020).

2.4. Características espaço-temporais da marcha em adultos mais velhos: aplicação móvel Phyphox®

As alterações espaço-temporais da marcha são fundamentais para compreender o controlo motor e a estabilidade em adultos mais velhos. Diversos estudos indicam que, comparados a adultos mais jovens, os adultos mais velhos apresentam maior variabilidade



no tempo da passada, sugerindo perdas de coordenação neuromuscular associadas ao envelhecimento (Stergiou & Decker, 2011). Apesar destes contributos, grande parte da evidência baseia-se em amostras pequenas ou desenhos transversais, limitando a compreensão sobre a evolução destas alterações ao longo do tempo e a sua generalização para diferentes contextos funcionais.

A variabilidade rítmica de sistemas biológicos tende a exibir padrões fractais, ou seja, semelhanças estruturais em diferentes escalas temporais. Por esta razão, métricas que avaliam a qualidade da variabilidade, e não apenas a quantidade, têm ganho destaque na literatura, permitindo caracterizar a natureza dinâmica e adaptativa do sistema locomotor (Stergiou & Decker, 2011; Wang et al., 2025). No entanto, poucos estudos exploram como estas métricas refletem a adaptabilidade funcional em situações da vida quotidiana ou em adultos mais velhos com diferentes níveis de mobilidade. Quando a variabilidade se torna desorganizada e mal adaptativa, o risco de quedas e lesões aumenta, particularmente devido à dificuldade em ajustar a marcha a contextos exigentes.

Estudos recentes indicam que diferentes populações clínicas podem apresentar níveis semelhantes de variabilidade rítmica, mas com consequências funcionais distintas. Esta heterogeneidade sugere que apenas quantificar a variabilidade não é suficiente para avaliar risco funcional, apontando para a necessidade de métodos que capturem a qualidade adaptativa da marcha (Faure et al., 2022; Stergiou & Decker, 2011).

O envelhecimento ativo é essencial para preservar independência, mobilidade e qualidade de vida. Contudo, as alterações funcionais típicas da idade aumentam o risco de desequilíbrios posturais e quedas, atualmente a segunda principal causa de morte accidental no mundo, afetando sobretudo pessoas com mais de 65 anos (Giovannini et al., 2022). Grande parte da literatura sobre prevenção de quedas foca-se em intervenções de curta duração ou em contextos laboratoriais, limitando a compreensão do impacto de abordagens prolongadas e aplicáveis no dia a dia.

As consequências das quedas vão além das lesões físicas, incluindo perda de independência, medo de novas quedas e redução da prática de AF — fatores que aceleram o declínio funcional e favorecem o isolamento social (Sadaqa et al., 2023). Neste contexto, a avaliação clínica detalhada é essencial, incluindo historial de quedas, força muscular, amplitude articular, testes de marcha e equilíbrio. Apesar da disponibilidade destes instrumentos, há lacunas na monitorização contínua e no acesso a avaliações funcionais precisas fora do contexto clínico (Montero-Odasso et al., 2022).



2.4.1. Tecnologia como apoio à avaliação da marcha

O avanço tecnológico tem modernizado as práticas clínicas, destacando-se o uso de dispositivos móveis como ferramentas acessíveis, portáteis e de baixo custo. Smartphones podem recolher dados fisiológicos e funcionais relevantes, integráveis em programas de monitorização e apoio ao diagnóstico (Sampaio et al., 2017; Santos et al., 2019). Aplicações móveis específicas permitem que adultos mais velhos monitorizem parâmetros de saúde de forma autónoma e em tempo real, promovendo autogestão e personalização dos cuidados (Cajamarca et al., 2020).

Entre estas aplicações, o Phyphox®, desenvolvido no Instituto de Física da Universidade Técnica de Aachen (Alemanha), distingue-se por ser de código aberto e gratuito, utilizando sensores dos smartphones para experiências científicas e avaliações funcionais (Malacrida, 2021b; Staacks, 2018). Apesar das vantagens, a literatura ainda é limitada quanto à validação das medições frente a métodos laboratoriais padrão, à fiabilidade em adultos mais velhos com diferentes níveis de mobilidade, e à aplicabilidade em contextos clínicos rotineiros.

O Phyphox® permite medições em tempo real, visualizações gráficas interativas e exportação de dados, com sensores como acelerómetro, giroscópio, microfone, magnetómetro e sensor de luz, possibilitando análises detalhadas da marcha e equilíbrio (Cabo et al., 2023; Landeira et al., 2020). Ainda assim, poucas investigações examinaram o uso desta aplicação especificamente para caracterizar padrões espaço-temporais da marcha em adultos mais velhos, apontando uma lacuna que a presente tese procura colmatar.

2.5. Treino sensório motor: definição e tendências de pesquisa

Promover um envelhecimento saudável requer estratégias que não apenas aumentem os níveis de AF, mas também melhorem a adesão às recomendações internacionais. Uma abordagem valorizada é a integração do exercício na rotina quotidiana, como subir escadas em vez do elevador ou realizar exercícios funcionais durante tarefas domésticas (Izquierdo et al., 2021). Estudos sugerem que estas estratégias baseadas em atividades de vida diária podem ser mais eficazes do que programas tradicionais para prevenir quedas, tornando o exercício mais acessível e contextualizado, e favorecendo a adesão (Clemson et al., 2012). Apesar destes avanços, a adesão global continua baixa, evidenciada por dados norte-americanos que indicam um aumento de



apenas 17% para 23% na proporção de adultos que cumprem simultaneamente as diretrizes de exercício aeróbico e de resistência entre 2015 e 2019 (Bennie et al., 2019; Garcia-Hermoso et al., 2023). Isso sugere que intervenções mais eficazes e adaptadas ao cotidiano dos adultos mais velhos continuam a ser necessárias.

A OMS recomenda que indivíduos com ≥ 65 anos realizem 150 minutos de AF moderada ou 75 minutos de AF vigorosa por semana, complementados por fortalecimento muscular em pelo menos dois dias (World Health Organization, 2020). Programas multicomponentes — combinando resistência, equilíbrio e capacidade aeróbica — são recomendados especialmente em indivíduos frágeis (Di Lorito et al., 2021). Embora estas diretrizes sejam claras, o incumprimento generalizado destaca lacunas na implementação prática e na motivação individual, limitando os benefícios da AF em larga escala.

O sedentarismo está associado a sarcopenia, fragilidade, obesidade, DCV, diabetes tipo 2 e maior mortalidade, enquanto a AF regular apresenta benefícios consistentes na função muscular, saúde mental, qualidade de vida e redução de mortalidade (Cadore & Izquierdo, 2015; Fiuza-Luces et al., 2018; Stanaway et al., 2018). Intervenções que combinam PRT com treino de equilíbrio demonstram maior eficácia na prevenção de quedas, enquanto o PRT isolado é considerado a abordagem mais robusta para combater a sarcopenia (Guirguis-Blake et al., 2018; Lazarus et al., 2018; Rooks et al., 2020; Sherrington et al., 2020). No entanto, muitos estudos são limitados por curta duração, amostras pequenas ou ausência de grupos de controle, restringindo a generalização e a compreensão dos efeitos a longo prazo.

O sistema sensorio motor desempenha papel central na estabilidade funcional, integrando informações sensoriais (visão, sistema vestibular, propriocepção) com respostas motoras coordenadas. O envelhecimento provoca alterações biomecânicas que comprometem a marcha, o equilíbrio e a mobilidade, aumentando o risco de quedas e perda de autonomia (Bugnariu & Fung, 2007). O treino sensorio motor tem mostrado potencial para melhorar o equilíbrio dinâmico e estático, reduzir risco de quedas e aumentar a confiança na mobilidade. Apesar disso, ainda não há consenso sobre os seus efeitos diretos em parâmetros biomecânicos relacionados ao envelhecimento, e a literatura disponível frequentemente apresenta limitações metodológicas significativas — como curta duração, amostras pequenas e falta de grupos de controle (Afonso et al., 2021; Alizadeh et al., 2022; Pšeničnik Sluga & Kozinc, 2024).

Esta lacuna evidencia a necessidade de ensaios clínicos robustos, com amostras maiores e intervenções de médio a longo prazo, capazes de consolidar a evidência sobre



os efeitos do treino sensório motor no envelhecimento. A Tabela 2 sintetiza os principais benefícios físicos e cognitivos identificados na literatura, servindo como referência para o delineamento de intervenções futuras e para a justificação da presente tese.

Tabela 2- Principais benefícios físicos e cognitivos do treino sensório motor em adultos mais velhos.

Domínio	Benefícios associados	Referências principais
Físico	Melhoria do equilíbrio estático e dinâmico; aumento da força e potência muscular; redução do risco de quedas; maior coordenação motora; otimização do tempo de reação.	Bugnariu & Fung (2007); Pšeničnik Sluga & Kozinc (2024); Afonso et al. (2021)
Cognitivo	Estimulação das funções executivas; melhoria da atenção dividida; aumento da confiança motora; prevenção e/ou atraso do declínio cognitivo associado à idade.	Castellote-Caballero et al. (2024); Vásquez-Carrasco et al. (2025)

Nota. Adaptado a partir da revisão de literatura apresentada nesta secção.

2.6. Treino sensório motor: ajustes para pessoas reformadas e pré-reformadas

A adaptação do treino sensório motor às necessidades específicas de pessoas reformadas e pré-reformadas é essencial para maximizar benefícios e garantir a segurança das intervenções. Nesta fase da vida, marcada por declínio gradual da mobilidade e da capacidade funcional, os principais objetivos são preservar a autonomia, reduzir o risco de quedas e promover a qualidade de vida (Varjan et al., 2024). Embora os estudos desta área enfatizem os benefícios gerais do treino sensório motor, ainda há escassez de investigação que diferencie estratégias específicas para pré-reformados e reformados, dificultando a personalização das intervenções.

Os programas devem priorizar estabilidade postural, mobilidade articular e coordenação motora. Exercícios em superfícies instáveis, tarefas em apoio unipedal, treinos em DT e o uso de plataformas de equilíbrio mostram resultados promissores na redução do risco de quedas (Ahmad et al., 2019). Paralelamente, o fortalecimento dos músculos dos membros inferiores e do core é determinante para atividades diárias seguras, como levantar-se de uma cadeira ou subir escadas (Kang, 2015). Apesar destes contributos, a maioria dos estudos utiliza amostras pequenas, durações curtas de intervenção ou ausência de seguimento longitudinal, limitando a generalização dos resultados e a compreensão dos efeitos a médio e longo prazo.

Intervenções combinadas com estimulação cognitiva têm ganho destaque, dado que desempenhos motores e cognitivos estão interligados, particularmente em tarefas que exigem atenção dividida, memória de trabalho ou planeamento. Essa abordagem integrada pode atrasar o declínio cognitivo e preservar funções executivas (Castellote-

Caballero et al., 2024; Vásquez-Carrasco et al., 2025). No entanto, ainda existem lacunas quanto à intensidade e frequência ideais deste tipo de treino, bem como à sua aplicabilidade em contextos comunitários fora do laboratório.

Para indivíduos pré-reformados, geralmente mais ativos e com maior reserva funcional, recomenda-se progressão gradual da intensidade e complexidade dos exercícios, adaptada ao nível físico e objetivos individuais (Di Lorito et al., 2021). Apesar da potencialidade preventiva desta abordagem, poucos estudos avaliaram intervenções nesta população específica, representando uma oportunidade para investigar estratégias que promovam uma transição saudável para a reforma.

Além dos benefícios físicos, o treino sensório motor contribui para o bem-estar psicológico, autoestima e integração social. A prática em grupo pode reduzir isolamento e reforçar o sentimento de pertença, fatores importantes para a saúde mental em idades avançadas (Mahindru et al., 2023; Martín-Rodríguez et al., 2024). Apesar destes efeitos promissores, a evidência sobre a relação causal entre treino sensório motor e melhorias psicológicas ou sociais ainda é limitada, exigindo ensaios controlados mais robustos.

Para garantir eficácia e segurança, recomenda-se integração de avaliações regulares de equilíbrio, tempo de reação e velocidade da marcha, ajustando os planos de treino de acordo com os resultados, com acompanhamento por profissionais especializados. Ainda assim, a literatura apresenta escassez de protocolos padronizados e diretrizes claras para adaptação individualizada do treino sensório motor, evidenciando uma lacuna que esta tese procura abordar.

A Tabela 3 apresenta um resumo comparativo dos principais objetivos e estratégias de treino sensório motor para pessoas pré-reformadas e reformadas, sintetizando o que se conhece e destacando áreas que carecem de investigação futura.

Tabela 3- Ajustes do treino sensório motor para pessoas pré-reformadas e reformadas.

Aspeto	Pré-reformados	Reformados
Objetivo principal	Prevenir limitações futuras e otimizar reserva funcional	Manter autonomia, reduzir risco de quedas e preservar qualidade de vida
Nível funcional	Geralmente mais elevado, maior capacidade de progressão	Tendência a declínio funcional, necessidade de maior segurança
Tipo de exercícios	Progressão gradual de intensidade e complexidade	Ênfase em exercícios básicos e seguros (estabilidade, mobilidade, equilíbrio)
Exemplos práticos	Treinos em superfícies instáveis, DT, exercícios de potência adaptados	Apoio unipedal, treino de equilíbrio estático/dinâmico, fortalecimento de membros inferiores



Aspeto	Pré-reformados	Reformados
Integração cognitiva	Estimulação de memória de trabalho e atenção dividida em tarefas complexas	Estímulos simples e práticos para preservar funções executivas
Benefícios adicionais	Prepara para uma transição saudável para a reforma	Reduz isolamento, promove autoestima e integração social
Monitorização	Progressão baseada em objetivos individuais e desempenho físico	Avaliações frequentes (equilíbrio, marcha, tempo de reação) para ajustar treino

Nota. A tabela apresenta as principais diferenças na adaptação do treino sensório motor para pessoas pré-reformadas e reformadas. *Fonte:* Adaptado de Varjan et al. (2024), Ahmad et al. (2019), Kang (2015), Castellote-Caballero et al. (2024), Vázquez-Carrasco et al. (2025).



Capítulo 3 | Objetivos e hipóteses

Objetivo geral

Avaliar a adequação e os efeitos da incorporação do treino sensório motor (TSM) em indivíduos com idades compreendidas entre os 55 e os 80 anos, enquanto estratégia para a melhoria das capacidades motoras, redução do risco de quedas e promoção da qualidade de vida relacionada com a saúde.

Objetivos específicos

1. Avaliar se a intervenção baseada em TSM induz alterações significativas nos parâmetros de agilidade após 24 semanas.
2. Avaliar os efeitos do TSM nos parâmetros de força muscular dos membros superiores e inferiores após 24 semanas.
3. Analisar se o TSM promove melhorias significativas nos parâmetros de flexibilidade dos membros superiores e inferiores após 24 semanas.
4. Determinar o impacto do TSM nos parâmetros lineares e não lineares do controlo postural após 24 semanas de intervenção.
5. Avaliar os efeitos do TSM nos parâmetros lineares e não lineares da variabilidade da marcha após 24 semanas.
6. Avaliar o impacto do TSM na qualidade de vida relacionada com a saúde e na adesão à prática regular de AF.

Hipóteses de investigação

H1: Hipotetiza-se que a prática de treino sensório motor induz melhorias estatisticamente significativas nos parâmetros de agilidade, força muscular, flexibilidade e controlo postural em adultos mais velhos após 24 semanas de intervenção.

H2: Hipotetiza-se que o TSM promove melhorias significativas nos parâmetros lineares e não lineares da variabilidade da marcha, refletindo um padrão locomotor mais eficiente e uma redução do risco de quedas.

H3: Hipotetiza-se que a participação em programas de TSM contribua para melhorias na qualidade de vida autorreferida e para uma maior adesão à prática regular de AF.



3.1. Resultados primários esperados

Os resultados primários incidem nos domínios físicos e funcionais diretamente associados à prevenção de quedas e à manutenção da autonomia funcional. Espera-se que, após a intervenção:

- **Agilidade:** apresente melhorias significativas, traduzindo-se numa maior capacidade de resposta a estímulos externos e numa execução mais eficiente das atividades da vida diária.
- **Força muscular:** aumente de forma significativa nos membros superiores e inferiores, contribuindo para tarefas funcionais como levantar-se, transportar objetos e subir escadas, e para a mitigação do risco de sarcopenia.
- **Flexibilidade:** seja otimizada, promovendo maior amplitude articular e prevenindo limitações funcionais associadas ao envelhecimento.
- **Controlo postural:** seja significativamente reforçado, reduzindo oscilações corporais e aumentando a estabilidade em condições estáticas e dinâmicas.
- **Parâmetros lineares e não lineares da marcha:** evidenciem melhorias, refletindo maior regularidade, variabilidade adaptativa saudável e eficiência do padrão locomotor.

No conjunto, espera-se que estes ganhos se traduzam numa redução significativa do risco de quedas e num aumento da autonomia funcional, promovendo uma vida mais independente e segura.

3.2. Resultados secundários esperados

Os resultados secundários incidem em dimensões psicossociais, comportamentais e cognitivas relevantes para o envelhecimento ativo:

1. **Qualidade de vida relacionada com a saúde:** melhoria dos indicadores de bem-estar físico, psicológico e social, avaliados através de instrumentos validados.
2. **Prática de atividade física:** aumento dos níveis de AF autorreferida e maior adesão a programas estruturados de exercício.
3. **Função cognitiva:** benefícios indiretos ao nível da atenção, memória e velocidade de processamento, resultantes da integração de estímulos motores e cognitivos.



4. **Saúde mental e socialização:** redução da percepção de solidão, melhoria do humor e aumento da interação social em contextos de prática coletiva.

Estes resultados secundários deverão reforçar o impacto global da intervenção, demonstrando que o TSM não só melhora parâmetros físicos objetivos, como também contribui para o bem-estar psicológico, social e motivacional da população idosa.

Capítulo 4 | Metodologia

A metodologia adotada nesta investigação assentou numa abordagem mista, que combinou estudos de revisão, revisões bibliométricas, relatos de caso e ensaios experimentais, incluindo ensaios clínicos randomizados e controlados (RCTs). Este desenho permitiu construir uma base científica sólida e abrangente, capaz de sustentar recomendações fundamentadas para a promoção da saúde e do bem-estar de pessoas idosas através da AF. No total, foram publicados ou submetidos doze artigos, organizados em diferentes categorias de acordo com os objetivos e natureza metodológica:

- **Revisões da literatura:** dois artigos (um publicado, um submetido), focados na síntese do conhecimento sobre envelhecimento, saúde e exercício físico.
- **Revisões bibliométricas:** dois artigos publicados, que caracterizam a produção científica e tendências da área.
- **Protocolo metodológico:** um artigo publicado, descrevendo em detalhe o delineamento geral dos estudos.
- **Estudos de caso:** dois artigos publicados, abordando marcha e capacidades físicas em adultos mais velhos com diabetes, respetivamente.
- **Ensaio clínico randomizado e controlado (RCT):** três artigos publicados e dois submetidos, explorando capacidades físicas, qualidade de vida, controlo postural e variabilidade da marcha.

Esta diversidade metodológica permitiu analisar de forma abrangente os efeitos do exercício físico em populações idosas, assegurando validade interna e externa dos resultados. A estratégia sequencial, começando por revisões e estudos exploratórios (casos) e culminando em RCTs, garantiu uma progressão metodológica consistente, culminando em evidência de elevada qualidade.



4.1. Recrutamento, triagem e dimensão da amostra para o protocolo de intervenção

4.1.1. Caracterização da amostra

O cálculo do tamanho da amostra foi realizado através do software G*Power 3.1.9.4 (Universidade de Kiel, Kiel, Alemanha), selecionando o teste estatístico adequado para comparar a diferença entre duas médias independentes. Considerando um risco alfa de 0.05 e um risco beta de 0.2 num teste bilateral, e assumindo um tamanho de efeito moderado de 0.5, determinou-se que um total de 160 participantes, divididos equitativamente entre o grupo experimental (GE) e o GC, seria suficiente para atingir uma potência mínima de 90%.

Os participantes foram distribuídos aleatoriamente entre os grupos experimental, correspondente ao programa de reforma ativa, e de controlo. Para garantir essa randomização, foi utilizado o software Research Randomizer (versão 4.0, Geoffrey C. Urbaniak e Scott Plous, Middletown, CT, EUA; <http://www.randomizer.org>) para gerar uma sequência de randomização, sendo este processo conduzido por um membro da equipa de investigação que não participou na intervenção. A atribuição dos participantes foi registada num ficheiro informático protegido por palavra-passe.

Embora os participantes tivessem conhecimento do grupo a que pertenciam, os avaliadores dos resultados e os analistas de dados permaneceram cegos à atribuição dos grupos.

Foram definidos como critérios de inclusão: ser reformado, ter entre 55 e 80 anos, aceitar participar voluntariamente mediante consentimento informado, não possuir próteses (exceto dentária) e não ter sido submetido a cirurgia nos últimos seis meses. Como critérios de exclusão foram considerados: doenças músculo-esqueléticas, problemas de locomoção, perturbações psiquiátricas ou neurológicas e DCV.

O GC não participou em qualquer programa estruturado de exercício, mantendo apenas as suas atividades habituais e realizando as avaliações nos mesmos momentos do GE (pré e pós-intervenção). Após a conclusão do estudo, ser-lhes-á oferecida a oportunidade de realizar o programa de exercícios. Para garantir a segurança dos participantes, serão aplicadas diversas estratégias:

- Realização de anamnese para todos os participantes.
- Higienização do material utilizado durante as sessões.
- Introdução de pausas entre os exercícios para evitar fadiga excessiva.



- Presença de mais do que um investigador para auxiliar nas sessões.
- Aplicação da escala de percepção de esforço para monitorizar a intensidade dos exercícios.

4.1.2. Protocolo de intervenção

O programa de intervenção consistiu num TSM estruturado de acordo com o princípio Frequência, intensidade, tempo e tipo (FITT), amplamente utilizado para a prescrição individualizada de exercício físico. A duração total da intervenção foi de 24 semanas, com duas sessões semanais de aproximadamente 45 minutos cada.

A estrutura das sessões foi padronizada em três fases principais:

- **Aquecimento (10 minutos):** caminhada leve e exercícios de mobilidade articular.
- **Treino principal (25 minutos):** circuito composto por quatro voltas de oito exercícios, realizados durante 50 segundos com 15 segundos de pausa entre exercícios. As atividades focaram-se no equilíbrio, coordenação, força e estimulação proprioceptiva.
- **Retorno à calma (10 minutos):** alongamentos estáticos e exercícios respiratórios.

A progressão da carga foi individualizada, acompanhando o nível de tolerância e condição física de cada participante, e dividiu-se em três fases:

1. **Semanas 1–8 (fase inicial):** exercícios sem resistência externa, centrados no controlo postural e nos padrões funcionais de movimento;
2. **Semanas 9–16 (fase intermédia):** introdução de resistência leve através de faixas elásticas, caneleiras e pesos manuais;
3. **Semanas 17–24 (fase avançada):** incremento progressivo da intensidade utilizando o mesmo material, promovendo maior exigência de força e controlo neuromuscular.



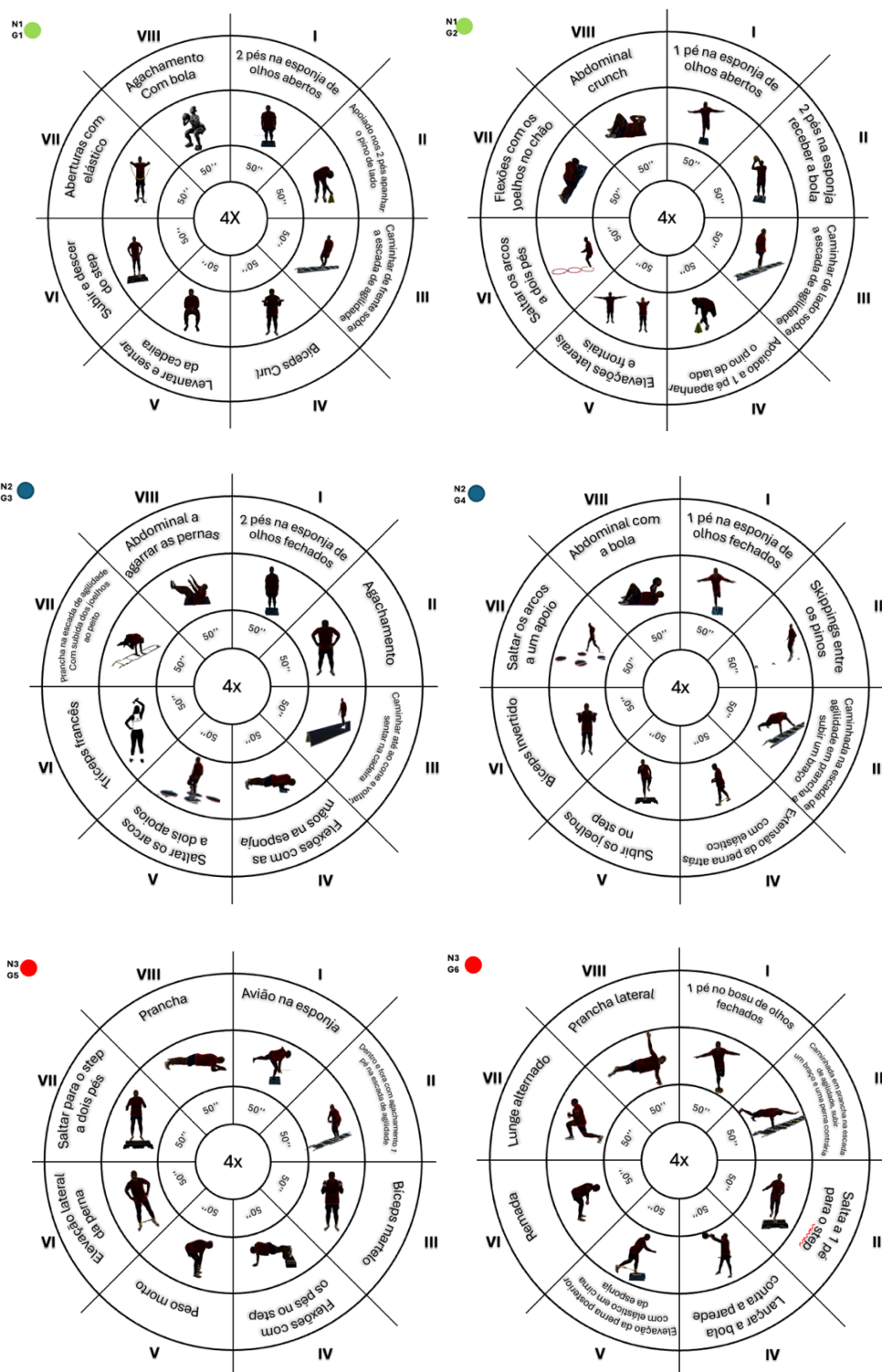


Figura 3- Planificação das sessões das aulas.

A percepção subjetiva de esforço foi monitorizada em todas as sessões por meio da escala de percepção subjetiva do esforço de Borg CR10 (0–10), validada para populações idosas e amplamente utilizada em contextos de exercício e reabilitação (Borg, 1998; Chen



et al., 2002) , enquanto a adesão e satisfação foram avaliadas mensalmente através da escala de prazer com atividade física (PACES) (Teques et al., 2020).

Uma variedade de ferramentas foi utilizada para a recolha de dados. Todas as medições foram realizadas em três momentos distintos: na linha de base, no final da intervenção e um ano após o seu término (fase de acompanhamento). Antes da primeira avaliação, todos os participantes passaram por uma fase de familiarização para se habituarem aos diferentes instrumentos e procedimentos incluídos no estudo. Ferramentas utilizadas:

a) Antropometria e composição corporal: Foram avaliados o peso corporal e a altura. Antes das medições, os participantes removeram os sapatos, meias e peças de vestuário mais pesadas (casacos, camisolas, entre outros). Também foram instruídos a esvaziar os bolsos e retirar cintos e acessórios (como fitas e colares). A altura foi medida com um estadiómetro (Seca 22, Hamburgo, Alemanha), colocado numa superfície vertical com a escala de medição perpendicular ao solo. Os participantes foram posicionados em pé, com os ombros equilibrados e os braços relaxados ao longo do corpo. A altura foi registada em centímetros, arredondada ao milímetro mais próximo. O peso corporal foi avaliado através de uma balança, sendo registado em quilogramas. O Índice de massa corporal (IMC) foi calculado através da fórmula: $\text{peso (kg)} / \text{altura}^2 (\text{m}^2)$.

b) Aptidão física: Os participantes vestiram calças de fato de treino e removeram quaisquer acessórios ou objetos dos bolsos. Foram realizadas as seguintes medições:

- Agilidade e velocidade de execução: avaliadas através do teste TUG, que consistiu em levantar-se de uma cadeira, caminhar até uma linha reta a três metros de distância, regressar e sentar-se novamente (Gerhardy et al., 2019).
- Controlo postural: testado através de uma plataforma de forças (Bertec 4060-Columbus, EUA), onde se avaliaram oscilações em posição bípede estática, com olhos abertos (OA) (dois minutos) e olhos fechados (OF) (dois minutos) (Salehi et al., 2010).
- Marcha: avaliada com a aplicação móvel “Phyphox”, colocada na pele, junto à borda interna da tíbia, para quantificar o número de passos e o tempo de deslocação. Os participantes percorreram um trajeto pré-estabelecido, sem declives ou obstáculos, durante 10 minutos à sua cadência natural (Malacrida, 2021b). Posteriormente, o



mesmo trajeto foi percorrido num ritmo imposto por estímulos auditivos (metrónomo).

- Resistência muscular: avaliada através do número de vezes que o participante conseguiu levantar-se de uma cadeira ou realizar flexões e extensões durante 30 segundos. A força dos membros inferiores foi analisada, considerando a ativação do vasto medial oblíquo (VMO) e do vasto lateral (VL) (Rikli & Jones, 1999).
- Força dos membros superiores: determinada pelo número de repetições realizadas durante 30 segundos, utilizando um peso e realizando flexo-extensão dos braços (Rikli & Jones, 1999).
- Flexibilidade: avaliada através de dois testes. O primeiro, "sentar e alcançar", mediu a flexibilidade dos membros inferiores, onde os participantes, a partir de uma posição sentada e com uma perna estendida, se inclinaram lentamente, deslizando as mãos pela perna até tocarem (ou ultrapassarem) os dedos dos pés. O segundo teste, "alcançar atrás das costas", avaliou a amplitude total de movimento do ombro, medindo a distância entre os dedos médios atrás das costas com uma régua (Rikli & Jones, 1999).

c) Qualidade de vida relacionada com a saúde: Foi avaliada através do questionário de bem-estar e saúde geral SF-36 (Ware, 1993) na sua versão em português (Ferreira, 2000a, 2000b). Este instrumento continha 36 perguntas e gerava oito dimensões de estado de saúde (função física, papel físico, dor corporal, saúde geral, vitalidade, função social, papel emocional e saúde mental), bem como dois componentes sumários (físico e mental). As dimensões e os componentes foram pontuados de 0 a 100, sendo 0 o pior estado e 100 o melhor.

d) Nível de atividade física: Foi validado através do questionário internacional de atividade física – versão curta (IPAQ-SF) (Lee et al., 2011). Este instrumento incluía quatro questões sobre frequência (dias/semana) e duração (minutos/dia) de caminhadas diárias e atividades físicas de intensidade moderada a vigorosa, além do tempo gasto em atividades sedentárias durante a semana e fins de semana. A AF foi classificada em três categorias: sedentário (<600 Met-min/semana), ativo (≥600 Met-min/semana) e muito ativo (≥3.000 Met-min/semana) (Cruz et al., 2018).



e) **Percepção subjetiva de esforço:** Foi avaliada com a Escala de Percepção de Esforço de Borg (Borg, 1998), composta por 10 itens, onde os participantes classificaram o seu esforço numa escala de 1 ("nada") a 10 ("máximo").

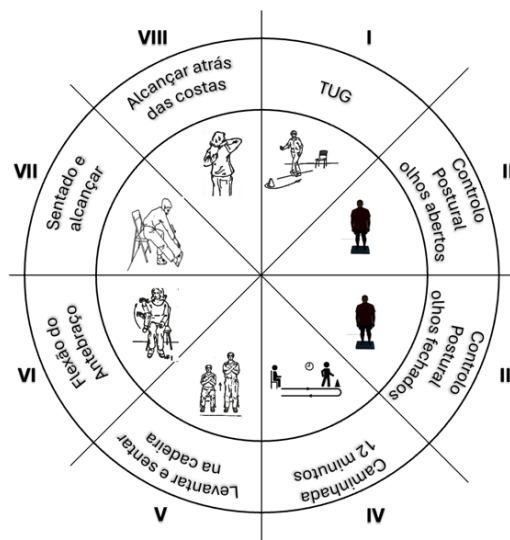


Figura 4- Avaliações para medições de aptidão física.

f) **Taxa de adesão:** Para medir a adesão ao programa de exercícios, foram monitorizados os seguintes parâmetros:

- Proporção de participantes que completaram o programa.
- Frequência de participação nas sessões.
- Número médio de sessões de exercícios realizadas por semana.
- Frequência às aulas, expressa pela proporção de participantes que atingiram determinados pontos de corte.
- Número de semanas e dias em que o exercício foi realizado.

Além disso, foram aplicadas estratégias para incentivar a adesão ao programa, incluindo simplificação das instruções, abordagem de fatores motivacionais (como autoeficácia e crenças sobre a saúde), apoio social e envio de lembretes (Flegal et al., 2007; Rivera-Torres et al., 2019).

g) **Nível de satisfação:** A satisfação com o programa foi avaliada através da PACES. Este questionário continha 8 itens, pontuados de 1 a 7 (1 = "gosto muito"; 7 = "detesto"; 4 = "neutro"). A pontuação total variava entre 8 e 56 pontos, sendo que pontuações mais elevadas indicavam maior nível de aproveitamento e satisfação com o programa. O questionário foi preenchido na sua versão em português (Teques et al., 2020).



4.2. Recrutamento, triagem e dimensão da amostra para o estudo de caso-controlo

Estes estudos funcionaram como etapas piloto para testar protocolos e avaliar a aplicabilidade do treino sensório motor em diferentes perfis populacionais.

4.2.1. Estudo de caso-controlo marcha

Um primeiro estudo piloto decorreu entre dezembro de 2021 e julho de 2022, envolvendo participantes do grupo de atividades físicas do Município de Almada (MA), em parceria com a Universidade de Évora. A amostra incluiu cinco participantes (três mulheres e dois homens; idades médias de 73 ± 10.5 e 75.5 ± 7.8 anos, respetivamente). O estudo foi aprovado pela Comissão de Ética da Universidade de Évora (n.º 21040), e todos assinaram consentimento informado.

Foram aplicados critérios de inclusão (idade >65 anos, ausência de próteses — exceto dentárias —, ausência de cirurgias recentes e residência no concelho de Almada) e de exclusão (doenças músculo-esqueléticas, problemas de locomoção, distúrbios psiquiátricos ou neurológicos e DCV). Realizou-se avaliação antropométrica e cálculo do IMC, de acordo com a metodologia do Centros de controlo e prevenção de doenças (CDC).

Embora de pequena dimensão, este estudo permitiu recolher dados exploratórios sobre a variabilidade da marcha em indivíduos saudáveis, fornecendo indicadores úteis para a adaptação do programa de treino a populações com risco aumentado de declínio funcional.

A avaliação consistiu no teste da marcha através da aplicação móvel “Phyphox”, colocada na pele, junto à borda interna da tíbia, para quantificar o número de passos e o tempo de deslocação. Os participantes percorreram um trajeto pré-estabelecido, sem declives ou obstáculos, durante 10 minutos à sua cadência natural. Posteriormente, o mesmo trajeto foi percorrido num ritmo imposto por estímulos auditivos (metrónomo).

4.2.2. Estudo de caso-controlo capacidades físicas em diabéticos

Complementarmente, realizou-se um estudo quase-experimental piloto, integrado no protocolo registado no ClinicalTrials.gov (NCT05398354), designado *Active Retirement: Effects of the Application of a Training Program*. O desenho incluiu dois grupos paralelos (intervenção e controlo), com avaliações em dois momentos (pré e pós-intervenção), entre janeiro e julho de 2022.



Participaram dez mulheres com idade superior a 65 anos, todas com diagnóstico de DM2 e sob tratamento com insulina, selecionadas da amostra total de 160 participantes do estudo principal. As participantes apresentavam características antropométricas semelhantes (peso, altura e IMC), diferindo apenas na idade. Foram alocadas aleatoriamente em dois grupos: cinco integraram o GI, que realizou o programa de TSM durante 24 semanas, e cinco integraram o GC, que manteve a sua rotina habitual, sem intervenção estruturada.

O programa TSM seguiu o princípio FITT, com duas sessões semanais de 45 minutos durante 24 semanas, divididas em três fases progressivas: inicial (semanas 1–8), com exercícios sem resistência externa e foco no equilíbrio e controlo postural; intermédia (semanas 9–16), com resistência leve através de bandas elásticas e pesos; e avançada (semanas 17–24), com incremento progressivo da carga para estimular força e controlo neuromuscular. Cada sessão incluía 10 minutos de aquecimento (caminhada leve e mobilidade articular), 25 minutos de treino em circuito (4 voltas de 8 exercícios, 50 segundos de trabalho/15 segundos de pausa) e 10 minutos de retorno à calma (alongamentos e exercícios respiratórios). A perceção de esforço foi monitorizada pela Escala de Borg, e a satisfação pelo PACES.

As avaliações incluíram antropometria e IMC, bem como medidas de capacidades físicas em dois momentos (pré e pós): agilidade e velocidade (TUG), força dos membros inferiores (*Chair Stand Test*) e superiores (*Arm Curl Test*), e flexibilidade (*Sit and Reach*; *Back Scratch left and right*). Todos os instrumentos utilizados apresentavam fiabilidade validada em populações idosas (Coeficiente de correlação intraclasse (ICC) = 0.80–0.97).

O estudo foi aprovado pela Comissão de Ética da Universidade de Évora (n.º 21040) e obteve consentimento informado de todas as participantes. O tamanho da amostra foi previamente calculado com o G*Power (poder de 0.80; $\alpha = 0.05$; efeito estimado $d = 0.99$), indicando a suficiência de 5 participantes por grupo para este estudo piloto.

Apesar da dimensão da amostra reduzida em alguns estudos piloto, o desenho metodológico privilegiou a validade ecológica, a aplicação em contexto real e a calibração dos protocolos de intervenção, constituindo uma etapa fundamental para a robustez metodológica dos ensaios clínicos subsequentes.



4.3. Recrutamento, triagem e dimensão da amostra para o estudo de RCTs

4.3.1. Procedimento de randomização e ocultação

Para garantir a validade interna do ensaio clínico randomizado, foi implementado um procedimento rigoroso de randomização e ocultação da alocação dos participantes. A randomização foi realizada por meio de um gerador eletrónico de números aleatórios, assegurando que cada participante tivesse a mesma probabilidade de ser atribuído ao GE (intervenção) ou ao GC.

A sequência de randomização foi elaborada por um investigador externo ao processo de recolha de dados, com o objetivo de evitar enviesamentos. Para assegurar a ocultação da alocação, os códigos correspondentes aos grupos foram inseridos em envelopes opacos, numerados sequencialmente e selados. A abertura dos envelopes ocorreu apenas no momento da inclusão dos participantes, garantindo que nem os avaliadores nem os participantes tivessem conhecimento prévio da designação de grupo.

Este procedimento assegurou a imprevisibilidade da atribuição, reduzindo o risco de enviesamento de seleção e reforçando a credibilidade dos resultados. Além disso, os avaliadores responsáveis pela recolha de dados foram cegos em relação ao grupo de pertença dos participantes, assegurando que as medições se mantivessem isentas de influência consciente ou inconsciente.

4.3.2. Fluxo de estudo

A equipa do estudo visitará o local de aplicação da intervenção, neste caso o Complexo Municipal dos Desportos de Almada, para consultar o Diretor do Departamento de Desporto. Os objetivos incluem planear e agendar visitas, testar o protocolo proposto, avaliar todos os equipamentos relevantes, identificar e corrigir possíveis erros antes do início da colheita inicial de dados. Durante esta reunião, serão realizadas entrevistas com o Diretor do Departamento para avaliar as necessidades percebidas dos participantes durante as sessões de treino. Os insights obtidos, juntamente com as descobertas da literatura, orientarão a adaptação da intervenção.

Uma sessão de recolha de dados de base foi organizada no Complexo dos Desportos de Almada, com os participantes do estudo selecionados aleatoriamente com base na disponibilidade e localização, sendo avaliados ao longo de três semanas consecutivas durante o horário das 8h às 16h. A supervisão da recolha de dados será assegurada por especialistas em Exercício Desportivo e Saúde, técnicos responsáveis pelo complexo de Almada e o coordenador do estudo.



O GI integrará uma aula de 45 minutos no Complexo dos Desportos de Almada, duas vezes por semana durante um período de 24 semanas. Todos os participantes deverão frequentar todas as sessões ao longo dos 6 meses.

A recolha de dados pós-intervenção será realizada após a conclusão do programa de intervenção, com os participantes do estudo, divididos aleatoriamente com base na disponibilidade e localização, sendo avaliados durante três semanas consecutivas no Complexo dos Desportos de Almada, durante o horário das 8h às 17h.

A supervisão será assegurada por especialistas em Exercício Desportivo e Saúde, técnicos da Câmara Municipal de Almada e o coordenador do estudo. Após a conclusão do estudo, o GC receberá as mesmas aulas de yoga de 24 semanas, em conformidade com as considerações éticas.

4.3.3. Intervenção

O programa de treino sensório motor teve a duração de 24 semanas, com duas sessões semanais de 45 minutos, estruturadas segundo o princípio FITT. Cada sessão incluía aquecimento, circuito principal com exercícios de equilíbrio, força, coordenação e estimulação propriocetiva, e uma fase final de retorno à calma. A progressão da intensidade foi gradual, passando de exercícios sem carga para utilização de resistência leve e, por fim, aumento progressivo com elásticos e pesos. O esforço percebido foi monitorizado pela Escala de Borg e a adesão acompanhada através do PACES. O GC manteve as suas rotinas habituais, realizando apenas as avaliações, e posteriormente teve acesso ao programa. Para garantir a segurança, foram aplicadas medidas preventivas como anamnese prévia, higienização do material e pausas regulares.

4.3.4. Materiais e métodos

A recolha de dados ocorreu em três momentos (pré-intervenção, pós-intervenção e follow-up de um ano) e incluiu medidas de antropometria, aptidão física, qualidade de vida, NAF, esforço percebido, adesão e satisfação. A composição corporal foi avaliada por peso, altura e cálculo do IMC. A aptidão física incluiu testes validados para agilidade (TUG), força (levantar-sentar da cadeira e flexão-extensão de braços), flexibilidade (senta e alcança e alcançar atrás das costas), controlo postural (plataforma de forças- Bertec 4060-Columbus, EUA) e marcha (aplicação Phypbox®). O bem-estar e saúde geral foram medidos pelo SF-36, enquanto o NAF foi avaliado pelo IPAQ-SF. O esforço subjetivo foi registado pela escala de Borg CR10 (0–10) (Borg, 1998; Chen et al., 2002) e a satisfação pelo questionário PACES (Teques et al., 2020). A adesão foi monitorizada pelo número de sessões concluídas e pela frequência semanal.



4.4. Análise estatística

A análise estatística dos estudos incluídos nesta tese foi realizada de acordo com o desenho metodológico de cada investigação, respeitando os procedimentos reportados nos artigos originais. Todas as análises estatísticas foram conduzidas com recurso ao software Jamovi (versões entre 1.6 e 2.6), e os resultados foram apresentados sob a forma de média $\pm$ desvio padrão ($M \pm DP$). O nível de significância estatística foi fixado em $p < 0.05$.

4.4.1. Testes preliminares

Antes da aplicação dos testes inferenciais, foram realizados procedimentos preliminares para assegurar a adequação das análises estatísticas:

- Normalidade da distribuição dos dados: avaliada através do teste de Kolmogorov–Smirnov ou do teste de Shapiro–Wilk, consoante o delineamento do estudo e o tamanho amostral, considerando valores de $p > 0.05$ como indicativos de distribuição normal (Field, 2013).
- Homogeneidade das variâncias: verificada com o teste de Levene, sempre que aplicável.

Quando os pressupostos de normalidade e homogeneidade foram cumpridos, recorreram-se a testes paramétricos; caso contrário, utilizaram-se testes não paramétricos.

4.4.2. Revisões bibliométricas

Para as revisões bibliométricas, após a identificação e seleção dos documentos relevantes nas bases de dados científicas, a análise foi efetuada com base em leis bibliométricas clássicas, permitindo caracterizar a evolução temporal da produção científica, os autores mais influentes, as instituições de referência e as tendências emergentes de investigação. A Lei de De Solla Price foi utilizada para avaliar o crescimento exponencial do número de publicações ao longo do tempo, recorrendo ao coeficiente de determinação (R^2), enquanto a Lei de Lotka permitiu identificar os autores mais produtivos e influentes através do cálculo do índice h . A Lei de Zipf foi aplicada para analisar a frequência e relevância das palavras-chave, possibilitando a identificação dos principais temas e linhas de investigação. Os dados foram analisados e organizados em Microsoft Excel® (versão 2006), sendo a visualização das redes de coautoria, cocitação e coocorrência de termos realizada através do software VOSviewer (versão 1.6.19), utilizando métodos de normalização baseados em forças de atração e repulsão.



4.4.3. Estudos de caso

Nos estudos de caso, foi inicialmente realizada uma análise descritiva para caracterização das amostras, recorrendo às médias e desvios padrão. A normalidade da distribuição dos dados foi verificada através dos testes de Shapiro–Wilk ou Kolmogorov–Smirnov, e a homogeneidade das variâncias foi avaliada com o teste de Levene. Sempre que os pressupostos estatísticos foram cumpridos, utilizaram-se testes paramétricos; caso contrário, recorreram-se a testes não paramétricos. As comparações intra-grupo, entre os momentos pré e pós-intervenção, foram realizadas com o teste t de Student para amostras emparelhadas ou com o teste de Wilcoxon. As comparações intergrupo foram efetuadas através do teste t de Student para amostras independentes ou do teste de Mann–Whitney. Em alguns estudos, foi ainda calculada a variação percentual do efeito do tratamento. A magnitude das alterações foi avaliada através do cálculo do tamanho do efeito (ES), recorrendo ao Cohen's d, interpretado como trivial, pequeno, moderado, grande, muito grande ou extremamente grande. Quando aplicável, foi também calculado o ICC para avaliar a fiabilidade das medições, classificado como fraco, moderado, bom ou excelente.

4.4.4. Ensaio clínico randomizado e controlado (RCTs)

Nos RCTs, após a verificação da normalidade, da distribuição dos dados e da homogeneidade das variâncias, foram utilizados modelos estatísticos paramétricos para testar as hipóteses de investigação. A análise das diferenças entre grupos e ao longo do tempo foi efetuada através de ANOVA de medidas repetidas de dois fatores (grupo $\times$ tempo), permitindo avaliar os efeitos principais do tempo, do grupo e da interação entre ambos. Sempre que se observaram diferenças estatisticamente significativas, foram aplicados testes *post-hoc* com correção de Bonferroni para múltiplas comparações. Em alguns estudos, recorreu-se à análise de covariância (ANCOVA), utilizando os valores pós-intervenção como variáveis dependentes e os valores pré-intervenção como co variáveis, com o objetivo de controlar diferenças basais entre os grupos experimental e de controlo. As comparações intra grupo foram realizadas com o teste t de Student para amostras emparelhadas, enquanto as comparações intergrupo foram efetuadas com o teste t para amostras independentes, sempre que os pressupostos estatísticos foram respeitados. A magnitude do efeito foi expressa através do eta quadrado parcial (η^2p), classificado como pequeno, médio ou grande, e do Cohen's d, acompanhado de intervalos de confiança a 95%.



4.4.5. Procedimentos adicionais

Em todos os estudos empíricos, os dados foram codificados e analisados por investigadores cegos à alocação dos grupos, de forma a garantir a imparcialidade das análises. Foram ainda realizadas análises complementares relacionadas com a adesão aos programas de intervenção, perceção de esforço e satisfação dos participantes, bem como análises correlacionais entre estas variáveis e os desfechos físicos, funcionais e de qualidade de vida. Os resultados foram apresentados em tabelas e gráficos, incluindo médias, desvios padrões, intervalos de confiança e tamanhos do efeito, assegurando uma interpretação clara, rigorosa e alinhada com os padrões metodológicos utilizados nos artigos incluídos na presente tese.

4.4.6. Considerações éticas

Todos os procedimentos adotados nos estudos que integram esta tese respeitaram os princípios éticos estabelecidos na Declaração de Helsínquia para investigação envolvendo seres humanos. O projeto foi aprovado pela Comissão de Ética da Universidade de Évora (n.º 21040) e registado no ClinicalTrials.gov – PRRS Protocol Registration and Results System (NCT05398354). Todos os participantes foram previamente informados sobre os objetivos, procedimentos, potenciais riscos e benefícios do estudo, tendo assinado o consentimento informado antes da sua inclusão. Foi garantida a confidencialidade dos dados e o anonimato dos participantes, em conformidade com a legislação nacional e europeia em vigor relativa à proteção de dados pessoais.



Capítulo 5 | Resultados

5.1. Resultados das revisões da literatura

5.1.1. Physical training programs improve sensorimotor skills in older people: systematic review with relevance to COVID-19

Esta revisão sistemática teve como objetivo analisar os efeitos dos programas de exercício físico nas competências sensório motoras durante o envelhecimento, com especial enfoque no período da pandemia de COVID-19.

A pesquisa bibliográfica inicial resultou num total de 94 artigos, dos quais apenas seis estudos foram selecionados por cumprirem os critérios de inclusão definidos para a revisão sistemática (Figura 5).

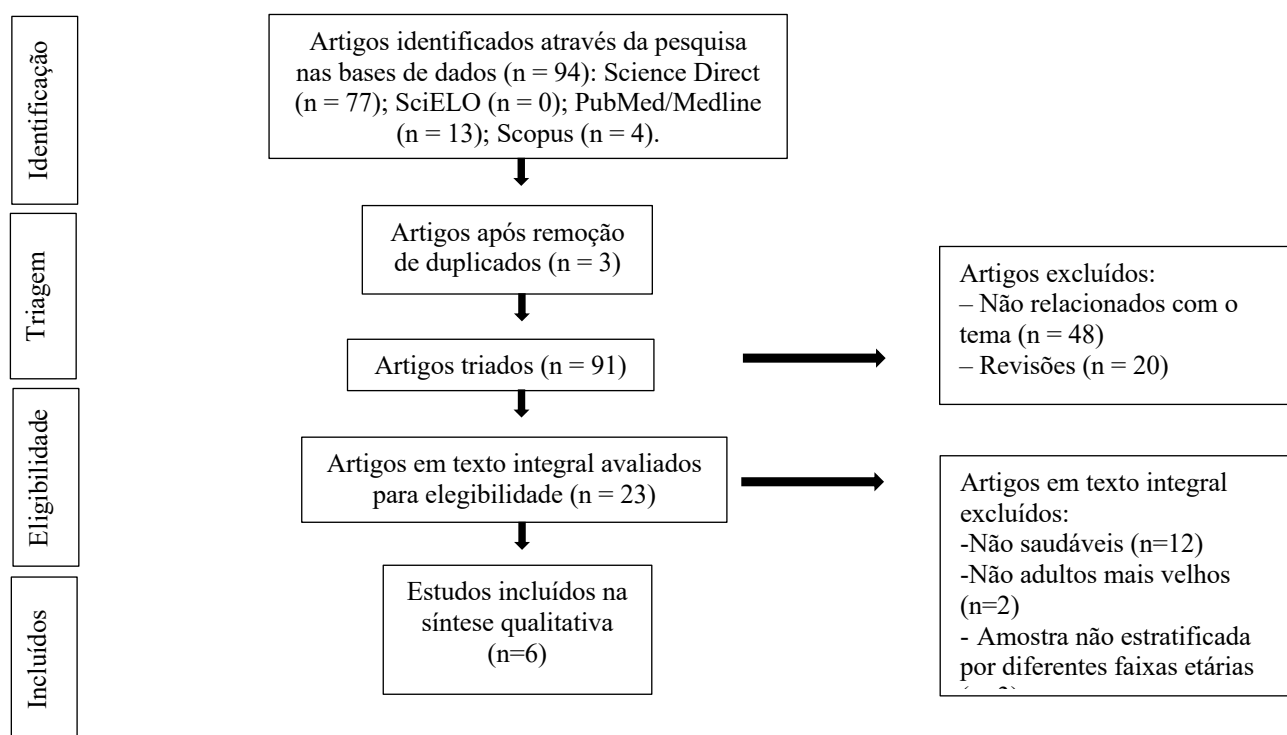


Figura 5- Fluxograma de seleção dos estudos.

As principais características dos estudos selecionados estão resumidas na Tabela 4. Todos os artigos foram redigidos em língua inglesa e publicados nos últimos cinco anos. Relativamente aos locais onde os estudos foram conduzidos, um foi realizado em Itália (Verghese et al., 2021), um nos Estados Unidos da América (Corley et al., 2021), um na Escócia (Das & Bhattacharyya, 2021), um na Índia (Thiel et al., 2021), um na Alemanha (Dupuy et al., 2021) e um no Canadá (Ferrucci et al., 2016). Dos artigos selecionados, quatro correspondem a estudos longitudinais e quatro a estudos



transversais. No total, os estudos analisaram 895 participantes com idades compreendidas entre os 60 e os 90 anos.

O estudo revelou a utilização de diversos instrumentos para medir os resultados de programas de AF durante a pandemia de COVID-19. As variáveis mais frequentemente reportadas foram de natureza física, psicológica, qualidade do sono e saúde psicossocial relacionada com a COVID-19. Fatores pessoais como a qualidade de vida relacionada com a saúde, a espasticidade do tônus muscular, o padrão da marcha e a capacidade aeróbia associada à tolerância ao exercício foram também frequentemente analisados pelos autores (Tabela 4).

Outras variáveis em estudo incluíram força muscular, equilíbrio, avaliação da marcha e composição corporal. Alguns autores avaliaram ainda a funcionalidade e incapacidade dos adultos mais velhos, recorrendo a testes que analisam diversas dimensões relacionadas com a mobilidade, a vida doméstica e os hábitos de vida em geral.

Tabela 4- Descrição dos estudos selecionados.

Autores	País	Objetivos	Amostra	Intervenções	Resultados
Corley et al. (2021)	Escócia	O objetivo do estudo é analisar se durante a COVID-19, o bem-estar físico e mental autorrelatado em adultos mais velhos esteve associado à utilização de jardins domésticos.	n=171; 84 ± 0.5 anos	Cerca de dois meses após o início da COVID-19, foi solicitado a 171 participantes que preenchessem um questionário online. O inquérito incluía 145 questões sobre dados demográficos, conhecimento e experiência relativos à COVID-19, bem como saúde física, psicológica e psicossocial.	Os resultados do estudo indicam que as associações podem ser bidirecionais e que os jardins domésticos podem constituir um recurso positivo para a saúde durante a pandemia de COVID-19.
Das et al. (2021)	Índia	O objetivo é desenvolver serviços de voluntariado, aconselhamento, planos de sensibilização e políticas que tornem as estratégias de coping mais viáveis para combater esta crise inesperada.	n=15; >60 anos	A intervenção nos participantes foi realizada através de chamadas telefónicas, de modo a cumprir todas as regras de distanciamento social.	As principais fontes das redes sociais mantêm-se fundamentais no apoio recíproco e emocional. Este apoio contribui para a redução do stress e da depressão, promovendo o bem-estar entre os participantes.
Dupuy et al. (2021)	Canadá	O objetivo é documentar os efeitos de seis meses de exercício físico domiciliário isolado versus exercício domiciliário combinado com treino cognitivo nas funções cognitivas e físicas.	n=122; > 50 anos	Todos os participantes foram avaliados em quatro momentos de teste, através de videoconferência e questionários online, ao longo de um período de 7 a 10 dias no início do estudo, aos 3 meses e aos 6 meses. Aos 12 meses, foi realizada uma avaliação de seguimento para explorar o potencial de manutenção dos efeitos da intervenção..	O principal resultado avaliado foi a cognição. Os resultados secundários corresponderam às funções físicas. Os resultados exploratórios incluíram ansiedade, humor e qualidade de vida relacionada com a saúde.
Thiel et al. (2021)	Alemanha	Este artigo tem como objetivo descrever os objetivos do estudo, o desenho, os métodos, os tipos de avaliação, os cronogramas de recolha de dados e as considerações para a análise dos dados sobre os facilitadores e as barreiras à promoção da atividade física em lares.	n=200	Foi concebido um estudo de intervenção participativo, com uma abordagem de avaliação por métodos mistos, em lares selecionados. Os dados recolhidos serão utilizados para desenvolver e avaliar um método integrado de promoção da atividade física, combinando intervenções orientadas para o ambiente e aconselhamento individual.	Este estudo permitiu aumentar o conhecimento sobre a forma de alcançar um grupo caracterizado por inatividade, multimorbilidade e elevada prevalência de demência, através do exercício físico em lares.
Vitale et al. (2020)	Itália	O objetivo foi avaliar, durante o confinamento domiciliário causado pela pandemia de COVID-19, o efeito de um programa de treino de resistência realizado em casa na saúde muscular e no desempenho físico de adultos mais velhos ao longo de seis meses.	n=9 ± 68 anos	A intervenção envolveu pessoas idosas divididas em dois grupos: um grupo experimental que realizou exercícios durante seis meses (EXE) e um grupo de controlo (CON). Os participantes foram avaliados quanto à força muscular, equilíbrio, marcha e composição corporal por absorciometria de dupla energia por raios X e imagiologia por	O programa de treino de resistência realizado no domicílio resultou apenas em melhorias da força muscular dos membros inferiores. O confinamento domiciliário devido à COVID-19 reduziu o regime diário de atividade física e alterou os padrões alimentares, o que poderá explicar parcialmente o aumento da gordura corporal total.



		ressonância magnética, no momento basal (PRE) e após seis meses (POST).		
Verghese et al. (2021)	USA	O objetivo foi verificar se existem melhorias na marcha em pessoas com 70 anos ou mais através de um programa informatizado de reabilitação cognitiva.	n=378 age =>70 years	A intervenção consistiu na aplicação de “brain games”, ou seja, um programa informático de intensidade e complexidade progressivas, durante oito semanas. Os participantes apresentaram alterações na velocidade da marcha em ritmo normal e nas condições de marcha durante a fala.

Foram identificados 20 instrumentos para medir as variáveis descritas: (a) escala hospitalar de ansiedade e depressão (HADS) (Das & Bhattacharyya, 2021); (b) programas informatizados (“brain games”) com complexidade progressiva para melhoria da marcha (Corley et al., 2021); (c) absorciometria de dupla energia por raios X e ressonância magnética para força muscular, equilíbrio, marcha e composição corporal (Verghese et al., 2021); (d) guias de entrevista sobre percepções e dificuldades associadas à pandemia (Thiel et al., 2021); (e) testes de força em cicloergómetro (Verghese et al., 2021); (f) teste de sentar-e-levantar em 30 s (CST) para força dos membros inferiores (Verghese et al., 2021); (g) força de preensão manual (HGS) para força isométrica máxima; (h) Avaliação Cognitiva de Montreal (MoCA) para cognição (Ferrucci et al., 2016); (i) apoio unipedal para funções físicas e equilíbrio (Ferrucci et al., 2016); (j) Levantar caminhar e sentar (TUG) para mobilidade e marcha (Ferrucci et al., 2016); (k) levantar da cadeira cinco vezes para força dos membros inferiores (Ferrucci et al., 2016); (l) questionário de Matthews para aptidão cardiorrespiratória (Ferrucci et al., 2016); (m) escala de depressão geriátrica (30 itens); (n) escala de stress percebido; (o) *State-Trait Anxiety Inventory* (36 itens); (p) *Perseverative Thinking Questionnaire*; (q) *Connor–Davidson Resilience Scale* (10 itens); (r) sistema GAITRite® para padrões de atividade física e interações em lares (Dupuy et al., 2021); (s) acelerómetros ACTiGraph wGT3X-BT para comportamento de atividade física (Dupuy et al., 2021); (t) escala de atividade física para idosos (PASE) (Dupuy et al., 2021).

As intervenções analisadas incluíram questionários, entrevistas, programas de treino, testes físicos e escalas. Muitos estudos investigaram o treino da marcha. Dois estudos focaram-se na eficácia de programas domiciliários, incluindo um programa de exercício e outro a utilização de jardins domésticos associada ao bem-estar físico e mental autorrelatado.

Conforme indicado na Tabela 5, item 1, a pontuação média da análise do risco de viés utilizando a ferramenta *Evidence Project* foi de 5.88 em 8, com um desvio-padrão de 1.31. As pontuações variaram entre 5 e 7. Apenas dois estudos cumpriram o item 2. O item 3 não foi cumprido por duas investigações. No entanto, os resultados relativos à



representatividade dos participantes mostraram-se mais inconsistentes. Todos os estudos cumpriram o item 4, relativo à atribuição aleatória dos participantes à intervenção. O item 5 (seleção aleatória dos participantes para avaliação) não foi cumprido por nenhuma publicação. Por fim, todos os estudos cumpriram os itens 6, 7 e 8.

Tabela 5- *Análise do risco de viés com a ferramenta Evidence Project.*

	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7	Item 8	
Autores	Desenho do estudo			Representatividade dos participantes		Equivalência dos grupos de comparação			Total
Corley et al. (2021)	Sim	Não	Não	Sim	Não	Sim	Sim	Sim	5/8
Das et al. (2021)	Sim	Não	Não	Sim	Não	Sim	Sim	Sim	5/8
Dupuy et al. (2021)	Sim	Não	Sim	Sim	Não	Sim	Sim	Sim	6/8
Thiel et al. (2021)	Sim	Não	Sim	Sim	Não	Sim	Sim	Sim	5/8
Verghese et al. (2021)	Sim	Sim	Sim	Sim	Não	Sim	Sim	Sim	7/8
Vitale et al. (2020)	Sim	Sim	Sim	Sim	Não	Sim	Sim	Sim	7/8

Os resultados evidenciam que a prática regular de exercício apresentou benefícios consistentes na saúde física, cognitiva, social e psicológica dos adultos mais velhos, sendo particularmente relevante num contexto de isolamento e restrições. Entre os principais efeitos positivos destacaram-se a melhoria do humor, a redução da ansiedade e o aumento da qualidade de vida relacionada com a saúde. Contudo, verificou-se também um aumento da gordura corporal, associado à redução da AF diária e a alterações nos hábitos alimentares durante o confinamento. Estas descobertas sublinham a importância de programas estruturados de exercício como ferramenta preventiva e terapêutica em situações de vulnerabilidade. A publicação do artigo encontra-se disponível no Apêndice 2 (DOI: 10.25242/8868144920242686).

5.1.2. The influence of postural control on the risk of falls in the older people: systematic review

Esta revisão sistemática analisou o impacto do controlo postural no risco de quedas em adultos mais velhos, considerando a relevância desta variável para a manutenção da autonomia funcional. Foram incluídos cerca de 785 participantes, com idades compreendidas entre os 60 e os 90 anos, abrangendo diferentes contextos de avaliação. As variáveis exploradas relacionaram-se com a saúde física e mental, mas também com a estabilidade postural, o equilíbrio, o risco de quedas e a qualidade de vida. Além disso, foram consideradas medidas adicionais como a composição corporal, a força muscular e a análise da marcha.



As principais características metodológicas dos estudos selecionados encontram-se resumidas na Tabela 6. Todos os artigos foram publicados em língua inglesa nos últimos dez anos. Dos estudos incluídos, sete apresentaram desenho longitudinal e dez um desenho transversal, evidenciando uma predominância de metodologias observacionais na investigação sobre controlo postural e risco de quedas em adultos mais velhos. Esta diversidade metodológica permitiu analisar o fenómeno em diferentes contextos e populações, contribuindo para uma compreensão mais abrangente dos fatores associados à estabilidade postural e à funcionalidade nesta população.

Tabela 6- Descrição dos estudos selecionados.

Título	Autores e ano	Amostra	Objetivos	Resultados
Efeito do treino de caminhada com meias com palmilha texturizada em adultos mais velhos	Pinvanichkul e Siriphorn (2022)	Trinta adultos mais velhos	Avaliar os efeitos de meias com palmilha texturizada no equilíbrio, parâmetros da marcha e risco de quedas em adultos mais velhos.	Meias com palmilha texturizada aumentaram o equilíbrio e reduziram o risco de quedas em adultos mais velhos na mesma medida que meias não modificadas. O efeito benéfico no equilíbrio durou pelo menos 2 semanas. Não foram observadas alterações significativas nos parâmetros da marcha em nenhum dos grupos.
Efeito de um ciclo de treino, destreino e re-treino de resistência na estabilidade postural e risco estimado de quedas em adultos mais velhos institucionalizados: intervenção de 40 semanas	Rodrigues et al. (2022)	Vinte e sete participantes institucionalizados, divididos em grupo de treino de força muscular (MSEG, n = 14) e grupo controlo (GC, n = 13)	Investigar os efeitos de um ciclo de 40 semanas de treino-destreino-re-treino de força muscular na estabilidade postural e risco estimado de quedas em octogenários	O estudo demonstrou que o treino de força melhorou efetivamente o controlo postural e reduziu os <i>scores</i> de risco de quedas. Além disso, as intervenções retardaram a deterioração do controlo postural nos octogenários, com maiores melhorias nos primeiros meses de treino.
Parâmetros bioelétricos e funcionalidade estão associados ao controlo postural em adultos mais velhos?	Bertolini et al. (2021)	21 participantes (homens: 77.3 ± 9.5 anos; mulheres: 74.2 ± 9.6 anos)	Avaliar o comportamento do equilíbrio em relação à bioimpedância e funcionalidade	Foi verificada uma correlação inversa entre o equilíbrio e variáveis de bioimpedância em todas as posições testadas, com coeficientes de determinação entre 20% e 74%. Correlações inversas significativas entre reatância e ângulo de fase foram verificadas na posição de apoio unipedal (62%-91%). Na posição semi-tándem com olhos fechados, observou-se correlação positiva com o TUG e inversa com parâmetros de bioimpedância e ângulo de pennação (21%-67%).
Praticantes de Tai Chi apresentam menor risco de queda em condições de tarefa dupla durante a descida de escadas	Li et al. (2021)	Quinze praticantes de Tai Chi com pelo menos 10 anos de experiência e quinze participantes sem exercício (NE)	Determinar se praticantes de Tai Chi têm menor risco de quedas sob condições de tarefa dupla durante descida de escadas comparados a não praticantes	Ambos os grupos adotaram uma marcha mais cautelosa na condição de tarefa dupla, mas os praticantes de TC foram menos afetados. Indica que praticantes de TC apresentam menor risco de quedas nessas condições.
Efeitos do exergaming na reponderação sensorial e estabilidade mediolateral em mulheres com mais de 60 anos: estudo de usabilidade	Sápi et al. (2021)	14 mulheres saudáveis (idade média 69.57 anos; IMC médio 26.21 kg/m ²)	Avaliar se treino de equilíbrio via Kinect exergame pode impactar a reponderação sensorial	Os resultados sugerem que o exergaming pode ser uma ferramenta segura e útil para melhorar a estabilidade postural na direção mediolateral, ajudando a reduzir o risco de quedas.
Caminhar em ambientes naturais como recomendação geriátrica para prevenção de quedas: resultados preliminares do modelo “Passiata Day”	Battaglia et al. (2020)	106 participantes (75 mulheres e 31 homens; média de idade 72.3 ± 8.2 anos)	Avaliar o equilíbrio corporal em adultos mais velhos que caminham regularmente versus sedentários	Caminhar regularmente ao ar livre pode melhorar o equilíbrio corporal em adultos mais velhos e ser recomendado por geriatras para prevenir quedas.
Avaliação da estabilidade da marcha antes e após implante coclear	Kaczmarczyk et al. (2019)	21 participantes do grupo experimental	Avaliar alterações na estabilidade da marcha após implante coclear	Melhorias na razão de estabilidade da marcha (GSR) em 17 sujeitos (média 6%). Outros parâmetros, como tempo de passo e velocidade na fase de apoio unipedal, também melhoraram significativamente.
Influência do implante coclear no controlo postural e risco de quedas	Louza et al. (2019)	33 pacientes adultos >60 anos	Analisar o efeito da reabilitação auditiva com implantes cocleares (CI) ativado e diferentes estímulos sonoros no controlo postural e risco de quedas	Com CI desativado, risco médio de queda de 45.5%. Após ativação, redução pequena, mas significativa; com estímulos adicionais (música ou fala), redução mais pronunciada (42-42.4%). 72% dos pacientes apresentaram melhoria com CI ativado.



Título	Autores e ano	Amostra	Objetivos	Resultados
Comparação do risco de quedas entre adultos mais velhos rurais e urbanos	de Arruda et al. (2018)	125 participantes (89 urbanos, 36 rurais)	Comparar o risco de quedas em adultos mais velhos urbanos e rurais	Ambos os grupos apresentaram alto risco de quedas, sem diferenças significativas. A perda auditiva e problemas nos membros foram determinantes do risco elevado. Uso de medicação e ocorrência de quedas anteriores foram maiores entre os rurais.
Papel do controlo postural no bem-estar social de mulheres idosas	Baranova e Kapilevich (2017)	20 mulheres com idades entre 60 e 70 anos	Analisar fatores hemodinâmicos no controlo postural feminino	Mudanças relacionadas com a idade no equilíbrio aumentam a área projetada do centro e a velocidade de movimento do centro de pressão. Alterações no fluxo sanguíneo periférico afetam principalmente o plano frontal; o efeito é parcialmente compensado pelo analisador visual.
Exercício combinado é mais eficaz que exercício aeróbico na melhoria dos fatores de risco de quedas: ensaio randomizado controlado em homens comunitários	Sousa et al. (2017)	66 participantes (69 ± 4.9 anos), distribuídos em grupo aeróbico ($n=22$), grupo combinado ($n=22$) e grupo controlo ($n=22$)	Comparar efeitos a longo prazo de programas de exercício na comunidade sobre fatores de risco de quedas	Adicionar treino de resistência ao aeróbico melhora fatores associados ao risco de quedas. Ambos os regimes (combinado ou aeróbico) foram mais eficazes do que não treinar.
Avaliação de capacidades de equilíbrio em adultos mais velhos através de teste clínico e plataforma de baixo custo	Sgrò et al. (2015)	34 participantes (10 homens e 24 mulheres; idade média 85 anos)	Avaliar associação de duas abordagens para estimar equilíbrio e capacidade de levantar-se em indivíduos comunitários	Wii Balance Board é um método recomendado para avaliação de equilíbrio e capacidades de sentar/levantar, complementando testes clínicos.
Existe relação entre queixas de desequilíbrio e perturbação do controlo postural em mulheres idosas comunitárias? Estudo transversal usando posturografia	Tanaka et al. (2015)	44 mulheres >60 anos (17 com queixas de desequilíbrio, 27 sem)	Investigar se a percepção subjetiva de desequilíbrio se associa a défices objetivos de controlo postural	A posturografia não mostrou diferenças; o teste de apoio unipedal temporal permitiu observar diferenças de desempenho entre mulheres com e sem queixas.
Viabilidade e efeitos da aplicação de vibração corporal total por ressonância estocástica em adultos mais velhos não treinados: estudo piloto randomizado crossover	Rogan et al. (2015)	20 participantes divididos em dois grupos de vibração	Determinar viabilidade e impacto da SR-WBV no equilíbrio estático/dinâmico e tempo de reação	Boa taxa de recrutamento (55%) e adesão (85%). Efeitos médios no teste levantar, caminhar e voltar a sentar expandido (ETGUG), indicando viabilidade da intervenção.
Efeitos do treino de vibração vertical e alternada lateral nos fatores de risco de quedas e remodelação óssea em adultos mais velhos com risco de quedas	Corrie et al. (2015)	61 participantes (37 mulheres, 24 homens; 80.2 ± 6.5 anos)	Avaliar influência da vibração vertical e alternada lateral na saúde musculoesquelética	Melhorias no tempo de cadeira, ETGUG, medo de cair e NEADL. Maior ganho de força nas pernas com VV; formação óssea aumentada em SV e VV. Oscilação corporal melhorou menos no VV do que no Sham.
Análise do equilíbrio em apoio unipedal para adultos mais velhos com unidades de medição inercial	Kong et al. (2014)	80 participantes saudáveis	Estudar estabilidade postural em apoio unipedal no plano frontal e estratégias usadas	No plano sagital não há padrão significativo; deslocamento e ajuste relativamente pequenos. Pernas e tronco são considerados um corpo rígido.
Aprendizagem a partir de quedas induzidas em laboratório: retenção motora a longo prazo em adultos mais velhos	Pai et al. (2014)	73 participantes (≥ 65 anos)	Desenvolver paradigmas de treino para reduzir quedas	Treino aumentou resiliência contra quedas induzidas em laboratório, reduzindo quedas de 42.5% na primeira escorregadela para 0% na 24ª. Retenção mantida em 6, 9 e 12 meses.

Abreviações: MSEG: Grupo de exercício de força muscular; GC: Grupo controlo; TUG: Levantar, caminhar e voltar a sentar ; TC: Tai chi; DT: Tarefa dupla; NE: Sem exercício; DP: Desvio padrão; ML: Medio lateral; GSR: Razão de estabilidade da marcha; CoM: Centro de massa; CI: Implantes cocleares; WC: Com queixas de desequilíbrio; NC: Sem queixas de desequilíbrio; SR-WBV: Vibração corporal total por ressonância; ETGUG: Teste levantar, caminhar e voltar a sentar expandido; VV: Vibração vertical; SV: Vibração alternada Lateral; NEADL: Índice Nottingham de atividades da vida diária estendidas.

A pontuação média da análise de risco de viés com a ferramenta *Evidence Project* foi 5.88 em 8 (DP 1.31), variando entre 4 e 7, conforme Tabela 7. Todos cumpriram o item 1; 10 cumpriram o item 2; 9 estudos cumpriram o item 3.

A avaliação da representatividade dos participantes mostrou resultados mais heterogéneos. O item 4 (“atribuição aleatória dos participantes à intervenção”) foi



cumprido por 11 estudos. Nenhum artigo cumpriu o item 5 (“seleção aleatória dos participantes para avaliação”). Todos os estudos cumpriram o item 6, apenas um estudo não cumpriu o item 7, e dois estudos não cumpriram o item 8.

Tabela 7- *Análise de risco de viés com a ferramenta Evidence Project.*

Estudo	Desenho do estudo			Ensaio com participantes representativos		Equivalência dos grupos de comparação			Pontuação total
	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7	Item 8	
Pinvanchikul e Siriphorn [27]	Sim	Sim	Não	Sim	Não	Sim	Sim	Sim	6/8
Rodrigues et al. [28]	Sim	Sim	Sim	Sim	Não	Sim	Sim	Sim	7/8
Bertolini et al. [5]	Sim	Não	Sim	Sim	Não	Sim	Sim	Sim	6/8
Li et al. [29]	Sim	Sim	Sim	Não	Não	Não	Sim	Não	5/8
Sapi et al. [30]	Sim	Não	Não	Sim	Não	Não	Sim	Sim	5/8
Battaglia et al. [31]	Sim	Sim	Sim	Não	Não	Sim	Sim	Não	5/8
Kaczmarczyk et al. [32]	Sim	Não	Sim	Não	Não	Sim	Sim	Sim	6/8
Louza et al. [33]	Sim	Não	Não	Sim	Não	Sim	Sim	Sim	5/8
de Arruda et al. [1]	Sim	Sim	Não	Sim	Não	Sim	Não	Sim	4/8
Baranova e Kaplievich [2]	Sim	Não	Sim	Sim	Não	Sim	Sim	Sim	6/8
Sousa et al. [34]	Sim	Sim	Sim	Sim	Não	Sim	Sim	Sim	7/8
Sprö et al. [35]	Sim	Sim	Sim	Sim	Não	Sim	Sim	Sim	7/8
Tanaka et al. [36]	Sim	Não	Sim	Sim	Não	Sim	Sim	Não	6/8
Rogan et al. [37]	Sim	Sim	Não	Sim	Não	Sim	Sim	Sim	5/8
Corrie et al. [38]	Sim	Sim	Não	Sim	Não	Sim	Sim	Sim	6/8
Kong et al. [39]	Sim	Não	Não	Sim	Não	Sim	Sim	Sim	5/8
Pai et al. [40]	Sim	Não	Sim	Não	Não	Sim	Sim	Sim	5/8



Os resultados confirmaram que o controlo postural desempenha um papel determinante na prevenção de quedas e que a sua melhoria pode reduzir significativamente os riscos associados ao envelhecimento.

5.2. Resultados das revisões bibliométricas

5.2.1. Evolution of the documents related to how a sedentary lifestyle influences the aging process: a bibliometric review

Este estudo bibliométrico analisou a produção científica internacional sobre os efeitos do comportamento sedentário no envelhecimento.

A Figura 6 mostra o número de documentos publicados em cada ano e o número total de citações por ano, de acordo com os documentos publicados. Os resultados indicam que o primeiro documento foi publicado em 1994; contudo, não há continuidade na publicação até 1997, ano em que pelo menos um documento foi publicado. Considerando o número de citações, 2009 é o ano com o maior número de citações ($n = 1601$). Por outro lado, analisando o número de documentos, 2021 apresenta o maior número ($n = 36$). Considerando 1997 como o primeiro ano, a amostra mostra um crescimento exponencial de 79.4% até aos dias de hoje.

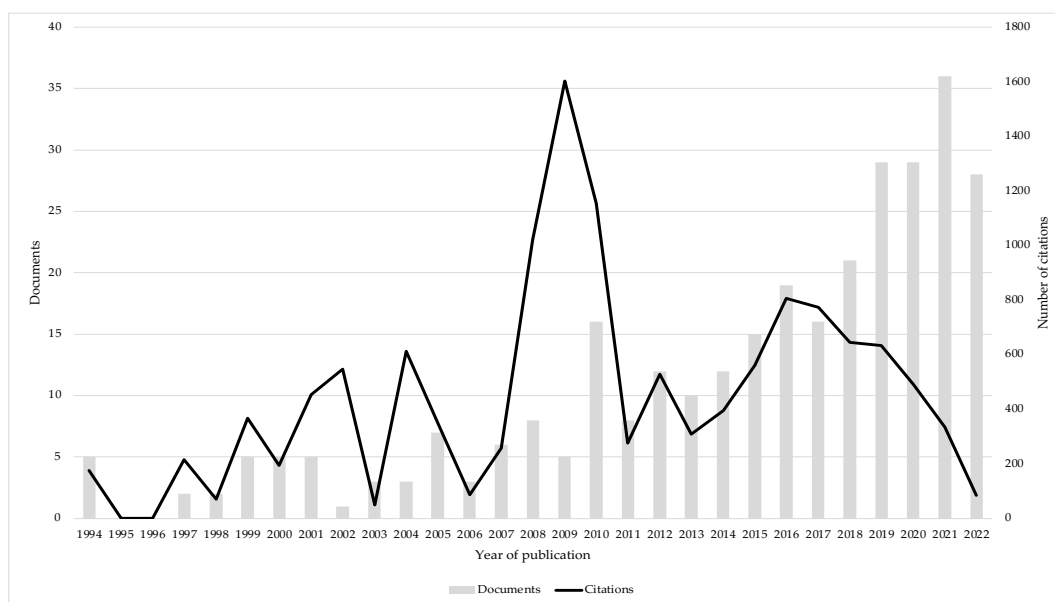


Figura 6- Número de documentos e citações por ano.

Para analisar as citações dos documentos, primeiro foi identificado o Índice H da amostra do número de citações por documento ($n = 58$). Isto significa que existem pelo menos 58 documentos com um mínimo de 58 citações desde a sua publicação até 31 de



dezembro de 2022. A análise mostra que seis documentos têm um número de citações superior a 300. A média de citações considerando os 58 documentos principais foi 101 (Figura 7).

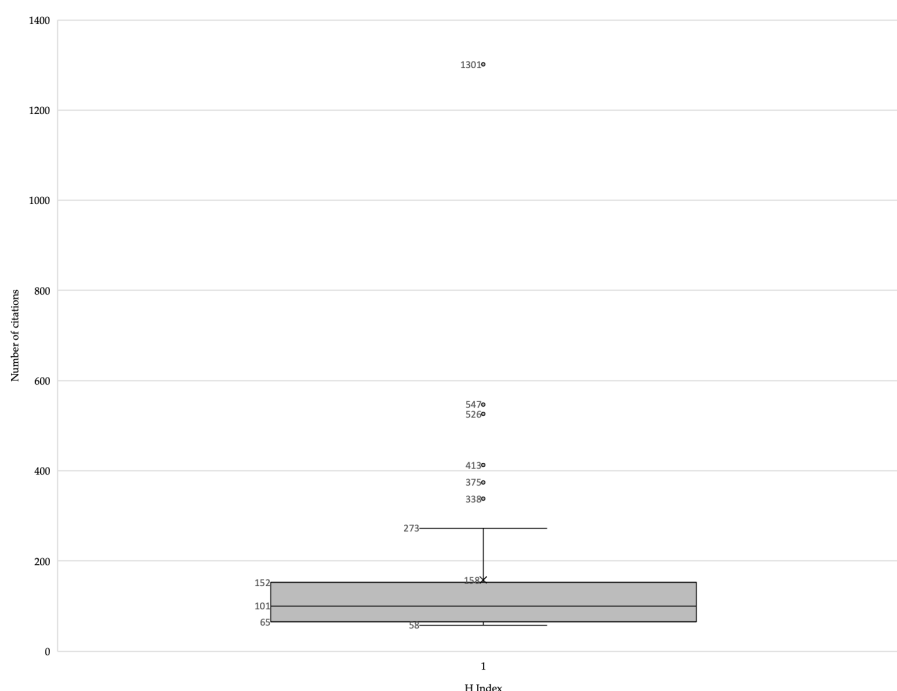


Figura 7- Índice H da amostra do número de citações.

A Tabela 8 apresenta os 10 documentos mais citados e a média de citações por ano. Esta informação permite analisar quais documentos são mais relevantes e despertam maior interesse na comunidade científica. Após análise, observa-se que o artigo de Chodzko-Zajko et al. (2009) apresenta o maior número de citações ($n = 1301$) e a maior média de citações por ano ($n = 92.93$), apesar de ter sido publicado em 2009, sendo considerado um estudo recente. Nesta linha, 50% dos estudos são classificados como Revisão, por realizarem uma revisão sistemática da literatura sobre diferentes tipos de variáveis, como *Position Stand*, capacidade de reserva do sistema neuromuscular ou consumo excessivo de alimentos.

De igual forma, a Figura 8 mostra as interações entre os autores mais citados, incluindo um total de 58 autores. O tamanho do nó corresponde ao número de citações por documento.



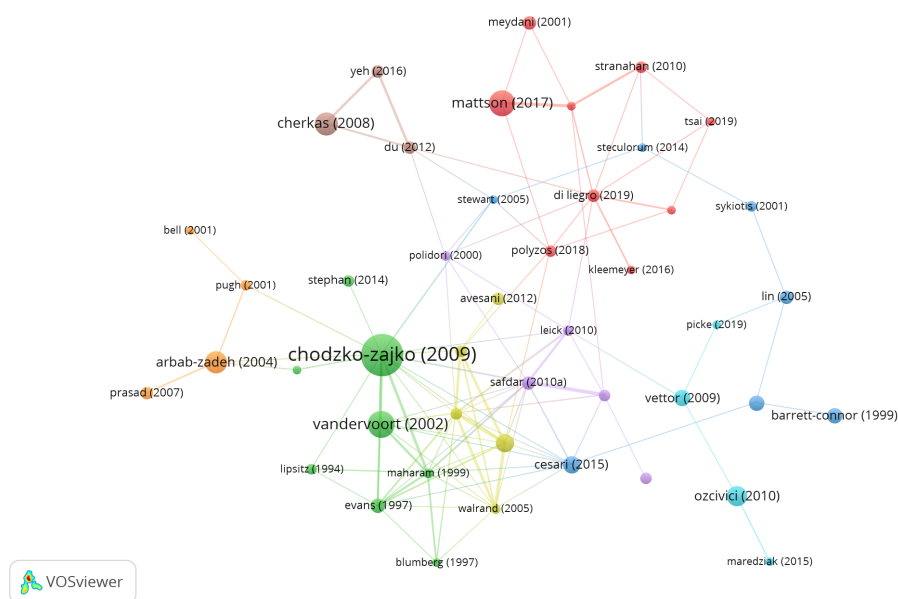


Figura 8- Acoplamento bibliográfico (Análise: Fracionalização; Atração: 3; Repulsão: -3).

Tabela 8- Dez artigos científicos e de revisão mais citados.

Autor/es	Título do Artigo	Resumo	Revista	Tipo de documento	Ano de publicação	Total de citações	Média de citações/ano
Chodzko-Zajko et al. (2009)	Exercise and Physical Activity for Older Adults	Esta Position Stand visa fornecer uma visão geral sobre a importância do exercício e atividade física em populações idosas.	Medicine & Science in Sports & Exercise	Revisão	2009	1301	92.93
Vandervoort (2002)	Aging of the human neuromuscular system	A perda de células do sistema motor ocorre com o envelhecimento, reduzindo neurónios motores e fibras musculares, levando à sarcopenia e aos efeitos do estilo de vida sedentário.	Muscle & Nerve	Revisão	2002	547	26.05
Mattson et al. (2017)	Impact of intermittent fasting on health and disease processes	O consumo excessivo de alimentos associado a sedentarismo leva a morbilidades metabólicas; o estudo analisa os efeitos do jejum intermitente.	Ageing Research Reviews	Revisão	2017	526	87.67
Cherkas et al. (2008)	The association between physical activity in leisure time and leukocyte telomere length	A inatividade física é fator de risco para doenças relacionadas com envelhecimento; o estilo de vida sedentário afeta o comprimento dos telômeros leucocitários.	Archives Of Internal Medicine	Artigo	2008	413	27.53
Arbab-Zadeh et al. (2004)	Effect of aging and physical activity on left ventricular compliance	A compliance ventricular esquerda diminui com a idade; treino de endurance prolongado pode preservá-la.	Circulation	Artigo	2004	381	20.05
Palazzo et al. (2016)	Risk factors and burden of osteoarthritis	A osteoartrite é uma doença comum que limita a atividade, sobretudo a marcha, afetando a qualidade de vida; fatores de risco incluem obesidade e sedentarismo.	Annals Of Physical And Rehabilitation Medicine	Artigo	2016	375	53.57



Autor/es	Título do Artigo	Resumo	Revista	Tipo de documento	Ano de publicação	Total de citações	Média de citações/ano
Ozceivici et al. (2010)	Mechanical signals as anabolic agents in bone	O envelhecimento e o sedentarismo reduzem massa óssea e muscular e comprometem estabilidade postural; os sinais mecânicos podem atuar como agentes anabólicos.	Nature Reviews Rheumatology	Revisão	2010	338	26.00
Paddon-Jones et al. (2008)	Role of dietary protein in the sarcopenia of aging	A sarcopenia é multifatorial; a ingestão inadequada de proteína e sedentarismo contribuem para perda muscular crônica relacionada com a idade.	American Journal Of Clinical Nutrition	Artigo	2008	273	18.20
Cesari et al. (2015)	A Physical Activity Intervention to Treat the Frailty Syndrome in Older Persons	A intervenção de atividade física visa reduzir a prevalência e severidade da fragilidade em adultos mais velhos.	Journals Of Gerontology Series A	Artigo	2015	239	29.88
Vettor et al. (2009)	The origin of inter-muscular adipose tissue and its pathophysiological implications	O tecido adiposo intermuscular (IMAT) origina-se de células estaminais musculares; este estudo analisa a sua função e origem.	American Journal Of Physiology-Endocrinology And Metabolism	Revisão	2009	199	14.21

Considerando as categorias WoS, *Geriatrics Gerontology* é a categoria com maior número de documentos (n = 50), representando 16% da amostra. *Public Environmental Occupational Health* ocupa o segundo lugar com 33 documentos, e *Sport Sciences* com 31 documentos. Estas três categorias compreendem ~36% do total (Tabela 9).

Tabela 9- Categorias WoS.

Categorias WoS	Documentos	%
Geriatrics Gerontology	50	16.07
Public Environmental Occupational Health	33	10.61
Sport Sciences	31	9.96
Endocrinology Metabolism	28	9.00
Nutrition Dietetics	20	6.43

A Tabela 10 mostra as revistas com maior número de documentos publicados sobre o tema. *Plos One* é a revista com mais documentos (n = 7), enquanto *Medicine and Science in Sports and Exercise* tem o maior fator de impacto (5.4) apesar de ter publicado apenas 4 documentos.



Tabela 10- Revistas com maior número de documentos publicados.

Revista	Documentos	%	IF*	Categoria	Quartil	JIF Rank
Plos One	7	2.25	3.7	Multidisciplinary Science	Q2	26/73
Experimental Gerontology	5	1.60	3.9	Geriatrics & Gerontology	Q2	27/54
International Journal of Environmental Research and Public Health	5	1.60	N/A	Environmental Science	N/A	N/A
Medicine and Science in Sports and Exercise	5	1.60	5.4	Sport Science	Q1	14/87
Frontiers in Physiology	4	1.28	4.0	Physiology	Q2	21/79

Dos 311 documentos identificados, foram selecionados 1509 autores, sendo 75 com pelo menos 2 documentos e 4 autores com pelo menos 4 documentos. Amagasa, S., Fukushima, N., Inoue, S., e Kikuchi, H. publicaram mais documentos relacionados com o tema ($n = 4$). Todos os autores foram incluídos na análise de coautoria; o tamanho do nó representa o número de documentos, e a espessura da ligação representa a força do vínculo (Figura 9).

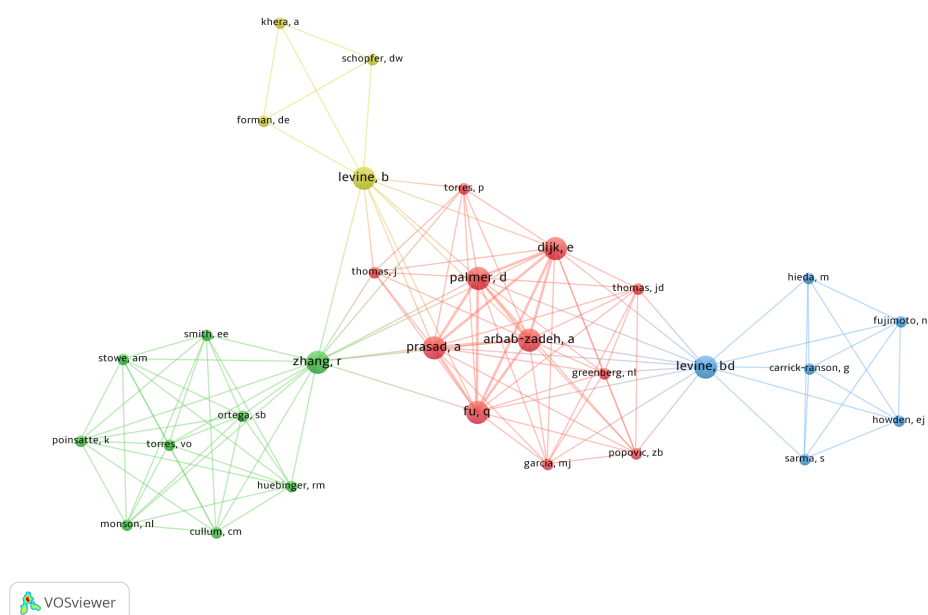


Figura 9- Coautoria dos documentos (Análise: Fracionalização; Atração: 3; Repulsão: -3).



Considerando o período de publicação, observa-se diferentes grupos de autores: o cluster roxo é o mais antigo e o amarelo o mais recente. O tamanho do nó corresponde ao número de citações recebidas. O grupo mais antigo apresenta o maior número de citações (Figura 10).

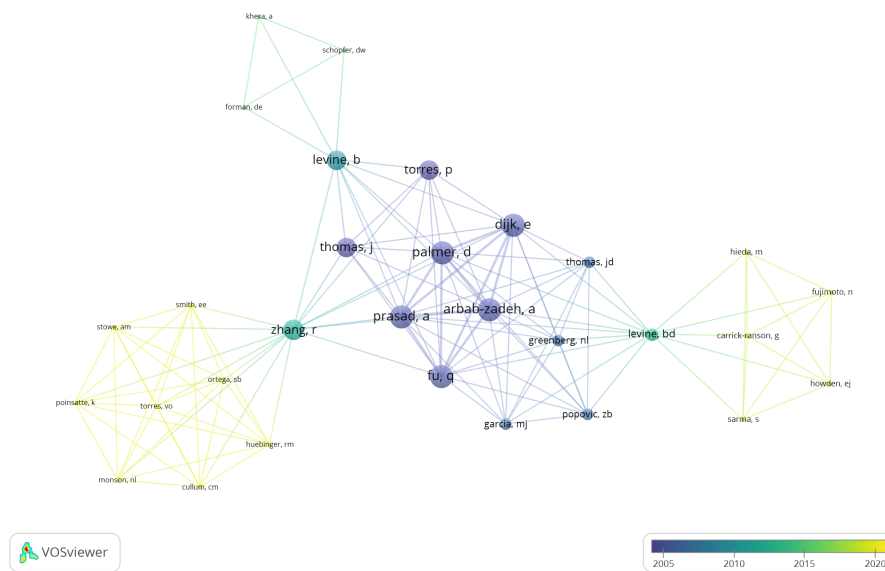


Figura 10- Visualização sobre o período de publicação (Análise: Fracionalização; Atração: 3; Repulsão: -3).

Foram detetadas 630 organizações colaboradoras. Apenas 5 tiveram pelo menos 5 documentos publicados. *Johns Hopkins University* e *University of Lisbon* publicaram 8 e 6 documentos, respetivamente. Em número de citações, *Johns Hopkins University* lidera com 876. O tamanho do nó representa o número de documentos por organização (Figura 11).



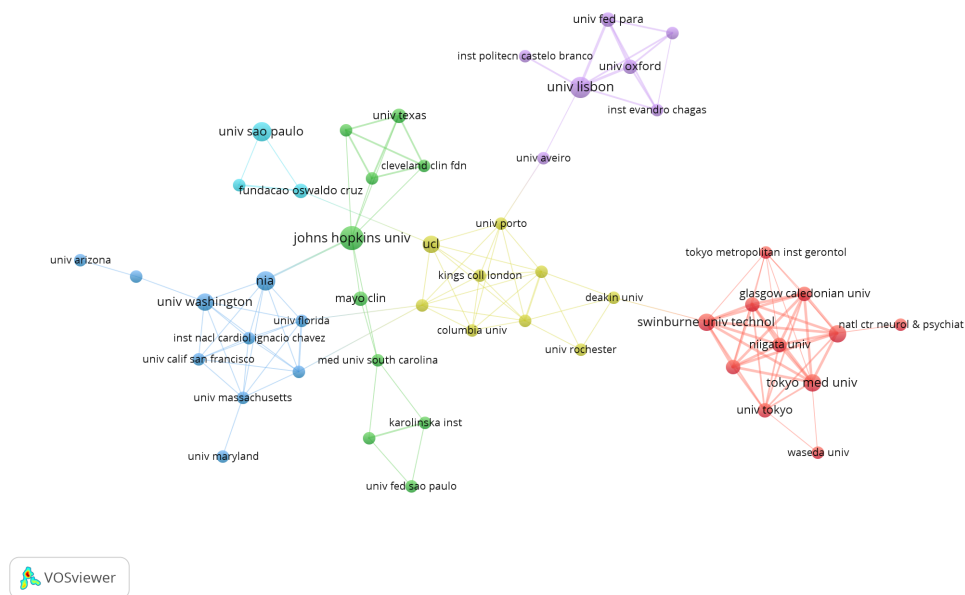


Figura 11- Coautoria por organização (Análise: Fracionalização; Atração: 3; Repulsão: -3).

Foram identificados 58 países colaboradores na produção dos 311 documentos. Apenas 3 tiveram pelo menos 21 documentos, e 13 tiveram pelo menos 10. Todos os países foram incluídos na análise. Estados unidos da América (EUA) lidera em número de documentos ($n = 100$) e citações ($n = 5749$). O tamanho do nó representa o número de documentos por país (Figura 12).

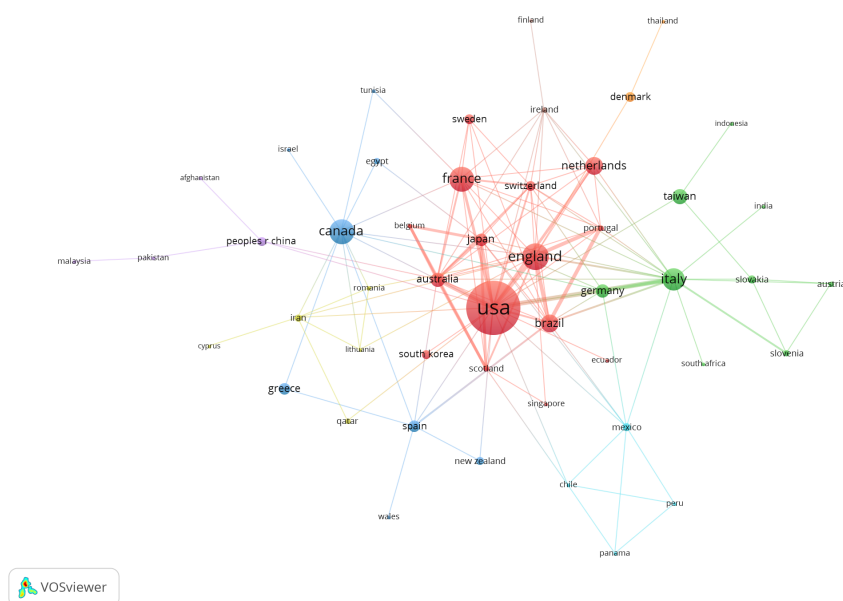


Figura 12- Coautoria considerando países (Análise: Fracionalização; Atração: 3; Repulsão: -3).



Foram detetadas 807 palavras-chave, sendo 34 com mais de 5 ocorrências. Para análise, foram incluídas 49 palavras com ocorrência superior a 4. *Aging*, *exercise*, *physical activity*, *sedentary lifestyle* foram os termos mais frequentes (97, 49, 41 e 37 ocorrências, respetivamente). O par com maior força de ligação foi *Aging e Sedentary lifestyle* (Figura 13).

Considerando o período de publicação, observa-se mudança nas tendências de pesquisa, focando-se agora em *Healthy aging*, *Covid-19*, *Sedentary behavior e Public health* (Figura 14). O tamanho do nó representa o número de documentos publicados e a espessura da linha a força de ligação.

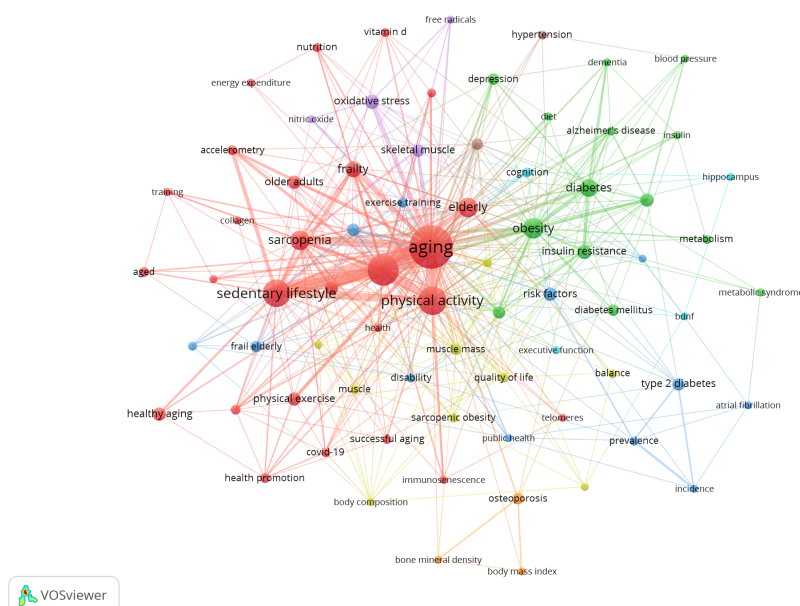


Figura 13- Co-ocorrência das palavras-chave dos autores (Análise: Fracionalização; Atração: 3; Repulsão: -3).



documento por ano, com continuidade de publicações até aos dias de hoje. Observa-se um crescimento exponencial de 77,4% entre os estudos mais antigos (1997-2008) e os estudos contemporâneos (2008-2023).

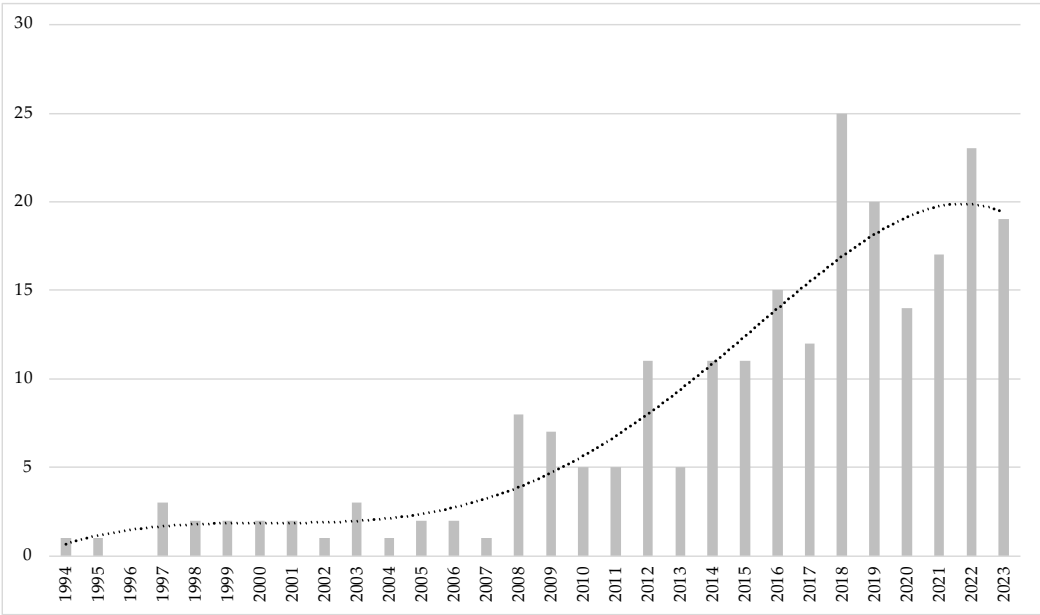


Figura 15- Crescimento exponencial da amostra.

Observou-se que, dentro das categorias WoS, *Geriatrics Gerontology* apresenta o maior número de documentos (n = 59). Além disso, *Experimental Gerontology* é a revista que publicou mais documentos dentro desta categoria (n = 7). Os dados estão apresentados na Tabela 11.

Tabela 11- Documentos classificados de acordo com as categorias WoS.

Categorias WoS	Documentos	%	Nome da revista	Documentos
Geriatrics Gerontology	59	27.44	Experimental Gerontology	7
Sport Sciences	36	16.74	Journal of Aging and Physical Activity	5
Public Environmental Occupational Health	31	14.41	International Journal of Environmental and Public Health	6
Gerontology	21	9.76	Journal of Aging and Physical Activity	6
Medicine General Internal	15	6.97	Preventive Medicine	3
Physiology	14	6.51	Frontiers in Physiology	3
Nutrition Dietetics	13	6.04	Journal of Nutrition Health Aging	3



Categorias WoS	Documentos	%	Nome da revista	Documentos
Rehabilitation	13	6.04	Brazilian Journal of Physical Therapy	3
Cardiac Cardiovascular Systems	11	5.11	American Journal of Geriatric Cardiology	2
Medicine Research Experimental	9	4.18	Contemporary Clinical Trials	3

A Tabela 12 mostra as 5 revistas mais relevantes relacionadas com o estudo da AF e capacidade funcional ao longo do envelhecimento. São também apresentados o quartil e a classificação da revista em relação ao fator de impacto. Os resultados indicam que a revista com o maior número de documentos é *Experimental Gerontology*, representando 3% dos documentos selecionados. Este resultado evidencia a variabilidade das revistas escolhidas para publicar estes estudos.

Tabela 12- Revistas com mais artigos publicados relacionados com o tema do estudo.

Revista	Documentos	%	IF*	Categoria	Quartil	JIF Rank
Experimental Gerontology	7	3.24	3.9	Geriatrics & Gerontology	Q2	27/54
International Journal of Environmental Research and Public Health	6	2.77	N/A	Environmental Science	N/A	N/A
Journal of Aging and Physical Activity	6	2.77	1.5	Geriatrics & Gerontology	Q4	50/54
Archives of Gerontology and Geriatrics	4	1.85	4.0	Geriatrics & Gerontology	Q2	24/54
Plos One	4	1.85	3.7	Multidisciplinary Science	Q2	26/73

Para analisar as citações, primeiro foi identificado o Índice H da amostra (n = 44). Este valor permite identificar os autores mais influentes relacionados com o tema. O Índice H é definido como o número h de documentos que têm pelo menos h citações.

A Figura 16 mostra a tendência de publicação dos documentos e o total de citações por ano. Os resultados indicam que 2009 foi o ano com o maior número de citações (n = 1811), com um total de 7 documentos publicados. Por outro lado, 2018 foi o ano com o maior número de documentos (n = 25). Observa-se que o número de citações tem sido reduzido desde 2020 até agora, devido à recente publicação dos artigos, sendo 2022 o ano com o maior número de citações nos últimos quatro anos (n = 137).



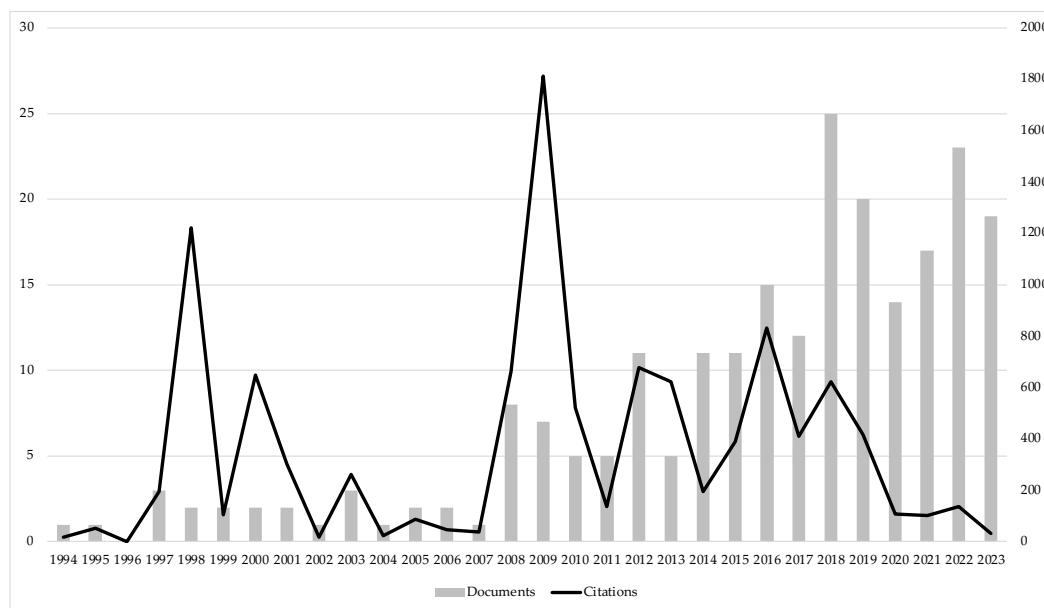


Figura 16- Número de documentos e citações por ano.

A Tabela 13 mostra os 10 documentos mais citados relacionados com o tema selecionado. Os resultados indicam que o artigo de Chodzko-Zajko et al. (2009) possui o maior número de citações e a maior média de citações por ano, com 99.5 citações por ano. Para a análise, foram incluídas as autocitações.

Tabela 13- Dez documentos de pesquisa mais citados.

Título	Autores	Ano de publicação	Revista	Total de citações	Média de citações/ano
Exercise and Physical Activity for Older Adults	Chodzko-Zajko et al.	2009	Medicine & Science in Sports & Exercise	1293	99.5
ACSM Position Stand: Exercise and Physical Activity for Older Adults	Mazzeo et al.	1998	Medicine & Science in Sports & Exercise	1072	44.7
Social-cognitive and perceived environment influences associated with physical activity in older Australians	Booth et al.	2000	Preventive Medicine	508	23.1
Age-related decrease in physical activity and functional fitness among elderly men and women	Milanovic et al.	2013	Clinical Interventions in Aging	414	46



Título	Autores	Ano de publicação	Revista	Total de citações	Média de citações/ano
Updating the Evidence for Physical Activity: Summative Reviews of the Epidemiological Evidence, Prevalence, and Interventions to Promote Active Aging	Bauman et al.	2016	Gerontologist	404	67.3
Protecting muscle mass and function in older adults during bed rest	English and Paddon-Jones	2010	Current Opinion in Clinical Nutrition and Metabolic Care	313	26.1
The danger of weight loss in the elderly	Miller and Wolfe	2008	Journal Of Nutrition Health & Aging	272	19.4
Aging, exercise, and muscle protein metabolism	Koopman and van Loon	2009	Journal Of Applied Physiology	254	19.5
Physical work capacity in older adults: Implications for the aging worker	Kenny et al.	2008	American Journal of Industrial Medicine	202	14.4
Fish-oil supplementation enhances the effects of strength training in elderly women	Rodacki et al.	2012	American Journal of Clinical Nutrition	199	19.9

Foram identificados 1071 autores, sendo que apenas 8 autores têm um mínimo de quatro documentos publicados, e 81 autores com dois documentos. A Figura 17 mostra a interação entre os autores e coautores. O autor com maior número de artigos publicados é Aubertin-Leheudre, M., porém não aparece na figura devido às interações raras com outros autores.



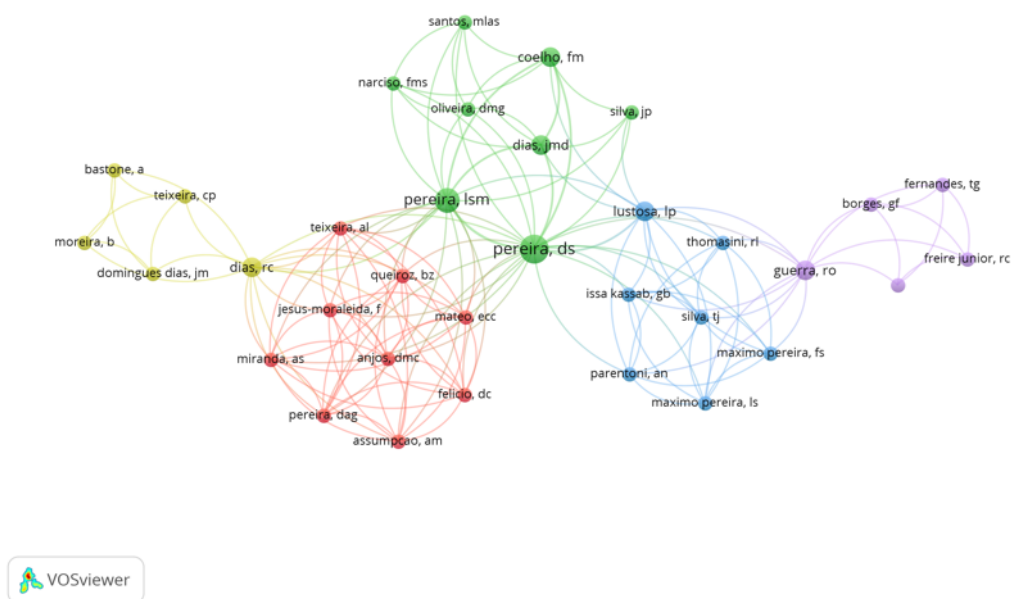


Figura 17- Rede de autores e coautores.

A Figura 18 mostra a evolução do grupo de autores focados na influência da AF e capacidade funcional em adultos mais velhos. O *cluster* formado por Thomasini, R.L., Issa Kassab, G.B., Silva, T.J., Perentoni, A.N., Maximo Pereira, L.S., e Maximo Pereira, F.S. é o mais recente, com publicações de 2020 até hoje. Por outro lado, os autores com maior número de citações têm uma média de publicações entre 2010 e 2014.



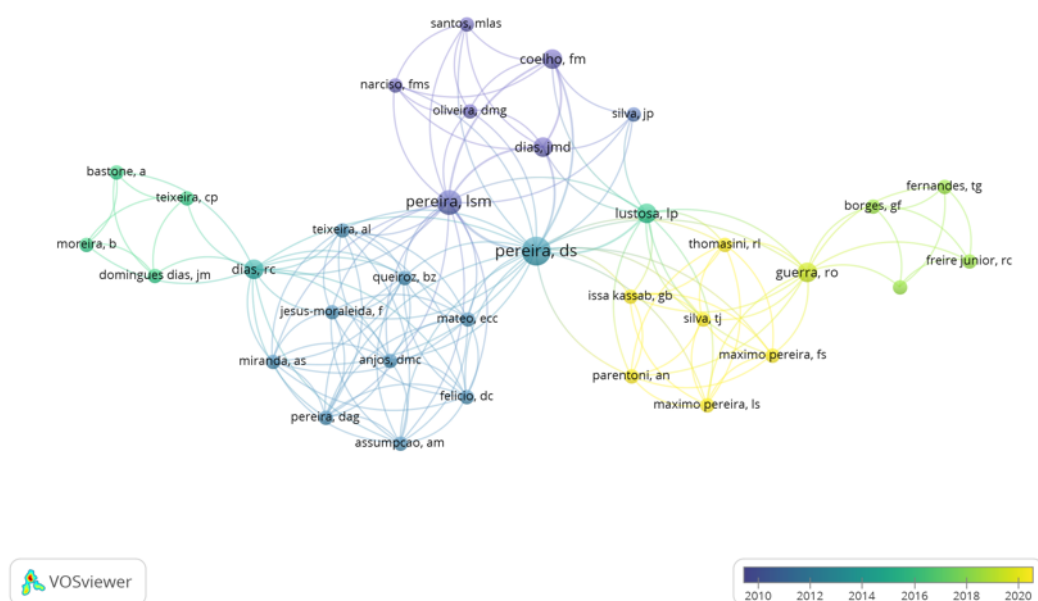


Figura 18- Interações dos autores em função do período de publicação.

Foram identificados 40 países contribuindo para a produção dos estudos. Doze países tiveram um mínimo de 5 documentos e nove países pelo menos 10 artigos. A Tabela 14 mostra os 10 países mais prolíficos. Brasil e EUA totalizam 109 documentos. Na análise, a interação entre os países é ilustrada nas Figuras 19 e 20. O país com mais citações é os EUA ($n = 2355$), seguido da Austrália ($n = 1410$).

Tabela 14- Países mais prolíficos.

País	Documentos	%	Citações
Brasil	57	26.51	926
EUA	52	24.18	2355
Espanha	21	9.76	434
Austrália	16	7.44	1410
Canadá	16	7.44	749
Finlândia	12	5.58	427
França	11	5.11	360
Japão	11	5.11	187
Inglaterra	10	4.65	539
Itália	9	4.18	347



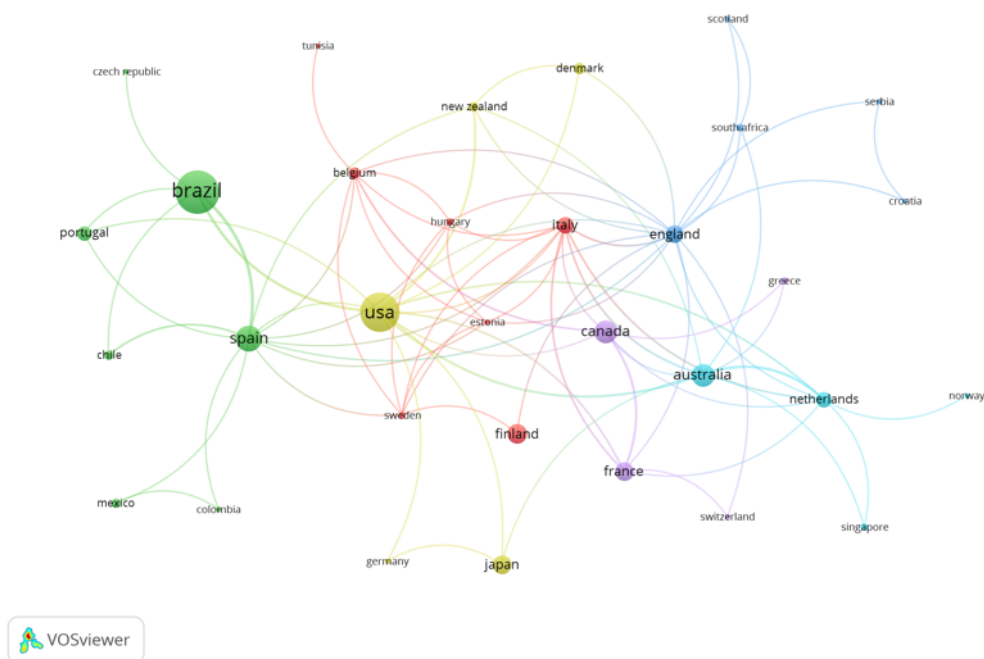


Figura 19- Interações entre países com base no número de documentos publicados.

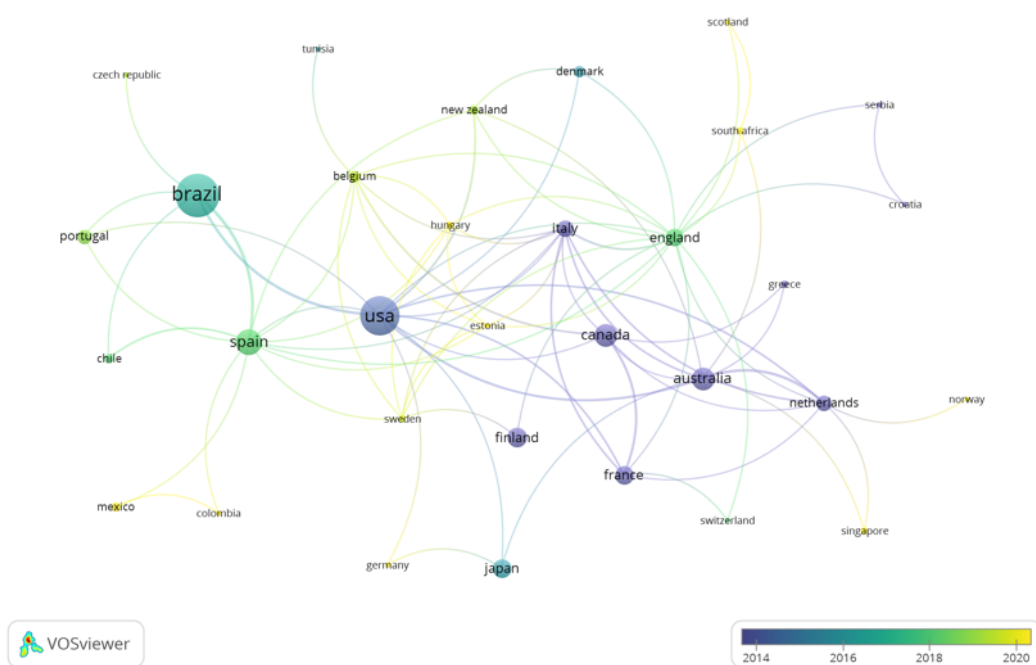


Figura 20- Interações entre países em função do período de publicação.



Foram detetadas 440 organizações que participaram na elaboração dos documentos. Apenas 8 organizações possuem pelo menos 5 documentos publicados. Para análise aprofundada, foram incluídas apenas organizações com um mínimo de dois documentos ($n = 72$). A Universidade Federal do Rio Grande do Sul é a mais prolífica com 9 documentos. Quanto às citações, a *University of Sydney* lidera com 890 citações (Figura 21).

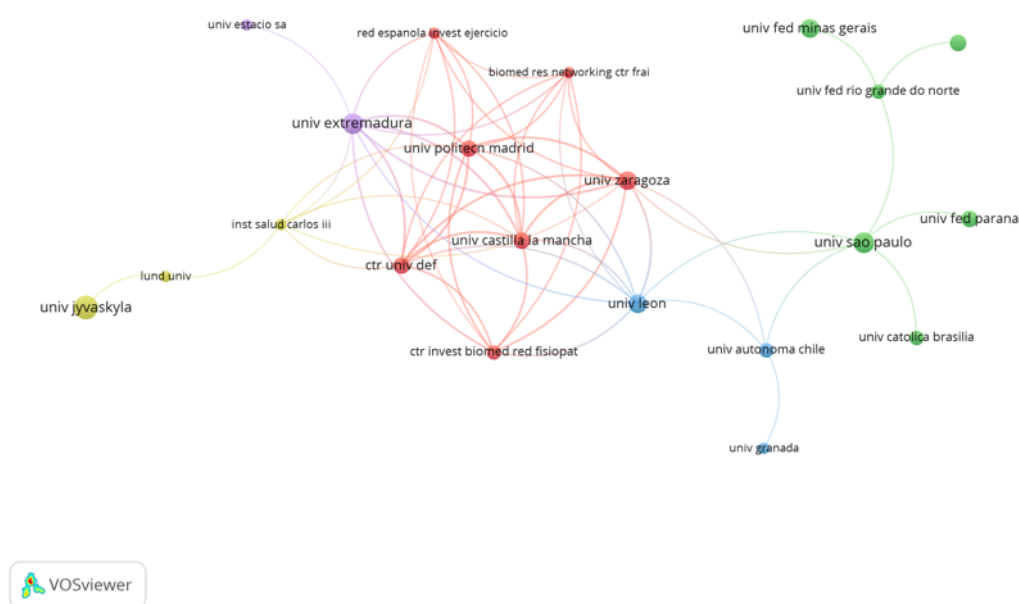


Figura 21- Rede de organizações.

Considerando o período de publicação, observa-se que a *University of Castilla y León* e a *Polytechnical University of Madrid* são as organizações mais recentes em termos de média de anos de publicação. Da mesma forma, a *University of Extremadura* apresenta publicações recentes (Figura 22).



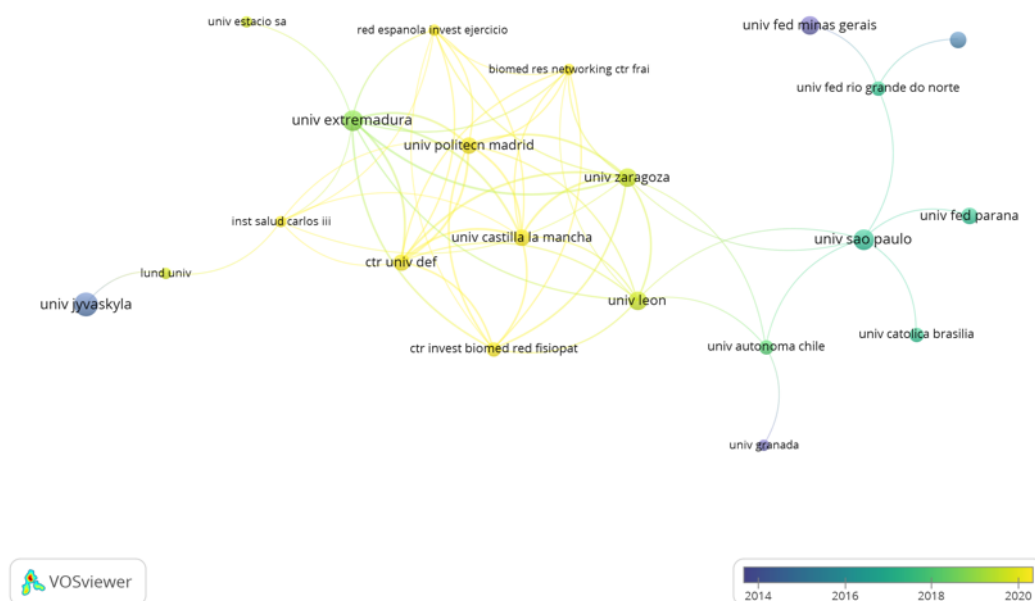


Figura 22- Interações entre organizações em função da temporalidade da publicação.

Foram identificadas 472 palavras-chave entre os estudos selecionados. Apenas 24 palavras apresentaram ocorrência igual ou superior a 5. Para melhor compreensão e visualização das interações, foram incluídas apenas palavras-chave com um mínimo de três ocorrências ($n = 53$). Os termos mais frequentes foram *aging*, *physical activity* e *functional capacity*, com 102, 42 e 39 ocorrências, respectivamente (Figura 23).



5.4. Resultados dos estudos de caso

5.4.1. Assessment of spatiotemporal characteristics of gait, through the Phyphox® app: case report

Este estudo de caso explorou a aplicação da ferramenta móvel Phyphox na avaliação das características espaço-temporais da marcha. Os participantes realizaram deslocações a uma cadência natural, registrando-se diferenças significativas entre indivíduos. Dois participantes apresentaram mais de 80 passos por minuto (81.14 ± 0.01 ; 86.67 ± 0.02), enquanto os restantes se situaram entre 55 e 65 passos por minuto (Figura 24).

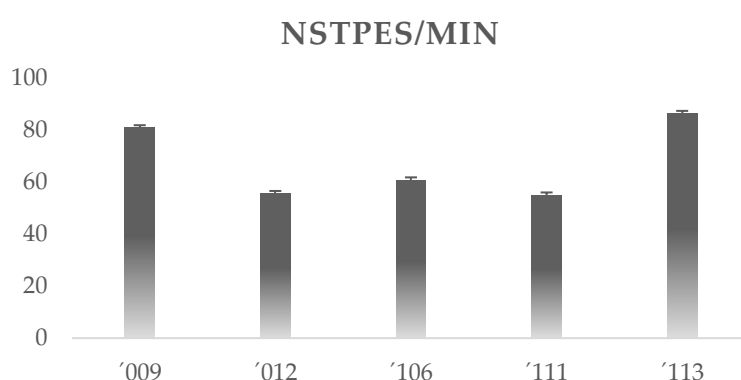


Figura 24- Número total de passos por minuto de cada participante.

Quanto ao coeficiente de variação, apenas um participante apresentou 10.08%, sendo que os restantes apresentaram valores entre 2% e 4%. No que diz respeito ao número total de passos, três dos participantes tiveram valores superiores a 1000 passos, enquanto os outros dois registaram aproximadamente 600 passos (Tabela 15).

Tabela 15- Resultados resumidos de todas as variáveis da marcha estudadas em todas as condições.

nPassos/min	±	desvio-padrão	%CV	nPassos	Fractal
81.147	±	0.012	2.688	1309	0.712
55.783	±	0.045	4.851	667	1.059
61.028	±	0.051	10.076	1154	0.685
55.203	±	0.019	2.075	646	0.831
86.678	±	0.016	3.282	1188	0.771

A variabilidade da passada foi analisada por análise flutuação detrendida (DFA), tendo um dos participantes apresentado valores superiores a 1, indicativos de padrões fractais. Este estudo destaca o potencial da tecnologia móvel na análise da marcha



fisiológica de forma acessível e inovadora. A publicação encontra-se disponível no Apêndice 6 (DOI: 10.1186/s13256-023-04296-z).

5.4.2. The impact of sensorimotor training on physical fitness in older women with diabetes: a pilot study

Este estudo piloto avaliou os efeitos de seis meses de treino sensório motor na aptidão física de mulheres idosas com DM2. Dez participantes foram distribuídas entre GI (n=5) e GC (n=5). As avaliações incluíram agilidade (TUG), força (sentar e levantar e flexão do antebraço) e flexibilidade (sentar e alcançar e alcançar atrás das costas).

Os valores do teste *t de Student* indicam que não existem diferenças significativas entre os grupos, exceto para a idade, que apresentou diferença significativa ($p = 0.048$).

Para avaliar a aptidão física, foram realizados os seguintes testes: agilidade e velocidade de execução; força; e flexibilidade. Tanto o peso como o IMC de ambos os grupos diminuíram, sendo que o GI apresentou uma redução mais acentuada.

Relativamente à agilidade e velocidade, como mostrado na Tabela 2, o GC, apesar de apresentar um valor inicial de 9.26 s, superior ao do GI, conseguiu melhorar o tempo de execução do teste após a intervenção para 7.59 s. O GI iniciou com 8.46 s e alcançou 7.49 s na segunda avaliação.

No que diz respeito à capacidade de força, a força dos membros inferiores foi avaliada através do teste sentar e levantar da cadeira (SSL), e a força dos membros superiores através do teste de flexão do antebraço (FF). No teste SSL, o GC apresentou um valor médio mais baixo na primeira avaliação (11.60 repetições) e, na segunda avaliação, aumentou para 13.80 repetições. O GI começou com um valor ligeiramente superior (12.20 repetições) e aumentou para 13.20 repetições na segunda avaliação.

Na Tabela 16 observa-se que, no teste FF, o GC apresentou 16.80 repetições na primeira avaliação e aumentou para 18.20 repetições na segunda avaliação. O GI obteve um valor superior na primeira avaliação (18.80 repetições), mas reduziu para 18.20 repetições, igualando o GC na segunda avaliação.

Embora não se tenham obtido valores de p significativos, alguns testes apresentaram tamanho de efeito (ES) moderado, como peso ($p = 0.351$), IMC ($p = 0.406$), SSL ($p = 0.330$), FF ($p = 0.166$), RBBR ($p = 0.290$), e alguns tamanhos de efeito grande, como TUG ($p = 0.649$) e SR ($p = 0.719$). Como o objetivo era compreender o impacto do exercício nestes participantes, como mostrado na Tabela 16, tanto o GI como o GC apresentaram melhorias. Em outras palavras, o grupo que recebeu a intervenção



apresentou diferenças substanciais, mesmo não existindo diferenças significativas entre os grupos, o que reforça o ES previamente reportado.

Tabela 16- Principais resultados entre a primeira e a segunda avaliação em ambos os grupos (GC n=5; GI n=5).

Variáveis	Antes do exercício		Após o exercício 24 semanas		<i>p</i>	η^2	CI 95%
	GC	GI	GC	GI			
	M $\pm$ DP	M $\pm$ DP	M $\pm$ DP	M $\pm$ DP			
Peso (kg)	72.80 $\pm$ 19.90	74.90 $\pm$ 14.80	71.50 $\pm$ 19.10	72.30 $\pm$ 15.4	<i>p</i> = 0.351	0.109 [#]	(54.1;91.6)
IMC (kg/m²)	31.20 $\pm$ 8.20	31.60 $\pm$ 6.16	30.60 $\pm$ 7.79	30.50 $\pm$ 6.63	<i>p</i> = 0.406	0.088 [#]	(23.4;38.5)
TUG (s)	9.26 $\pm$ 2.38	8.46 $\pm$ 1.36	7.80 $\pm$ 1.63	7.49 $\pm$ 0.80	<i>p</i> = 0.649	0.027 [#]	(7.1;9.5)
SSL (rep)	11.60 $\pm$ 2.70	12.20 $\pm$ 1.92	13.8 $\pm$ 4.09	13.20 $\pm$ 1.30	<i>p</i> = 0.330	0.118 [#]	(10.1;15.3)
FF (rep)	16.80 $\pm$ 3.03	18.80 $\pm$ 5.22	18.20 $\pm$ 3.56	18.20 $\pm$ 4.38	<i>p</i> = 0.166	0.225 [#]	(13.4;22.6)
SR (cm)	-6.80 $\pm$ 14.40	-4.40 $\pm$ 9.18	-1.60 $\pm$ 9.48	-0.20 $\pm$ 8.98	<i>p</i> = 0.719	0.017 ⁺	(-15.1;8.6)
RBBR (cm)	-23.30 $\pm$ 18.00	-17.60 $\pm$ 15.30	-20.20 $\pm$ 17.90	-10.20 $\pm$ 11.10	<i>p</i> = 0.290	0.138 [#]	(-37.8;-5.7)
RBBL (cm)	-28.40 $\pm$ 13.30	-19.60 $\pm$ 14.30	-35.00 $\pm$ 18.80	-13.60 $\pm$ 11.70	<i>p</i> = 0.083	0.329 [*]	(-46;-2.3)

Notas: GC: Grupo de controlo; GI: Grupo de intervenção; IMC: índice de massa corporal; TUG: teste levantar, caminhar e voltar a sentar; SSL: teste sentar e levantar; FF: teste flexão do antebraço; SR: teste sentar e alcançar; RBBR: teste alcançar atrás das costas à direita; RBB: teste alcançar atrás das costas à esquerda. Dados apresentados como média $\pm$ desvio padrão (DP).

A ANOVA foi usada para avaliar o efeito global do grupo em todos os momentos. O teste *post hoc* revelou os resultados dentro de cada grupo; um valor de *p* <0.05 indicou significância estatística.

Pequeno tamanho de efeito (0.01-0.06); # Tamanho de efeito médio (0.06-0.14);
* Tamanho de efeito grande (>0.14)

Relativamente à flexibilidade, analisou-se a flexibilidade dos membros inferiores através do teste SR e a dos membros superiores através dos testes RBBR e RBBL.

Como mostrado na Tabela 17, no teste SR, o GC obteve -6.80 cm na primeira avaliação, pior que o GI (-4.40 cm), mas melhorou cinco cm na segunda avaliação, alcançando -1.60 cm. O GI passou de -4.40 cm para -0.20 cm, melhorando também. Ambos os grupos apresentaram melhoria média neste teste.



No teste RBBR, o GC começou com -23.30 cm (pior que o GI: -17.60 cm) e melhorou 3 cm para -20.20 cm, enquanto o GI melhorou 7 cm, passando para -10.20 cm. Neste caso, o GI obteve melhores resultados.

No teste RBBL, o GC apresentou -28.40 cm, pior que o GI (-19.60 cm), aumentando para -35.00 cm. O GI, que iniciou com valor inferior, reduziu a distância média em 5 cm, terminando a segunda avaliação com -13.60 cm.

Tabela 17- *Análise comparativa da variação após o programa de exercício (GC n=5; GI n=5).*

Variáveis	GC (24 semanas)	p value	GI (24 semanas)	p value
TUG (s)	1.46	0.221	0.97	0.020
SSL (rep)	-2.20	0.051	-1.00	0.298
FF (rep)	-1.40	0.052	0.40	0.646
SR (cm)	5.20	0.079	4.20	0.049
RBBR (cm)	3.10	0.212	7.40	0.080
RBBL (cm)	-6.60	0.343	6.00	0.023

Notas: GC: Grupo de controlo; GI: Grupo de intervenção; AV1: 1.^a avaliação; AV2: 2.^a avaliação; TUG: teste levantar, caminhar e voltar a sentar; SSL: teste sentar e levantar; FF: teste flexão do antebraço; SR: teste sentar e alcançar; RBBR: teste alcançar atrás das costas à direita; RBB: teste alcançar atrás das costas à esquerda; *p* value: $p < 0.05$ indica diferença significativa.

Para observar a evolução distinta de indivíduos que realizaram a intervenção e os que não realizaram, foi feita uma análise estatística da variação. Confirmou-se que existiram diferenças significativas nos resultados dos testes TUG ($p=0.020$), SR ($p=0.049$) e RBBL ($p=0.023$), conforme mostrado na Tabela 3.

Estes resultados sugerem que o treino sensório motor contribui para ganhos neuromusculares e proprioceptivos, essenciais na prevenção de quedas e na manutenção da independência funcional. Para pessoas com diabetes, estas melhorias são particularmente importantes, dado o impacto positivo na mobilidade, no controlo glicémico e na prevenção de complicações como a neuropatia periférica. A publicação encontra-se disponível no Apêndice 7 (DOI: 10.1186/s12877-025-06591-4).



5.5. Resultados dos ensaios clínicos randomizados (RCTs)

5.5.1. Evaluating the effects of sensorimotor training on the physical capacities of the older people

Este ensaio clínico randomizado teve como objetivo avaliar os efeitos de um programa de treino sensório motor na aptidão física de adultos mais velhos. A amostra incluiu 90 participantes, distribuídos entre GC com n=44 e GE com n=46. O programa de intervenção decorreu ao longo de 24 semanas, sendo as capacidades físicas avaliadas no início e no final do estudo. Foram aplicados os testes de Rikli e Jones (1999) para força e flexibilidade, e o TUG para agilidade e velocidade.

A Tabela 18 apresenta os principais resultados de acordo com os valores pré- e pós-intervenção. Todas as variáveis analisadas mostraram melhoria do pré- para o pós-intervenção, particularmente as variáveis “Alcançar atrás das costas (direito)” e “Alcançar atrás das costas (esquerdo)”, que apresentaram os valores mais elevados de tamanho de efeito (ES).

Tabela 18- *Análise descritiva e inferencial dos valores pré- e pós-intervenção considerando o grupo experimental (GE).*

Variáveis	Média	DP	Teste <i>t de Student</i>	Diferenças de média	<i>p</i>
Levantar, caminhar e voltar a sentar (pré) (s)	7.26	±1.23	3.90	0.416	<0.001
Levantar, caminhar e voltar a sentar (pós) (s)	6.85	±0.81			
Levantar e sentar com inclinação (pré) (rep)	13.00	±2.30	-3.64	-1.043	<0.001
Levantar e sentar com inclinação (pós) (rep)	14.00	±1.97			
Levantar e sentar sem inclinação (pré) (rep)	15.30	±2.95	-5.04	-1.370	<0.001
Levantar e sentar sem inclinação (pós) (rep)	16.60	±2.57			
Flexão de antebraço (pré) (rep)	17.30	±5.83	-3.33	-2.522	0.002
Flexão de antebraço (pós) (rep)	19.80	±4.04			
Sentado e alcançar (pré) (rep)	-2.54	±8.70	-4.43	-3.565	<0.001
Sentado e alcançar (pós) (rep)	1.02	±8.24			
Alcançar atrás das costas (direito) (pré) (m)	-13.80	±11.70	-7.29	-6.261	<0.001
Alcançar atrás das costas (direito) (pós) (m)	-7.50	±9.12			



Variáveis	Média	DP	Teste <i>t de Student</i>	Diferenças de média	<i>p</i>
Alcançar atrás das costas (esquerdo) (pré) (m)	-18.50	±11.00	-8.97	-7.391	<0.001
Alcançar atrás das costas (esquerdo) (pós) (m)	-11.20	±9.43			

s: segundos; rep: repetições; m: metros; DP: desvio padrão; Df: graus de liberdade; $p < 0,005$.

Considerando os valores do GC, a Tabela 19 não apresenta diferenças em nenhuma das variáveis estudadas. Observa-se que a variável com menor valor de p foi “sentar e alcançar” ($p = 0.155$). Estes valores indicam que o GC não melhorou as suas capacidades da mesma forma que o GI.

Tabela 19- *Análise descritiva e inferencial dos valores pré- e pós-intervenção considerando o GC.*

Variáveis	Média	DP	Teste <i>t de Student</i>	Diferenças de média	<i>p</i>
Levantar, caminhar e voltar a sentar (pré) (s)	8.15	±2.89	0.763	0.076	0.450
Levantar, caminhar e voltar a sentar (pós) (s)	8.08	±2.94			
Levantar e sentar com inclinação (pré) (rep)	13.50	±3.42	-0.947	-0.318	0.349
Levantar e sentar com inclinação (pós) (rep)	13.80	±2.96			
Levantar e sentar sem inclinação (pré) (rep)	15.50	±4.31	-0.120	-0.045	0.905
Levantar e sentar sem inclinação (pós) (rep)	15.60	±3.63			
Flexão de antebraço (pré) (rep)	18.30	±4.69	1.007	0.386	0.319
Flexão de antebraço (pós) (rep)	17.90	±4.11			
Sentado e alcançar (pré) (rep)	-0.61	±9.97	1.446	1.204	0.155
Sentado e alcançar (pós) (rep)	-1.82	±9.37			
Alcançar atrás das costas (direito) (pré) (m)	-9.32	±12.50	1.100	2.636	0.277
Alcançar atrás das costas (direito) (pós) (m)	-12.00	±20.40			
Alcançar atrás das costas (esquerdo) (pré) (m)	-15.80	±12.90	-1.310	-1.056	0.197
Alcançar atrás das costas (esquerdo) (pós) (m)	-14.80	±11.90			

s: segundos; rep: repetições; m: metros; DP: desvio padrão; Df: graus de liberdade; $p < 0.005$.



De acordo com a análise estatística comparando os grupos GE e GC, não foram observadas diferenças significativas ao comparar as médias dos grupos. O tamanho de efeito (ES) das diferenças, juntamente com os seus intervalos de confiança correspondentes, é apresentado na Tabela 20. Ao analisar o ES, podemos avaliar a relevância prática do impacto da intervenção nas diversas capacidades físicas, para além da mera significância estatística.

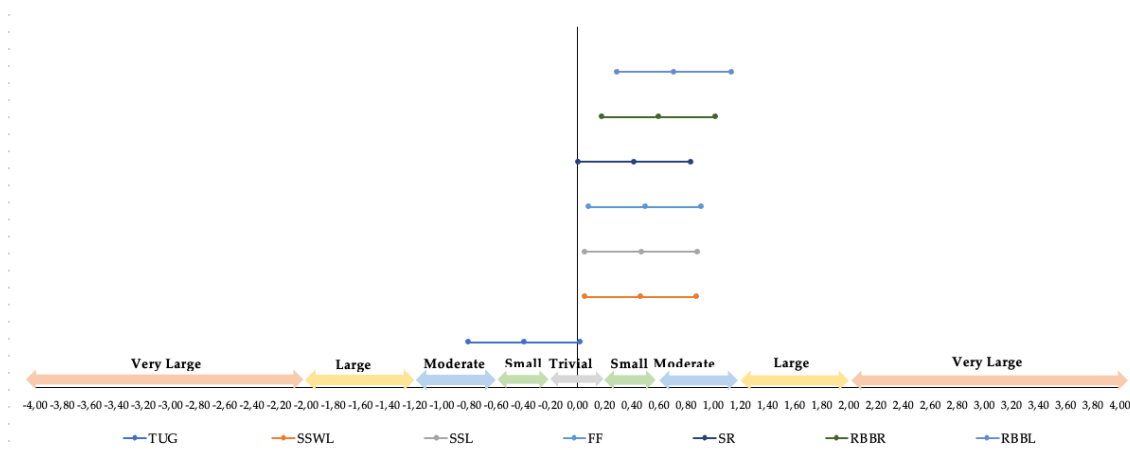
Tabela 20- Análise do tamanho de efeito considerando os valores pré- e pós-intervenção.

Variáveis	Pré- intervenção	Pós- intervenção	ES	σ	IC 95%
	M	DP	n	M	DP
Levantar, caminhar e voltar a sentar	7.26	1.23	46	6.85	0.81
Levantar e sentar com inclinação	13.00	2.30	46	14.00	1.97
Levantar e sentar sem inclinação	15.30	2.95	46	16.60	2.57
Flexão de antebraço	17.30	5.83	46	19.80	4.04
Sentado e alcançar	-2.54	8.70	46	1.02	8.24
Alcançar atrás das costas (direito)	-13.80	11.70	46	-7.50	9.12
Alcançar atrás das costas (esquerdo)	-18.50	11.00	46	-11.20	9.43

M: média; DP: desvio padrão; ES: tamanho de efeito; IC: intervalo de confiança; LL: limite inferior; UL: limite superior; $p < 0.005$

A Figura 25 amplia a interpretação abrangente dos dados da Tabela 20, considerando a proposta de interpretação dos valores de ES (Hopkins et al., 2009). Esta figura evidencia que o teste TUG apresentou um ES negativo e moderado. Por outro lado, as variáveis “Alcançar atrás das costas (direito)” e “Alcançar atrás das costas (esquerdo)” foram as que apresentaram os maiores ES positivos.





Nota. Levantar, caminhar e voltar a sentar (TUG); Levantar e sentar com inclinação (SSWL); Levantar e sentar sem inclinação (SSL); Flexão de antebraço (FF); Sentado e alcançar (SR); Alcançar atrás das costas (direito) (RBBR); Alcançar atrás das costas (esquerdo) (RBBL). O ES é considerado trivial (0–0.2), pequeno (0.2–0.6), médio (0.6–1.2), grande (1.2–2), muito grande (2–4) e extremamente grande (>4) (Cohen's d).

Figura 25- Interpretação do tamanho de efeito considerando as variáveis analisadas.

Os resultados revelaram melhorias significativas em todas as variáveis no GE ($p < 0.005$), contrastando com o GC, que não apresentou alterações relevantes, nomeadamente no teste de “sentar e alcançar”. A análise do ES evidenciou ganhos expressivos nos parâmetros de flexibilidade dos ombros (“esticar as mãos atrás das costas”), com valores de ES = 0.60 (direita) e 0.71 (esquerda). Estes resultados reforçam a eficácia do treino sensório motor no desenvolvimento das capacidades físicas essenciais ao envelhecimento saudável. A publicação encontra-se disponível no Apêndice 8 (DOI: 10.3390/ejihpe15040050).

5.5.2. Effectiveness of different physical activity programs in improving older adults' physical capacities: a randomized controlled trial

Este estudo comparou a eficácia de diferentes modalidades de exercício físico — pilates, hidroginástica e treino sensório motor — na melhoria das capacidades físicas dos adultos mais velhos, de modo a identificar a intervenção mais adequada para promover a autonomia funcional e reduzir o risco de quedas.

A Tabela 21 mostra as diferenças entre os valores pré- e pós-intervenção de acordo com os programas desenvolvidos. Estes resultados indicam que os utilizadores incluídos nos programas de intervenção apresentaram diferenças significativas nas variáveis analisadas. Nesse sentido, os participantes do Grupo de aqua aeróbica apresentaram diferenças entre os valores pré- e pós-intervenção em determinadas variáveis (levantar e sentar com inclinação, levantar e sentar sem inclinação, flexão de antebraço e alcançar



atrás das costas (esquerdo)). Nesta população, o tamanho de efeito (ES) foi negativo, pequeno e moderado.

Tabela 21- *Análise inferencial dos valores pré- e pós-intervenção de acordo com os diferentes programas de intervenção.*

Variáveis (valores pré e pós)	Grupo de controlo p value	Grupo sensório motor ES	Grupo aqua aeróbica p value	Grupo pilates ES	Efeito da intervenção momento*grupo p value
Levantar, caminhar e voltar a sentar (TUG) (s)	0.450	0.115	<0.001	0.575	0.085
Levantar e sentar com inclinação (rep)	0.349	-0.142	<0.001	-0.537	<0.001
Levantar e sentar sem inclinação (rep)	0.905	-0.018	<0.001	-0.743	<0.001
Flexão do antebraço (rep)	0.319	0.151	0.002	-0.490	0.005
Sentar e alcançar (rep)	0.155	0.218	<0.001	-0.653	0.203
Alcançar atrás das costas (direito) (m)	0.277	0.165	<0.001	-1.074	0.126
Alcançar atrás das costas (esquerdo) (m)	0.197	-0.197	<0.001	-1.323	0.002

Nota. s: segundos; rep: repetições; m: metros; ES: tamanho de efeito; $p < 0.05$. Cohen's d para ES: trivial (0-0.2), pequeno (0.2-0.6), moderado (0.6-1.2), grande (1.2-2), muito grande (2-4) e extremamente grande (>4). Partial Eta Squared para ES (η^2): Pequeno (0.01-0.06); Médio (0.06-0.14); Grande (>0.14).

A análise do efeito de interação momento*grupo revelou diferenças significativas entre os grupos, exceto no teste TUG, onde não se encontraram diferenças significativas. Relativamente ao ES, o teste Alcançar atrás das costas apresentou os valores mais elevados, com ES moderado no lado direito e ES grande no lado esquerdo. Estes resultados evidenciam o impacto substancial da intervenção na flexibilidade da parte superior do corpo, particularmente na mobilidade dos ombros.

A Figura 26 apresenta os resultados relacionados com o ES da análise (Hopkins et al., 2009), facilitando a compreensão dos resultados obtidos. A análise do ES revelou



diferenças notáveis entre os grupos em vários testes de função física. O grupo de treino sensorimotor apresentou os efeitos positivos mais expressivos, especialmente nas medidas de flexibilidade e controlo postural. Isto foi particularmente evidente no teste Alcançar atrás das costas (direito: ES = -1.074; esquerdo: ES = -1.323) e no teste sentar e alcançar (ES = -0.653), indicando melhorias significativas na mobilidade e flexibilidade do tronco.

O grupo de aqua aeróbica também apresentou efeitos moderados a fortes, embora geralmente inferiores aos do grupo sensório motor, especialmente nas tarefas de alcance e flexibilidade dos membros superiores. O grupo de pilates exibiu apenas efeitos ligeiros e localizados, com pequenas melhorias na força da parte superior do corpo (ex.: “Flexão de Antebraço,” ES = 0.207). Como esperado, o GC apresentou tamanhos de efeito mínimos ou inconsistentes, sem melhorias significativas. Estes resultados destacam a eficácia do treino sensório motor na melhoria da mobilidade funcional e estabilidade postural em adultos mais velhos.

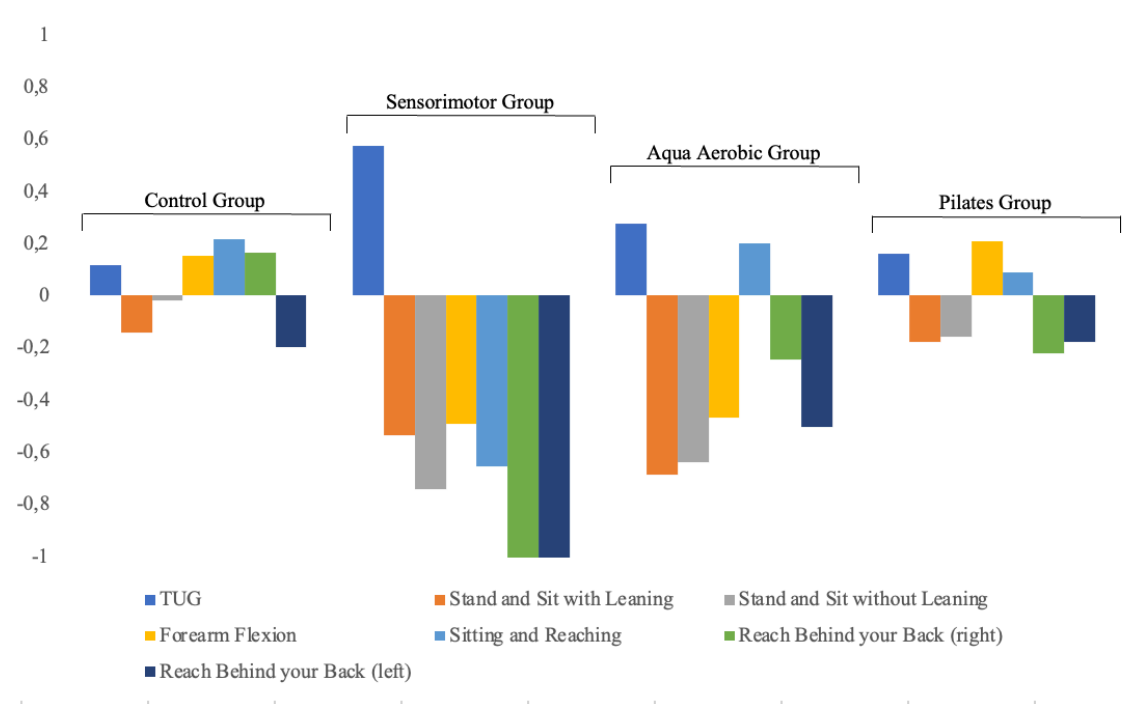


Figura 26- ES das variáveis analisadas de acordo com os diferentes programas de atividade física.

Nota. Levantar, caminhar e voltar a sentar (TUG); Levantar e sentar com inclinação (SSWL); Levantar e sentar sem inclinação (SSL); Flexão do antebraço (FF); Sentado e alcançar (SR); Alcançar atrás das costas (direito) (RBBR); Alcançar atrás das costas (esquerdo) (RBBL). O ES é considerado trivial (0-0.2), pequeno (0.2-0.6), médio (0.6-1.2), grande (1.2-2), muito grande (2-4) e extremamente grande (>4) (Cohen's d).



Foram observadas melhorias significativas em todas as variáveis entre as avaliações pré e pós-intervenção. O grupo de treino sensório motor apresentou resultados positivos em todos os testes ($p < 0.05$), enquanto o grupo de hidroginástica destacou-se em variáveis específicas, incluindo o teste de sentar e levantar com e sem inclinação ($p < 0.001$), a flexão do antebraço ($p = 0.005$) e o alcançar atrás das costas – lado esquerdo ($p = 0.002$). Estes resultados sugerem que diferentes modalidades de exercício podem ser eficazes, embora o treino sensório motor demonstre impacto mais consistente e global na aptidão física dos adultos mais velhos. A publicação encontra-se disponível no Apêndice 9 (DOI: 10.3389/fphys.2025.1540776).

5.5.3. The role of physical exercise in enhancing health, quality of life and joy among older adults

Este RCT teve como objetivo examinar o papel do exercício físico na promoção da saúde, da qualidade de vida e do bem-estar em adultos mais velhos, integrando dimensões físicas e psicológicas como fatores de adesão. A intervenção consistiu num programa estruturado de treino sensório motor com duração de 24 semanas, realizado em duas sessões semanais.

Relativamente à composição corporal, os resultados do IMC de ambos os grupos diminuíram desde a linha de base até às 24 semanas seguintes, sendo que o GE apresentou uma redução maior (Tabela 22). Não se verificaram diferenças significativas nesta variável ($p = 0.141$). O tamanho de efeito (ES) também foi pequeno ($P\eta^2 = 0.018$).

O questionário PACES revelou pequenas diferenças entre a avaliação inicial e a realizada após 24 semanas em ambos os grupos. Não se observaram diferenças significativas nesta variável. Além disso, apenas a variável “Não revigorante / Muito revigorante (1-7)” apresentou um ES moderado ($P\eta^2 = 0.007$), enquanto as restantes apresentaram ES pequeno.

O IPAQ mostrou diferenças entre o pré- e o pós-teste em ambos os grupos. No entanto, apenas a variável “Atividade de caminhada (minutos/semana)” apresentou resultados significativos ($p = 0.022$). Além disso, as variáveis “Atividade moderada (minutos/semana)” e “Atividade física total (minutos/semana)” apresentaram ES moderado ($P\eta^2 = 0.065$; $P\eta^2 = 0.076$, respetivamente), enquanto a variável “Atividade de caminhada (minutos/semana)” apresentou ES grande ($P\eta^2 = 0.148$).

Embora se tenha observado significância estatística no domínio da Atividade de caminhada, é importante destacar a relevância clínica potencial desta descoberta. Um aumento do tempo de caminhada por semana entre adultos mais velhos está fortemente



associado a melhorias na mobilidade funcional e à redução do risco de quedas, especialmente quando a caminhada excede 150 minutos por semana. Este limiar é frequentemente referenciado nas diretrizes de AF para populações idosas e tem sido associado a melhor equilíbrio, aptidão cardiorrespiratória e resistência muscular. Assim, o aumento observado nos minutos de caminhada não é apenas estatisticamente relevante, mas poderá também traduzir-se em melhorias significativas na independência e segurança nas atividades diárias.

O questionário SF-36 (dimensões, escala 0-100) revelou pequenas diferenças entre os dois momentos de avaliação em ambos os grupos. Não se verificaram diferenças significativas nesta variável. Além disso, todas as variáveis apresentaram ES pequeno ($P\eta^2 < 0.06$).

Tabela 22- Composição corporal, atividade física e qualidade de vida relacionada com a saúde, medidas na linha de base e alterações após 24 semanas de treino físico (GE n = 46; GC n = 78).

	Linha de base		12 semanas		Tratamento (%)	Tamanho do efeito	<i>p</i>
	Grupo de exercício	Grupo de controlo	Grupo de exercício	Grupo de controlo	Média (95%CI)	η^2	
Média ± DP	Média ± DP	Média ± DP	Média ± DP	Média (95%CI)	η^2		
Composição corporal							
Índice de massa corporal (kg/m²)	27.4 ± 5.0	28.3 ± 4.6	26.8 ± 5.1	28.0 ± 4.5	-1.1 (-2.6 to 0.4)	0.018	0.141
Escala de prazer com atividade física (PACES)							
Nada prazeroso / Muito prazeroso (1–7)	6.74 ± 0.57	6.82 ± 0.52	6.83 ± 0.48	6.66 ± 0.86	3.4 (-2.0 to 8.9)	0.013	0.217
Sem diversão / Muito divertido (1-7)	6.78 ± 0.46	6.74 ± 0.59	6.83 ± 0.43	6.66 ± 0.71	1.3 (-3.6 to 6.2)	0.002	0.605
Muito desagradável / Muito agradável (1-7)	6.80 ± 0.45	6.83 ± 0.54	6.76 ± 0.56	6.82 ± 0.45	-0.8 (-5.2 to 3.5)	0.001	0.707
Não revigorante / Muito revigorante (1-7)	6.76 ± 0.52	6.88 ± 0.45	6.72 ± 0.65	6.68 ± 0.65	2.4 (-2.6 to 7.3)	0.007	0.350
Não gratificante / Muito gratificante (1-7)	6.78 ± 0.46	6.85 ± 0.48	6.78 ± 0.47	6.78 ± 0.52	0.7 (-3.6 to 5.0)	0.001	0.749
Nada emocionante / Muito emocionante (1-7)	6.78 ± 0.47	6.77 ± 0.64	6.85 ± 0.42	6.74 ± 0.57	0.3 (-5.5 to 6.1)	0.000	0.915
Não estimulante / Muito estimulante (1-7)	6.76 ± 0.52	6.87 ± 0.46	6.76 ± 0.56	6.77 ± 0.56	1.5 (-2.9 to 6.0)	0.004	0.496
Nada refrescante / Muito refrescante (1-7)	6.78 ± 0.46	6.68 ± 0.90	6.63 ± 0.90	6.52 ± 0.98	-2.6 (-11.3 to 6.1)	0.003	0.555
International Physical Activity Questionnaire (IPAQ)							
Atividade vigorosa (minutos/semana)	160.0 ± 195.7	180.4 ± 163.6	155.3 ± 101.6	174.7 ± 144.9	0.2 (-29.7 to 27.7)	0.001	0.924
Atividade moderada (minutos/semana)	259.2 ± 177.4	233.7 ± 192.9	343.8 ± 263.6	255.1 ± 198.8	23.5 (-75.3 to 82.8)	0.065	0.103
Atividade de caminhada (minutos/semana)	145.1 ± 166.9	209.1 ± 184.0	248.8 ± 305.6	216.1 ± 238.9	68.1 (-26.7 to 109.7)	0.148	0.022
Atividade física total (minutos/semana)	564.3 ± 299.5	623.2 ± 369.8	747.9 ± 403.2	645.9 ± 396.1	28.9 (-80.9 to 89.4)	0.076	0.078
Sedentarismo total (minutos/semana)	680.9 ± 507.4	879.6 ± 369.7	692.6 ± 503.6	760.3 ± 461.5	15.3 (-23.7 to 60.4)	0.010	0.388
SF-36 (escala 0-100)							
Função física	77.1 ± 22.4	76.9 ± 21.7	79.8 ± 21.1	78.2 ± 20.9	1.8 (-7.8 to 16.9)	0.010	0.279
Problemas físicos (papel)	93.9 ± 16.5	88.5 ± 18.5	87.5 ± 21.9	85.7 ± 19.2	-3.6 (-17.9 to 12.2)	0.001	0.710
Dor corporal	68.9 ± 22.2	65.0 ± 24.8	67.8 ± 25.2	67.8 ± 25.2	-5.9 (-20.9 to 14.6)	0.001	0.725
Saúde geral	59.7 ± 17.7	65.7 ± 17.0	62.2 ± 17.9	67.3 ± 17.0	1.8 (-6.2 to 18.5)	0.008	0.327
Vitalidade	72.9 ± 12.4	68.7 ± 15.8	66.1 ± 16.0	64.9 ± 13.9	-3.8 (-14.4 to 3.4)	0.012	0.223
Função social	94.8 ± 14.6	90.5 ± 17.2	93.2 ± 14.1	91.9 ± 16.2	-3.2 (-19.6 to 8.7)	0.005	0.453
Problemas emocionais (papel)	97.8 ± 10.3	89.9 ± 18.5	91.8 ± 15.6	84.2 ± 20.1	12.5 (-17.5 to 27.5)	0.005	0.436
Saúde mental	66.1 ± 12.8	69.8 ± 15.7	67.8 ± 14.5	69.3 ± 13.8	3.3 (-8.3 to 11.6)	0.001	0.751

Valores de P da análise de variância para comparar diferenças entre grupos às 24 semanas. SF-36 = Questionário de Saúde SF-36. Partial Eta Squared ($P\eta^2$): $\eta^2 = 0,01$ indica efeito pequeno; $\eta^2 = 0,06$ indica efeito médio; $\eta^2 = 0,14$ indica efeito grande.



Ambos os grupos apresentaram pequenas reduções nos valores de composição corporal, não sendo estas diferenças estatisticamente relevantes. O único resultado significativo foi observado na variável relacionada com a atividade de marcha (minutos por semana), que favoreceu o GE ($p = 0.022$; $P\eta^2 = 0.148$). Não foram encontradas diferenças significativas nos níveis globais de AF, nas pontuações de satisfação (PACES) ou nas dimensões do questionário SF-36. Os tamanhos de efeito variaram entre $P\eta^2 = 0.001$ e 0.148 , com valores de p entre 0.022 e 0.78 . Apesar da ausência de diferenças robustas em algumas variáveis, o estudo reforça a relevância da AF como promotora de prazer, bem-estar e qualidade de vida, mesmo quando os efeitos fisiológicos imediatos são limitados. A publicação encontra-se disponível no Apêndice 10 (DOI: 10.1038/s41598-025-26683-w).

5.5.4. Effects of sensorimotor training on postural sway during quiet standing in healthy older adults: a randomized controlled trial

Este ensaio clínico analisou o impacto do treino sensório motor no controlo postural de adultos mais velhos saudáveis. Participaram 86 indivíduos, divididos aleatoriamente em GC ($n=43$; idade média: 73.50 ± 6.08) e GE ($n=43$; idade média: 72.40 ± 7.03). A intervenção consistiu em 24 semanas de treino, com sessões de 45 minutos, duas vezes por semana, em formato de circuito progressivo.

Primeiro, realizámos uma análise geral dos valores pré e pós-teste para identificar alterações globais em cada grupo e determinar se ocorreram melhorias significativas. No GC, observaram-se diferenças significativas (indicadas por *) nas seguintes variáveis: mdMLA_OA, mavR_OA, rmsRatio_OA, swayArea_OA, meanVx_OA, swayLenML_OA, swayLenTotal_OA, meanSwayML_OA, meanSwayTotal_OA, mdMLA_OF, rmsML_OF, rmsStab_OF, rmsRA_OF, rmsRatio_OF, swayArea_OF, meanVx_OF, swayLenML_OF, swayLenAP_OF, swayLenTotal_OF, meanSwayML_OF, meanSwayRA_OF e meanSwayTotal_OF.

No GE, encontraram-se alterações significativas pré-pós-teste para mdMLA_OA, mavR_OA, rmsAP_OA, rmsRatio_OA, swayArea_OA, meanVx_OA, swayLenML_OA, swayLenTotal_OA, meanSwayML_OA, meanSwayTotal_OA, mdMLA_OF, rmsML_OF, rmsRA_OF, rmsML_OF, meanVx_OF, swayLenML_OF, swayLenAP_OF, swayLenTotal_OF, meanSwayML_OF, meanSwayRA_OF e meanSwayTotal_OF.

Estes resultados indicam que ambos os grupos demonstraram alterações significativas em diversos parâmetros de controlo postural.



De seguida, realizámos uma ANCOVA para comparar os resultados pós-intervenção entre os GE e GC, controlando estatisticamente os valores iniciais (pré-teste). Este procedimento permitiu testar a hipótese nula e determinar se a intervenção produziu efeitos além daqueles explicados pelas diferenças iniciais entre os grupos.

A Tabela 23 apresenta os resultados destes modelos de ANCOVA, comparando as médias pós-teste ajustadas (com intervalos de confiança de 95%) para todas as variáveis de controlo postural nas condições OA e OF. A tabela fornece ainda os valores de F , p e os tamanhos de efeito parcial eta-quadrado (η^2) correspondentes a cada parâmetro. Os efeitos significativos entre grupos são identificados por $p < 0.05$.

Tabela 23- Resultados da ANCOVA comparando parâmetros de controlo postural entre grupos (médias pós-teste ajustadas com IC 95%), suportados pelos resultados da ANCOVA (valores de p , F e η^2 parcial para cada variável).

Variáveis	Grupo de controlo	Grupo experimental	ANCOVA
	Pré-teste	Pós-teste	Diferença média [IC 95%]
mdML_OA	0.45±0.13	0.50±0.17	0.05 [0.09; 0]*
mdAP_OA	0.36±0.13	0.36±0.15	0 [0.04; -0.05]
maxR_OA	2.93±1.77	2.49±0.93	-0.44 [0.11; -0.99]
rangeAP_OA	3.75±2.36	3.02±1.36	-0.73 [0.03; -1.5]
rangeRatio_OA	1.23±0.42	1.5±0.53	0.26 [0.46; 0.07]*
sway_deg_OA	61.38±24.7	70.98±21.05	9.59 [19.72; -0.53]
mean_V_OA	7.01±2.41	8.63±3.15	1.62 [2.3; 0.95]*
swayLenML_OA	126.01±45.76	168.81±70.48	42.8 [56.89; 28.71]*
swayLen-Total_OA	172.47±59.17	213.23±77.83	40.76 [57.64; 23.88]*
meanSpdML_OA	5.25±1.91	7.03±2.93	1.78 [2.37; 1.2]*
meanSpdTotal_OA	7.18±2.46	8.88±3.24	1.7 [2.4; 0.99]*
mdML_OF	0.42±0.16	0.48±0.13	0.05 [0.1; 0.01]*
maxML_OF	1.89±0.84	2.27±0.88	0.37 [0.66; 0.08]*
rmsML_OF	0.54±0.21	0.6±0.18	0.06 [0.11; 0.01]*
rangeML_OF	3.45±1.49	3.97±1.33	0.52 [0.94; 0.11]*
rangeRatio_OF	1.15±0.41	1.52±0.6	0.36 [0.56; 0.17]*
sway_deg_OF	55.61±27.22	68.36±20.92	12.75 [21; 4.5]*
mean_V_OF	6.45±2.15	8.67±3.24	2.21 [2.99; 1.44]*
swayLenML_OF	113.35±38.8	168.82±75.29	55.48 [72.59; 38.36]*
swayLenAP_OF	87.52±35.68	97.76±39.58	10.24 [19.52; 0.95]*
swayLen-Total_OF	159.16±51.69	214.34±78.99	55.18 [74.25; 36.1]*
meanSpdML_OF	4.72±1.62	7.03±3.14	2.31 [3.02; 1.6]*



Variáveis	Grupo de controle	Grupo experimental	ANCOVA
meanSpdAP_OF	3.64±1.49	4.07±1.65	0.43 [0.81; 0.04]*
meanSpdTotal_OF	6.63±2.15	8.92±3.29	2.3 [3.09; 1.5]*

Quando examinamos os resultados da ANCOVA, observámos que não surgiram diferenças significativas entre os grupos após o controlo dos valores pré-teste. Isto sugere que os valores iniciais influenciaram substancialmente os resultados pós-teste e que os efeitos da intervenção não foram suficientemente fortes para produzir diferenças estatisticamente detetáveis entre o GE e o GC.

Consequentemente, procedemos à exploração de tendências potenciais utilizando a visualização apresentada na Figura 27.

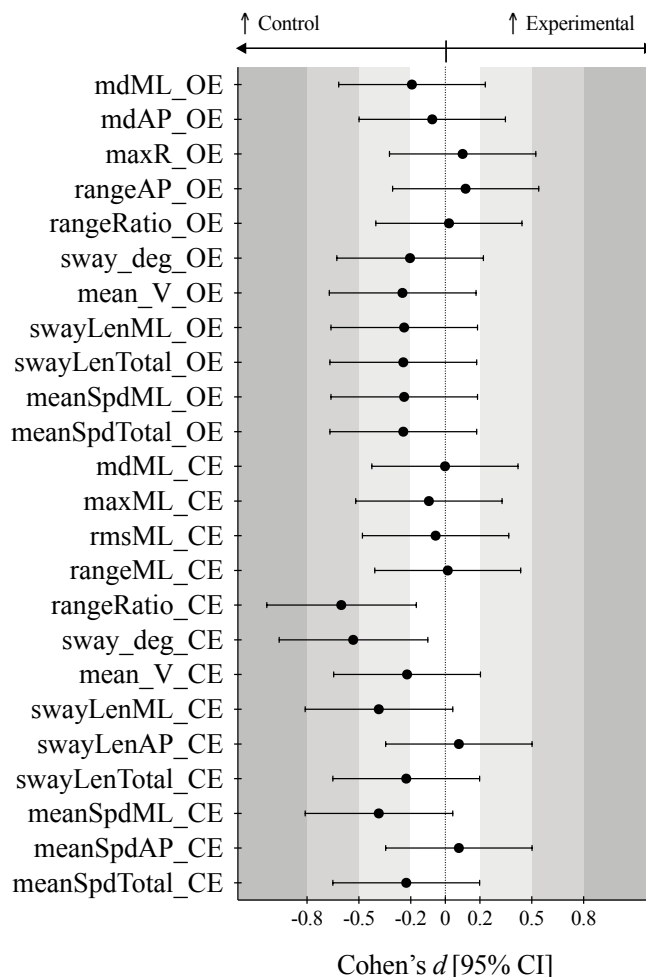


Figura 27- Diferenças de Cohen's *d* entre o grupo de controlo e o grupo experimental para as variáveis consideradas. As barras de erro indicam a incerteza nas alterações médias reais com intervalos de confiança de 95%.



De acordo com a Figura 27, as variáveis `rangeRatio_OF` e `sway_deg_OF` apresentam diferenças significativas, enquanto `mean_V_OA`, `swayLenML_OA`, `swayLenTotal_OA`, `meanSpdML_OA`, `meanSpdTotal_OA`, `swayLenML_OF` e `meanSpdML_OF` demonstram efeitos a nível de tendência. As restantes variáveis não apresentam tendências claras em nenhuma direção.

As diferenças significativas observadas na Figura 3 surgem principalmente no GC, que apresenta uma variação notavelmente maior nestes parâmetros. Especificamente, o GC demonstra aumentos substanciais em `rangeRatio_OF` (0.58 [0.90; 0.25]) e `sway_deg_OF` (0.48 [0.79; 0.16]), enquanto o GE não apresenta alterações comparáveis (`rangeRatio_OF` = -0.03 [-0.27; -0.33]; `sway_deg_OF` = -0.01 [0.29; -0.31]). Embora o GE apresente reduções em vez de aumentos, a ausência de grandes alterações não implica falta de efeitos da intervenção; antes, sugere que a intervenção poderá ter contribuído para estabilizar ou prevenir a deterioração observada no GC. A publicação encontra-se disponível no Apêndice 11 (DOI: 10.1007/s11332-026-01686-w).

5.5.5. Analysis of postural control through non-linear methods in older adults: a randomized controlled trial

O objetivo deste estudo foi explorar de que forma o envelhecimento afeta o controlo postural, utilizando métodos não-lineares para analisar alterações após um programa de treino sensorio motor. A amostra incluiu 86 indivíduos entre os 55 e os 80 anos, distribuídos em GC (n=43) e GE (n=43). O programa teve a duração de seis meses, com duas sessões semanais de circuitos progressivos de exercícios, ajustados às capacidades individuais.

Os resultados do controlo postural do GE e do GC foram analisados através da comparação das medições pré- e pós-intervenção. As diferenças intra-grupo foram calculadas comparando os resultados pré- e pós-intervenção, enquanto as comparações inter-grupos foram efetuadas utilizando os *scores* de variação (valores pós menos pré), analisados através de uma folha de cálculo personalizada.

Os dados são apresentados como média $\pm$ desvio padrão (DP). Vinte e dois participantes foram excluídos com base em critérios de elegibilidade predefinidos, incluindo idade, cirurgias recentes, utilização de dispositivos protésicos, condições musculoesqueléticas, neurológicas ou psiquiátricas, mobilidade reduzida ou doença cardiovascular diagnosticada clinicamente. Não ocorreram problemas técnicos nem perda de dados durante a recolha de dados; quaisquer dados dos indivíduos excluídos foram removidos antes da análise.



Esta secção apresenta uma análise das variáveis lineares de controlo postural que demonstraram diferenças estatisticamente significativas entre as avaliações pré- e pós-intervenção. Comparações post-hoc pareadas foram realizadas com correção de Bonferroni quando aplicável. A significância foi determinada através de testes t de Student pareados (Tabela 24), com os valores de p indicados por asteriscos (* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$).

Tabela 24- *Teste T de Amostras Pareadas.*

Variáveis pré	Variáveis pós	t	p	Significância
EnAp_AP_OA_pre	EnAp_AP_OA_post	-2.649	0.01	*
LyE_AP_OA_pre	LyE_AP_OA_post	-6.369	< 0.001	***
LyE_ML_OA_pre	LyE_ML_OA_post	-3.578	< 0.001	***
aAP_OA_pre	aAP_OA_post	4.483	< 0.001	***
LyE_AP_OF_pre	LyE_AP_OF_post	-5.067	< 0.001	***
LyE_ML_OF_pre	LyE_ML_OF_post	-2.391	0.019	*
aAP_OF_pre	aAP_OF_post	4.556	< 0.001	***
aML_OF_pre	aML_OF_post	3.845	< 0.001	***

Nota: $H_a \mu$ Medida 1 – Medida 2 $\neq 0$

Os resultados do teste t de amostras pareadas revelaram melhorias significativas no controlo postural após a intervenção, tanto em condições de OA como de OF. Especificamente, a variável EnAp apresentou alterações significativas em ambas as condições visuais. Para a condição de OA, EnAp_OA mostrou uma diminuição significativa ($p = 0.01$), enquanto EnAp_OF demonstrou um efeito ainda mais forte ($p = 0.005$). Estes resultados sugerem que a intervenção melhorou efetivamente a estrutura temporal e a organização do balanço postural na direção ântero-posterior em ambos os contextos sensoriais.

Foram também observadas melhorias significativas no expoente de lyapunov (LyE) em todas as condições e direções, indicando uma maior estabilidade dinâmica local após a intervenção. Especificamente, os valores de LyE diminuíram significativamente na direção ântero-posterior com OA (LyE_AP_OA: $p < 0.001$) e OF (LyE_AP_OF: $p < 0.001$), assim como na direção mediolateral (ML) em ambas as condições visuais (LyE_ML_OA: $p < 0.001$; LyE_ML_OF: $p = 0.019$).

Além disso, a análise dos parâmetros DFA revelou reduções significativas no DFA ântero-posterior em ambas as condições visuais (aAP_OA: $p < 0.001$; aAP_OF: p



< 0.001), assim como no DFA ML com OF (aML_OF: $p < 0.001$), reforçando a eficácia da intervenção na redução da instabilidade e do balanço excessivo.

Tabela 25- Resultados da ANCOVA comparando parâmetros de controlo postural entre grupos (médias ajustadas pós-teste com IC de 95%), suportados pelos outputs da ANCOVA (valores de p , F e η^2 parcial para cada variável).

Variáveis	Grupo de controlo Grupo experimental		ANCOVA
	Pré-teste	Pós-teste	Diferenças médias [IC 95%]
EnAp_AP_OA	0.68±0.06	0.70±0.06	0.02 [0.04; 0]
EnAp_ML_OA	0.69±0.09	0.67±0.07	-0.03 [3.24; -0.05]
LyE_AP_OA	14.82±3.75	17.69±3.45	2.87 [4.12; 1.62]*
LyE_ML_OA	13.32±4.14	15.47±4.24	2.15 [3.69; 0.61]*
aAP_OA	1.05±0.17	0.97±0.16	-0.09 [-0.03; -0.14]*
aML_OA	0.96±0.16	0.93±0.16	-0.04 [0.01; -0.09]
EnAp_AP_OF	0.67±0.05	0.69±0.05	0.02 [0.05; 0]*
EnAp_ML_OF	0.69±0.09	0.69±0.09	0 [0.03; -0.03]
LyE_AP_OF	15.12±4.27	18.01±3.48	2.89 [4.14; 1.63]*
LyE_ML_OF	13.07±4.41	15.89±3.59	2.82 [4.2; 1.44]*
aAP_OF	1.05±0.17	0.94±0.16	-0.11 [-0.05; -0.17]*
aML_OF	1.02±0.14	0.94±0.16	-0.07 [-0.02; -0.13]*

* $p < 0.05$

A ANCOVA (Tabela 25), realizada com os valores basais como covariáveis, indicou que a maioria dos resultados ajustados pós-teste não diferiu significativamente entre os grupos experimental e de controlo. EnAp apresentou uma diferença significativa apenas na direção ML com OA (EnAp_ML_OA: $F = 8.7$, $p = 0.004$, η^2 parcial = 0.10), indicando uma melhoria seletiva na organização temporal do balanço ML associada à intervenção. Todas as outras comparações de EnAp não foram significativas (todos $p > 0.72$).

Para o LyE, duas variáveis mostraram diferenças significativas entre grupos na condição de OF: LyE_AP_OF ($F = 4.0$, $p = 0.049$, η^2 parcial = 0.05) e LyE_ML_OF ($F = 13.6$, $p = 0.001$, η^2 parcial = 0.14). Estes resultados indicam melhorias na estabilidade dinâmica local para o GE com input visual reduzido, particularmente na direção ML. Nenhum efeito significativo foi observado nas condições de OA (todos $p > 0.49$).

O DFA (aAP e aML) não mostrou diferenças significativas entre grupos (todos $p > 0.17$), sugerindo que as reduções observadas nas comparações pareadas não foram específicas da intervenção.



No geral, os resultados da ANCOVA demonstram que a intervenção produziu melhorias seletivas, em vez de generalizadas, nos parâmetros não lineares de controle postural. Os efeitos significativos restringiram-se à entropia ML com OA e à estabilidade baseada no Lyapunov com OF. A ausência de diferenças generalizadas entre grupos sublinha a importância das análises ajustadas na interpretação dos efeitos da intervenção (Figura 3).

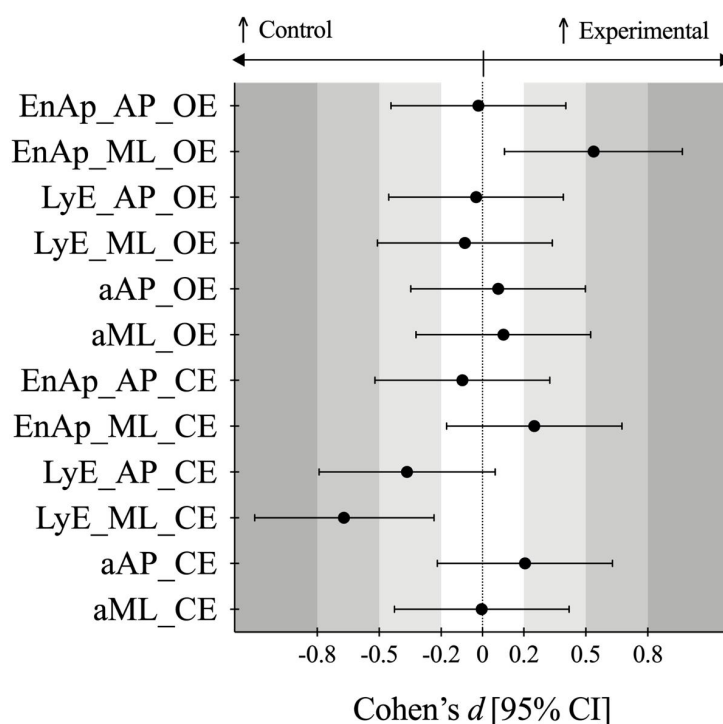


Figura 28- Diferenças de Cohen's *d* entre os grupos de controlo e experimental para as variáveis consideradas. As barras de erro indicam a incerteza na variação da média verdadeira com intervalos de confiança de 95%.

Segundo a Figura 28, as variáveis LyE_ML_OF e EnAp_ML_OA mostram diferenças significativas, enquanto LyE_AP_OF demonstra efeitos a nível de tendência. As restantes variáveis não apresentam tendências claras em nenhuma direção.

As diferenças significativas observadas na Figura 3 ocorrem principalmente no GE (EnAp_ML_OA), que mostra uma variação notavelmente maior nestes parâmetros. No entanto, existe também uma variável no GC (LyE_ML_OF) que apresenta diferenças significativas. Especificamente, o GE apresenta diminuições substanciais em EnAp_ML_OA (-0.03 [3.24; -0.05]), enquanto o GC não apresenta alterações comparáveis (EnAp_ML_OA = 0.02 [0.04; -0.01]).

Embora o GE apresente reduções em vez de aumentos, isso pode sugerir que a intervenção contribuiu para modular ou melhorar os mecanismos de controlo postural. A



diminuição destes parâmetros poderá refletir um efeito de estabilização, em que a intervenção preveniu a variabilidade excessiva ou flutuações descontroladas nos participantes experimentais, contrastando com as alterações mínimas observadas no GC. Em outras palavras, em vez de produzir apenas aumentos, a intervenção poderá ter melhorado a estabilidade e a eficiência do controlo motor, indicando um efeito positivo na manutenção ou otimização do desempenho do equilíbrio.

Síntese dos resultados

De forma global, os resultados apresentados ao longo deste capítulo demonstram de forma consistente os benefícios do TSM e de programas estruturados de exercício físico na população idosa. As revisões sistemáticas reforçaram a evidência de que o exercício promove ganhos significativos não apenas na saúde física, mas também no bem-estar psicológico e social, revelando-se essencial em contextos de vulnerabilidade, como durante a pandemia de COVID-19. As revisões bibliométricas evidenciaram uma tendência crescente e exponencial na produção científica, confirmando a relevância da temática do envelhecimento ativo e a necessidade de estratégias que combatam o sedentarismo e potenciem a capacidade funcional.

Os estudos de caso acrescentaram contributos inovadores, nomeadamente através do uso de ferramentas digitais, como a aplicação Phyphox, que permitem novas abordagens na análise da marcha e do controlo neuromuscular. Paralelamente, verificou-se que intervenções em grupos específicos, como mulheres idosas com DM2, podem ter efeitos particularmente significativos na melhoria da flexibilidade, agilidade e propriocepção, fatores fundamentais para a prevenção de quedas e para a promoção da autonomia.

Por sua vez, os RCTs apresentaram evidência robusta sobre a eficácia do TSM em variáveis centrais, como força, flexibilidade, agilidade e, sobretudo, controlo postural. Destacaram-se melhorias consistentes em parâmetros lineares e não lineares da oscilação corporal, sugerindo não apenas ganhos funcionais imediatos, mas também uma reorganização mais eficiente dos mecanismos de estabilidade. Ainda que algumas variáveis, como composição corporal ou níveis globais de AF, tenham apresentado resultados menos expressivos, foi possível constatar que a prática estruturada e regular de TSM contribui para ganhos significativos no equilíbrio, na capacidade funcional e na perceção de bem-estar.



Assim, os resultados convergem para a mesma conclusão: o treino sensório motor constitui uma intervenção eficaz e adaptável, capaz de melhorar capacidades físicas, cognitivas e psicossociais em adultos mais velhos. Estas descobertas sustentam a pertinência de integrar este tipo de programas em contextos comunitários e clínicos, oferecendo respostas concretas aos desafios do envelhecimento populacional.



Capítulo 6 | Discussão

6.1. Introdução à discussão

O presente capítulo tem como objetivo discutir os principais resultados apresentados no Capítulo 5, analisando-os à luz da literatura existente e, sobretudo, evidenciando o contributo específico deste trabalho para o avanço do conhecimento no domínio do envelhecimento ativo e do TSM. Mais do que uma síntese descritiva dos resultados, esta discussão procura interpretar os resultados, identificar convergências e divergências com estudos prévios e destacar os elementos inovadores que diferenciam esta investigação da literatura existente.

Este trabalho sugere que a prática regular de exercício físico, particularmente intervenções estruturadas que integrem força, equilíbrio e mobilidade, não só confirma benefícios amplamente descritos na literatura, como também reforça a importância de abordagens multicomponentes e adaptadas a contextos específicos, como situações de vulnerabilidade social, doenças crónicas e períodos de restrição de mobilidade, nomeadamente durante a pandemia de COVID-19. Os resultados apontam para ganhos consistentes na aptidão física, na capacidade funcional e em dimensões cognitivas, psicológicas e sociais, fundamentais para a manutenção da autonomia e da qualidade de vida da população idosa (García-Llorente et al., 2024; He et al., 2025; Liu & Latham, 2011).

Contrariamente a abordagens tradicionais que analisam o exercício físico de forma isolada, este trabalho destaca-se pela integração de diferentes desenhos metodológicos, incluindo revisões sistemáticas, revisões bibliométricas, estudos de caso e ensaios clínicos randomizados. Esta diversidade metodológica permitiu não apenas confirmar evidências existentes, mas também triangular resultados, identificar lacunas na investigação atual e propor linhas futuras de investigação mais robustas e contextualizadas.

Adicionalmente, a análise bibliométrica revelou um crescimento exponencial do interesse científico nas temáticas do sedentarismo, da AF e do envelhecimento, refletindo uma preocupação crescente da comunidade científica em responder aos desafios impostos pelo envelhecimento populacional (Cabo et al., 2024; Yang et al., 2023). Contudo, este aumento quantitativo da produção científica nem sempre se traduz em abordagens inovadoras ou integradas, reforçando a relevância do presente trabalho ao articular evidência quantitativa com aplicações práticas e clínicas.



Assim, a discussão que se segue está organizada por tópicos, acompanhando a estrutura do capítulo de resultados, com o objetivo de interpretar criticamente cada dimensão analisada, ao relacionar os resultados com a literatura existente e explorando as suas implicações clínicas, sociais e científicas.

6.2. Discussão dos resultados das revisões da literatura

6.2.1. Exercício físico, competências sensório motoras e pandemia de COVID-19

A revisão sistemática que analisou o impacto dos programas de exercício físico nas competências sensório motoras em adultos mais velhos, com enfoque particular no período da pandemia de COVID-19, apresentou contributos relevantes para a compreensão do papel do exercício em contextos de vulnerabilidade acrescida. Os resultados evidenciaram que a prática regular de exercício físico contribuiu de forma significativa para a manutenção e, em alguns casos, melhoria de múltiplas dimensões da saúde, incluindo os domínios físico, cognitivo, psicológico e social. Estes efeitos revelam-se particularmente importantes durante períodos de isolamento social e restrições impostas por medidas de confinamento, que frequentemente conduziram a uma redução acentuada da mobilidade e à deterioração da saúde mental da população idosa.

Este trabalho sugere que, durante a pandemia, o exercício físico assumiu uma função que ultrapassa o domínio estritamente fisiológico, atuando também como um elemento regulador da saúde mental e do bem-estar psicossocial. Os ganhos observados nos domínios físico, cognitivo, psicológico e social reforçam a ideia de que intervenções baseadas em exercício devem ser consideradas componentes essenciais em estratégias de resposta a crises de saúde pública que afetem desproporcionalmente a população idosa.

Os resultados são amplamente consistentes com a literatura existente, que reconhece o exercício físico como um fator protetor contra o declínio funcional e o agravamento de sintomas depressivos e ansiosos (Mura & Carta, 2013; Zhao et al., 2025). No entanto, este trabalho acrescenta uma perspetiva crítica, ao evidenciar que os benefícios do exercício não foram suficientes para contrariar o aumento da massa gorda observado durante a pandemia. Este achado sugere que intervenções exclusivamente centradas no exercício podem ser insuficientes em contextos de restrição prolongada, reforçando a necessidade de abordagens integradas que articulem exercício, nutrição e apoio psicossocial.



A diversidade de instrumentos utilizados para avaliação física, cognitiva e psicológica reflete a complexidade da análise do envelhecimento saudável. Embora esta heterogeneidade dificulte comparações diretas entre estudos, constitui também uma força, ao demonstrar que diferentes ferramentas convergem na identificação de benefícios associados à AF. Para a análise de força e equilíbrio, destacam-se: ciclo ergómetro (Balady et al., 2010), teste de 30 segundos de sentar e levantar (30s-CST) (Rikli & Jones, 1999), teste de força de preensão manual (HGS) (Benton et al., 2022) e teste de equilíbrio unipedal (*one-leg standing test*) (Michikawa et al., 2009). O ciclo ergómetro revelou benefícios cardiovasculares e metabólicos, além de melhorias na força muscular e na função cognitiva. O 30s-CST (teste 30 segundos sentar e levantar) é simples, fiável e frequentemente utilizado em contextos clínicos para avaliar a força funcional dos membros inferiores. O HGS correlaciona-se com níveis de aptidão física e mortalidade, sendo um indicador clínico robusto para a população idosa. O teste de equilíbrio unipedal permite identificar sinais de fragilidade e avaliar a eficácia de intervenções no controlo postural.

Outros instrumentos complementares incluíram técnicas de imagem para monitorização muscular, como a absorciometria por dupla energia (DXA) e a ressonância magnética, reconhecidas como padrão-ouro para a avaliação da massa muscular e da sarcopenia, e métodos de avaliação da AF, como acelerómetros, entrevistas guiadas e a escala de atividade física para idosos (PASE) (Washburn et al., 1993). O teste TUG foi utilizado para avaliação do equilíbrio dinâmico, recomendado por sociedades geriátricas internacionais e diretrizes clínicas para rastreio de risco de quedas (Podsiadlo & Richardson, 1991).

As capacidades cognitivas foram avaliadas principalmente com a MoCA (Nasreddine et al., 2005), capaz de detetar défices cognitivos ligeiros e alterações relacionadas com doenças neurodegenerativas. Foram também avaliadas dimensões sociais e psicológicas, incluindo ansiedade, depressão e stress, utilizando instrumentos como a HADS (Zigmond & Snaith, 1983), *State-Trait Anxiety Inventory* (Spielberger, 2010), a *Geriatric Depression Scale* (Yesavage et al., 1982) e a *Perceived Stress Scale* (Cohen et al., 1983). Estas avaliações confirmaram que a AF pode reduzir sintomas ansiosos e depressivos e melhorar a perceção de bem-estar social e individual.

Apesar da qualidade metodológica globalmente elevada, a predominância de estudos transversais, a limitação linguística e a variabilidade dos instrumentos utilizados constituem limitações importantes. Ainda assim, este corpo de evidência permite concluir



que o exercício físico é uma estratégia viável, eficaz e adaptável, mesmo em condições adversas, e sublinha a urgência de políticas públicas que garantam a continuidade da prática física em situações de crise.

6.2.2. O papel do controlo postural na prevenção de quedas

A segunda revisão sistemática analisada confirma de forma consistente que o controlo postural é um dos principais determinantes do risco de quedas em adultos mais velhos. Os resultados obtidos reforçam a ideia de que o equilíbrio não deve ser encarado como uma capacidade isolada, mas como o produto da interação entre força muscular, integração sensorial, controlo neuro motor e fatores cognitivos e psicológicos.

Este trabalho sugere que intervenções focadas exclusivamente na força ou na marcha podem ser insuficientes se não integrarem componentes específicas de treino do controlo postural. Contrariamente a abordagens tradicionais mais fragmentadas, os estudos analisados apontam para a eficácia de programas multicomponentes, capazes de melhorar simultaneamente equilíbrio, confiança motora e autonomia funcional.

A utilização de um elevado número de instrumentos (n=30), incluindo testes clássicos e tecnologias modernas: *Romberg Test* (Gallamini et al., 2021), TUG (Podsiadlo & Richardson, 1991), *force plates*, *Short Physical Performance Battery* (Guralnik et al., 1995), *Functional Reach Test* (Amano, 2024), *Extended Timed Get Up and Go* (ETGUG) (Giné-Garriga et al., 2010), sistemas de posturografia móvel (VertiGuard®) (Soto-Varela et al., 2021), GAIT Rite® (Sacco et al., 2023), evidencia a evolução metodológica nesta área. Contudo, esta diversidade também expõe uma lacuna relevante: a ausência de consenso sobre os instrumentos mais sensíveis e clinicamente relevantes para a avaliação do risco de quedas. Este trabalho destaca, assim, a necessidade de padronização de protocolos de avaliação, de forma a facilitar a comparação entre estudos e a transferência do conhecimento para a prática clínica.

Apesar do número relativamente reduzido de estudos incluídos, os resultados são suficientemente consistentes para sustentar que programas de treino orientados para o controlo postural reduzem a incidência de quedas, promovem a autonomia e melhoram a qualidade de vida, contribuindo simultaneamente para a redução dos custos associados a hospitalizações e cuidados prolongados.



6.3. Discussão dos resultados das revisões bibliométricas

6.3.1. Tendências científicas no estudo do sedentarismo e envelhecimento

As revisões bibliométricas permitiram contextualizar os resultados empíricos desta tese no panorama científico internacional, evidenciando um crescimento acentuado do interesse pelo sedentarismo e pelo envelhecimento ativo nas últimas décadas. Este aumento reflete não apenas uma preocupação crescente com a saúde pública, mas também o reconhecimento do sedentarismo como um fator de risco independente, com impacto direto na morbidade e mortalidade da população idosa.

No que respeita ao sedentarismo, verificou-se um crescimento acentuado do interesse científico a partir dos anos 2000, coincidente com a emergência de evidências robustas sobre os riscos da inatividade física para a saúde pública (Owen et al., 2010; Park et al., 2020). O aumento da prevalência de doenças crônicas não transmissíveis, como a DM2, as DCV e a obesidade, motivou um incremento substancial de estudos neste domínio. A análise bibliométrica demonstrou que o sedentarismo não deve ser entendido apenas como ausência de AF, mas sim como um comportamento de risco autónomo, com consequências fisiológicas e metabólicas específicas. Esta constatação reforçou o desenvolvimento de políticas públicas orientadas para a promoção da AF e para a redução do tempo sedentário, sobretudo em populações vulneráveis, como a população idosa.

Em termos de produção científica, foram identificados 1.509 autores na temática, dos quais apenas quatro apresentaram pelo menos quatro publicações cada: Amagasa, S., Fukushima, N., Inoue, S. e Kikuchi, H. Estes investigadores, pertencentes à primeira geração de estudos nesta área, registaram igualmente o maior número de citações, refletindo a relevância e a longevidade das suas contribuições. O aumento exponencial de publicações sobre sedentarismo em adultos mais velhos deve-se à crescente preocupação em elevar os NAF nesta população, com o objetivo de reduzir o declínio muscular, prevenir a sarcopenia e a osteoartrite e diminuir o risco de cancro.

Entre as categorias da Web of Science (WoS), destacam-se: “Geriatrics Gerontology” (50 documentos), “Public Environmental Occupational Health” (33 documentos) e “Sport Sciences” (31 documentos). Os periódicos mais influentes incluíram Plos One e “Medicine and Science in Sports and Exercise”, sendo este último o mais citado e com maior fator de impacto (5.4).

No plano institucional, 630 organizações contribuíram para a produção científica, com destaque para Johns Hopkins University e Universidade de Lisboa, com oito e seis documentos publicados, respetivamente. Relativamente aos países, os Estados Unidos da



América (EUA) lideram em produção (100 documentos) e citações (5.749), refletindo a relevância da problemática do sedentarismo e da obesidade naquele contexto.

A análise das palavras-chave revelou termos como “aging”, “exercise”, “physical activity” e “sedentary lifestyle” como os mais recorrentes, evidenciando a importância de uma seleção criteriosa de descritores para maximizar a visibilidade e o impacto dos estudos. Observou-se, ainda, uma mudança recente nas tendências de investigação, com a inclusão de termos como “healthy aging”, “COVID-19”, “sedentary behaviour” e “public health”, o que demonstra a crescente atenção dada à monitorização digital, às intervenções multicomponentes e às abordagens personalizadas de exercício físico.

Este trabalho destaca-se ao articular estas tendências bibliométricas com evidência aplicada, demonstrando que o aumento da produção científica nem sempre se traduz em soluções práticas eficazes. A concentração da produção em determinados países, instituições e autores sugere a existência de assimetrias no desenvolvimento do conhecimento, o que reforça a necessidade de abordagens mais diversificadas e contextualmente adaptadas.

6.3.2. Relevância da atividade física e capacidade funcional no envelhecimento

A análise bibliométrica relativa à AF e à capacidade funcional revelou uma tendência exponencial de crescimento nas publicações dos últimos 25 anos. O primeiro documento relevante foi publicado em 1994, embora a regularidade das publicações só se tenha verificado a partir de 1998. Comparando os períodos mais antigos (1997–2008) com os mais recentes (2008–2023), observou-se um aumento de 77.4% na produção científica. A categoria da WoS com maior número de documentos foi *Geriatrics Gerontology*, destacando-se o periódico *Experimental Gerontology*. O estudo mais citado (Chodzko-Zajko et al., 2009) registou 1.293 citações, confirmando a importância de publicar em revistas de elevado fator de impacto para aumentar a visibilidade e a influência científica.

No plano autoral, foram identificados 1.071 autores, embora apenas quatro autores apresentaram pelo menos quatro publicações. Entre os mais recentes, destacam-se Thomasini, R.L., Issa Kassab, G.B., Silva, T.J., Perentoni, A.N., Máximo Pereira, L.S. e Máximo Pereira, F.S., com publicações a partir de 2020. Estes autores refletem o interesse crescente na prevenção de quedas e na promoção da qualidade de vida através da prática regular de AF. A análise demonstrou ainda que o exercício físico sistemático contribui para melhorar o equilíbrio e a capacidade funcional, bem como para reduzir sintomas de



ansiedade, depressão e isolamento social, prevenindo doenças crônicas, cardiovasculares e oncológicas.

Foram identificados 40 países e 440 instituições com publicações relevantes. O Brasil destacou-se pelo maior número de documentos (57), enquanto os Estados Unidos da América (EUA) lideraram em número de citações (2.355). Entre as instituições, a Universidade federal do rio grande do sul revelou-se a mais prolífica em quantidade de publicações, enquanto a *University of Sydney* se destacou em número de citações (890). As palavras-chave mais recorrentes foram *aging*, *physical activity* e *functional capacity*, refletindo a centralidade destes conceitos na investigação sobre envelhecimento ativo e saudável.

A análise bibliométrica reforça a importância de desenvolver programas regulares de AF para a população idosa, com ênfase em exercícios aeróbicos, fortalecimento muscular, treino de marcha e atividades manuais, de forma a melhorar a função física, a autonomia e a qualidade de vida. A ausência de intervenção física potencia o sedentarismo e o declínio funcional, sublinhando a necessidade de estratégias eficazes e sustentáveis para a promoção da AF nesta população.

Entre as limitações desta análise, destacam-se a seleção restrita de documentos da base WoS, a escolha de palavras-chave, que pode introduzir enviesamentos na pesquisa, e a possível exclusão de estudos de menor impacto. Ainda assim, as revisões bibliométricas oferecem uma visão detalhada e abrangente sobre as tendências de investigação, as redes de coautoria, a evolução científica e as áreas prioritárias de intervenção, fornecendo uma base sólida para futuras investigações e para a formulação de políticas de promoção do envelhecimento ativo (Alwan et al., 2025; Wu et al., 2025).

No entanto, este trabalho vai além da quantificação da produção científica, ao evidenciar que a qualidade e a aplicabilidade das intervenções são tão importantes quanto o volume de investigação produzida. Os resultados reforçam que programas regulares de AF, particularmente aqueles que integram componentes aeróbias, de força, equilíbrio e coordenação, são fundamentais para preservar a autonomia funcional e prevenir o declínio associado ao envelhecimento.

6.4. Discussão do protocolo de estudo

6.4.1. Estrutura e relevância do protocolo

O protocolo de estudo apresentado centra-se na avaliação de um programa de TSM em adultos mais velhos portugueses e constitui uma etapa essencial para o avanço



da investigação no domínio do envelhecimento ativo. A definição explícita dos objetivos, procedimentos metodológicos e desfechos primários e secundários assegura transparência, rigor científico e replicabilidade, alinhando-se com recomendações internacionais para ensaios clínicos robustos (Lillo-Urzúa et al., 2025; Rodrigues, Matos, et al., 2024).

Um dos principais pontos fortes do protocolo reside na sua abordagem multidimensional, contemplando variáveis fundamentais para compreender o impacto do TSM, tais como a composição corporal, a aptidão física, QVRS e NAF. Esta diversidade de indicadores permite captar não apenas os efeitos fisiológicos do programa, mas também os impactos funcionais e psicossociais, alinhando-se com as orientações da OMS para o envelhecimento saudável (Leitão et al., 2022; Moradell et al., 2023)

A conceção do estudo, estruturada como ensaio clínico randomizado com grupos paralelos e avaliações pré- e pós-intervenção, é particularmente relevante, pois possibilita estabelecer relações de causalidade entre a intervenção e os resultados (Siepmann et al., 2016). Esta abordagem reforça o potencial do protocolo para gerar evidência científica de elevada qualidade e sustentar a implementação de programas de exercício físico baseados em evidência em contextos clínicos e comunitários (Handley et al., 2018).

A escolha do TSM como intervenção central é igualmente significativa, dado que integra componentes de equilíbrio, coordenação e proprioção, respondendo a necessidades críticas da população idosa, como a prevenção de quedas e a manutenção da autonomia funcional (Choudhary et al., 2025; Kasicki et al., 2025). Deste modo, o protocolo contribui para uma abordagem contemporânea da gerontologia, centrada não apenas na longevidade, mas também na funcionalidade e participação ativa dos adultos mais velhos (Gianfredi et al., 2025).

6.4.2. Aplicabilidade, limitações e perspetivas futuras

Apesar das virtudes apresentadas, o protocolo apresenta algumas limitações que merecem consideração. A generalização dos resultados poderá ser condicionada pela circunscrição da amostra à população portuguesa, cujas características socioculturais e demográficas podem diferir de outros contextos. Além disso, a adesão ao programa constitui um fator determinante, sendo recomendável a inclusão de estratégias estruturadas de motivação e acompanhamento comportamental para maximizar a eficácia da intervenção.



Embora o protocolo inclua múltiplas medidas físicas e funcionais, poderá beneficiar da integração sistemática de indicadores cognitivos e emocionais, uma vez que a evidência demonstra que o exercício físico regular promove melhorias significativas em funções executivas, memória e saúde mental (Xiong et al., 2021; Xu et al., 2023). A ausência destas variáveis pode limitar a compreensão do impacto global da intervenção na autonomia e qualidade de vida.

Em termos de aplicabilidade prática, o protocolo revela-se altamente promissor, podendo constituir uma estratégia custo-efetiva para reduzir quedas, melhorar a funcionalidade e prolongar a autonomia da população idosa. A utilização de instrumentos como a escala PACES (Teques et al., 2020), que avalia o prazer associado à prática de exercício, contribui para a monitorização da adesão ao longo das 24 semanas e para a individualização do treino.

O programa apresenta ainda elevada flexibilidade de implementação, podendo ser aplicado em contextos clínicos, comunitários e institucionais, sem necessidade de infraestruturas altamente especializadas, aumentando a sua replicabilidade. Estudos prévios com protocolos semelhantes indicam benefícios significativos em força, equilíbrio e mobilidade (Ghrouz et al., 2022; Li et al., 2025), reforçando a pertinência do presente estudo.

Entre as limitações adicionais destacam-se potenciais constrangimentos logísticos, como mobilidade reduzida dos participantes e custos de transporte, bem como eventuais requisitos sanitários associados a contextos pós-pandemia. Investigações futuras deverão incluir amostras mais amplas, diferentes faixas etárias e variáveis clínicas adicionais, como pressão arterial e perfis lipídicos, bem como avaliação médica pré-participação.

O valor acrescentado do estudo reside ainda na elaboração de um manual de intervenção e de uma biblioteca digital de exercícios de TSM, promovendo padronização, adaptação individualizada e transferência do conhecimento científico para a prática.

6.5. Discussão dos estudos de caso

Os estudos de caso apresentados oferecem contributos relevantes pelo seu carácter exploratório e inovador, complementando a evidência proveniente de revisões sistemáticas e ensaios clínicos randomizados. Embora a reduzida dimensão da amostra limite a generalização, esta abordagem permite testar metodologias emergentes, explorar mecanismos de intervenção e gerar hipóteses para estudos futuros de maior escala.



A proximidade ao contexto real de aplicação possibilita observar de forma detalhada os efeitos individuais da intervenção e compreender adaptações motoras, cognitivas e motivacionais frequentemente não captadas por estudos quantitativos de larga escala (Klatte et al., 2021). Assim, os estudos de caso assumem um papel relevante na translação do conhecimento científico para programas clínicos e comunitários personalizados.

6.5.1. Relevância do uso de tecnologias móveis na avaliação da marcha

O primeiro estudo de caso destacou a utilização da aplicação móvel Phyphox® para análise das características espaço-temporais da marcha em adultos mais velhos, evidenciando o potencial das tecnologias móveis como ferramentas acessíveis, portáteis e de baixo custo na avaliação funcional.

A análise individual dos participantes revelou padrões específicos de cadência, variabilidade da passada e características fractais, sugerindo que as tecnologias digitais podem constituir instrumentos complementares de monitorização clínica e comunitária. A avaliação demonstrou uma menor escala fractal nos participantes adultos mais velhos em comparação com adultos jovens saudáveis, o que indica maior aleatoriedade no padrão de marcha, uma alteração associada ao envelhecimento, a doenças neurológicas e a um aumento do risco de quedas (Hausdorff, 2007). Estas descobertas reforçam a utilidade de intervenções direcionadas à otimização da variabilidade da marcha, bem como a viabilidade do uso de smartphones na monitorização contínua do desempenho locomotor.

Além disso, o estudo evidencia a viabilidade e validade do uso de smartphones e dispositivos móveis na obtenção de medições precisas da marcha, permitindo treino direcionado da variabilidade da passada e democratizando o acesso a métricas de desempenho motor. Esta abordagem poderá integrar-se futuramente em rotinas de avaliação clínica e programas de saúde comunitária, promovendo monitorização contínua, personalizada e sustentável do envelhecimento funcional.

6.5.2. Efeitos do treino sensório motor em populações específicas (ex.: idosas com diabetes)

O segundo estudo de caso envolveu mulheres idosas com DM2, destacando a aplicabilidade do TSM em populações clínicas específicas.

Os resultados evidenciaram melhorias significativas na agilidade, força dos membros inferiores e flexibilidade, competências fundamentais neste grupo,



frequentemente afetado por neuropatia periférica, perda de sensibilidade e elevado risco de quedas (Kraiwong et al., 2019).

A intervenção demonstrou ganhos relevantes no controlo proprioceptivo, estabilidade postural e independência funcional, reforçando que o TSM pode exercer efeitos terapêuticos direcionados, complementando o tratamento da diabetes e promovendo maior autonomia e qualidade de vida. Observou-se que, apesar das melhorias expressivas na força dos membros inferiores, a força dos membros superiores apresentou alterações menos consistentes, refletindo a especificidade do programa centrado na função postural e nos membros inferiores. Este resultado sublinha a necessidade de personalização da intervenção para alcançar ganhos globais de força e funcionalidade.

As melhorias observadas na mobilidade, agilidade e flexibilidade indicam que a prática regular de TSM contribui para a prevenção de quedas e para a manutenção de padrões funcionais de movimento típicos de um envelhecimento saudável. No entanto, alguns indicadores permaneceram em percentis baixos, sugerindo que a inclusão de exercícios adicionais focados na mobilidade articular e coordenação poderia enriquecer e complementar o programa.

O estudo reforça a relevância do TSM como estratégia de intervenção adaptável e progressiva, baseada no princípio FITT (Baptista et al., 2024), permitindo o ajuste a diferentes níveis de aptidão física e condições clínicas. Os resultados sugerem ainda efeitos indiretos benéficos sobre a saúde cardiovascular e o controlo glicémico, posicionando o TSM como uma intervenção complementar eficaz na gestão multidimensional da diabetes tipo 2.

Entre as limitações identificadas, destacam-se a pequena dimensão da amostra e a variabilidade etária entre as participantes, o que reduz o poder estatístico e a generalização dos resultados. A inclusão exclusiva de participantes com diabetes poderá ter limitado a deteção de efeitos subtis, mas clinicamente relevantes. Assim, estudos futuros com amostras mais amplas e equilibradas, que incluam a avaliação de marcadores fisiológicos, como o metabolismo da glicose, são fortemente recomendados para aprofundar a compreensão dos efeitos multifacetados do TSM.

Em termos práticos, os estudos de caso demonstram a versatilidade e aplicabilidade do TSM, tanto em contextos experimentais como clínicos, permitindo validar protocolos de intervenção, explorar metodologias inovadoras e sustentar a implementação de estratégias de promoção da saúde e prevenção de quedas em



populações idosas. Estes trabalhos fornecem evidência preliminar essencial, que poderá ser expandida em ensaios clínicos de maior escala, consolidando a base científica do TSM como intervenção eficaz e segura para populações vulneráveis.

6.6. Discussão dos ensaios clínicos randomizados (RCTs)

Os RCTs incluídos nesta investigação forneceram evidência robusta acerca dos efeitos do TSM em múltiplas dimensões da funcionalidade e saúde dos adultos mais velhos, permitindo estabelecer relações causais entre a intervenção e os resultados observados. Globalmente, os estudos demonstraram que o TSM constitui uma estratégia segura, eficaz e acessível para melhorar a aptidão física funcional, o controlo postural e algumas dimensões psicossociais, reforçando o seu potencial como intervenção preventiva no contexto do envelhecimento ativo.

De forma transversal, observaram-se melhorias na força muscular, flexibilidade, agilidade e estabilidade postural, acompanhadas por aumentos nos NAF e indicadores de bem-estar percebido. Estes resultados sustentam o papel do TSM como abordagem multicomponente capaz de integrar estímulos neuromotores, proprioceptivos e cognitivos, promovendo adaptações relevantes para a manutenção da autonomia funcional e prevenção de quedas em populações idosas.

6.6.1. Efeitos do TSM na força, flexibilidade e agilidade

Os RCTs analisados evidenciaram de forma consistente que a prática regular de TSM conduz a melhorias significativas na força muscular, sobretudo dos membros inferiores, fator determinante para a mobilidade, independência funcional e prevenção de quedas. Estas descobertas corroboram a evidência científica existente, que associa o treino proprioceptivo a aumentos na ativação neuromuscular e a um recrutamento motor mais eficiente, favorecendo a resistência à fadiga e a manutenção da performance funcional (Cabo et al., 2024; Yang et al., 2023).

A flexibilidade, variável frequentemente subvalorizada em programas tradicionais de exercício (Micheo et al., 2012), apresentou também ganhos expressivos, refletindo maior amplitude articular e elasticidade muscular — elementos essenciais para a execução fluida, segura e autónoma das atividades da vida diária. A agilidade, entendida como a capacidade de responder rapidamente a estímulos e alterar a direção com estabilidade (Labott & Donath, 2023), registou igualmente melhorias significativas,



reforçando a eficácia do TSM na prevenção de quedas e na promoção da mobilidade funcional.

O TSM, ao exigir ajustes posturais constantes e respostas automáticas a perturbações externas, estimula a plasticidade neural e a eficiência dos mecanismos de controlo motor (Concha-Cisternas et al., 2024; Ghrouz et al., 2022). Em conjunto, os resultados dos RCTs evidenciam que este tipo de treino potencia a funcionalidade global dos adultos mais velhos, promovendo um desempenho motor mais eficiente e contribuindo para a preservação da autonomia nas atividades da vida diária.

No presente estudo, os participantes apresentavam características homogêneas em termos de idade, peso, altura e IMC, sendo ambos os grupos (masculino e feminino) classificados como acima do peso. O treino sensório motor, ao integrar funções sensoriais e motoras com ênfase na coordenação propriocetiva e neuromuscular, mostrou-se particularmente adequado para adultos mais velhos, respondendo à natureza multifatorial dos desafios de mobilidade (Freire & Seixas, 2024).

Exercícios que envolvem equilíbrio e propriocepção, como a permanência em superfícies instáveis ou a realização de movimentos unilaterais, estimulam o corpo a responder dinamicamente a estímulos externos, melhorando a estabilidade postural e o controlo neuromuscular e reduzindo o risco de quedas (Pšeničnik Sluga & Kozinc, 2024).

Os testes utilizados ((Levantar, caminhar e voltar a sentar (TUG) Sentar e levantar com inclinação (SSWL); Sentar e levantar sem inclinação (SSL); Flexão do antebraço (FF); Sentar e alcançar (SR); Alcançar atrás das costas à direita (RBBR); Alcançar atrás das costas à esquerda (RBBL)) avaliaram componentes específicas da função física, essenciais para a população idosa.

O TUG, amplamente utilizado para avaliar o equilíbrio, a mobilidade e o risco de queda, consiste em levantar-se de uma cadeira, caminhar 3 metros, virar e regressar ao assento. Este teste simples e funcional reflete tarefas quotidianas fundamentais para a independência. Tempos de execução mais longos estão associados a maior risco de quedas (Podsiadlo & Richardson, 1991), sendo recomendado por diretrizes geriátricas como ferramenta de rastreio (Barry et al., 2014). No presente estudo, o tempo médio dos participantes diminuiu de 7.26 s para 6.85 s após a intervenção, valores semelhantes aos relatados por Andrade et al., 2021; Bretan et al., 2013; e Martinez et al., 2016.

Os testes de sentar e levantar, realizados em superfícies planas e inclinadas, avaliaram a força dos membros inferiores, o equilíbrio e a coordenação. O 30s-CST, que mede o número de repetições completadas em 30 segundos, está amplamente validado



para adultos mais velhos ativos (Rikli & Jones, 1999). De acordo com os valores de referência de (Baptista & Sardinha, 2005), os participantes situaram-se entre os percentis 75 e 90, evidenciando excelente força inicial e ganhos adicionais após a intervenção. Como a melhoria da propriocepção dos membros inferiores depende parcialmente do efeito de aprendizagem, o aumento progressivo da dificuldade dos exercícios sensório motores contribuiu para ganhos sustentados ao longo do tempo.

O HGS foi igualmente aplicado, constituindo um marcador objetivo de força global e de risco de mortalidade em adultos mais velhos. Os testes de flexibilidade avaliaram a mobilidade articular e elasticidade muscular, cruciais para tarefas como vestir-se, alcançar objetos ou pentear-se. Segundo Ruivo (2018), os participantes posicionaram-se entre os percentis 50–75 para flexibilidade dos membros inferiores e entre 10–35 para os membros superiores, apresentando melhorias significativas em ambos os casos após o programa (Jones & Rikli, 2002).

A análise do GC revelou ausência de melhorias estatisticamente significativas, com valores estáveis em todas as variáveis — por exemplo, “sentar e alcançar” apresentou $p = 0.155$, indicando variação mínima. Estes resultados reforçam a eficácia da intervenção, dado que apenas o GE apresentou ganhos relevantes. A análise MANOVA confirmou diferenças significativas nas variáveis TUG ($F = 79.0907$, $p < 0.001$), SSL ($F = 8.1732$, $p = 0.005$), FF ($F = 9.4793$, $p = 0.003$) e RBBL ($F = 12.7130$, $p < 0.001$), evidenciando impacto claro na mobilidade funcional e no equilíbrio dinâmico.

Estes resultados estão em consonância com os estudos de Granacher et al., 2011, Lesinski et al., 2015; e Sherrington et al., 2017, que demonstraram que o TSM melhora o controlo postural, a força e a flexibilidade, reduzindo a incidência de quedas. Estudos complementares (Muehlbauer et al., 2015; Pizzigalli et al., 2011) sugerem que o TSM favorece adaptações neuromusculares e propriocetivas, fundamentais para a estabilidade postural e coordenação global. O programa demonstrou ainda impacto positivo na qualidade de vida e redução do risco de queda, confirmando a sua utilidade clínica na reabilitação geriátrica.

Apesar dos resultados favoráveis, algumas limitações devem ser consideradas, incluindo a ausência de GC ativo e as condicionantes logísticas associadas ao período pandémico, que poderão ter influenciado a adesão e a interação social durante o programa. Estudos futuros deverão incluir amostras mais amplas, avaliações de retenção a longo prazo e análise de marcadores clínicos adicionais.



6.6.2. Comparação entre modalidades de exercício (TSM, pilates, hidroginástica)

Os RCTs comparativos entre TSM, pilates e hidroginástica revelaram diferenças relevantes quanto à magnitude e à especificidade dos efeitos de cada modalidade. O TSM destacou-se pela sua eficácia superior na melhoria do equilíbrio, da propriocepção e do controlo postural, resultado do foco em estímulos instáveis e em feedback sensorial contínuo. Em contraste, o pilates, embora também promova a estabilidade central e a coordenação, evidenciou resultados mais expressivos ao nível da flexibilidade e da consciência corporal, mas com menor impacto na resposta automática ao desequilíbrio. A hidroginástica, por sua vez, demonstrou benefícios a nível cardiorrespiratório e articular, mas apresentou melhorias mais modestas na estabilidade postural, possivelmente devido à redução das forças gravitacionais proporcionada pelo meio aquático.

O estudo que comparou estas modalidades (Freire & Seixas, 2024) integrou quatro grupos de intervenção (grupo de controlo, grupo de treino sensório motor, grupo de hidroginástica e grupo de pilates) ao longo de 24 semanas, permitindo uma avaliação robusta das alterações na aptidão física em adultos mais velhos. Os resultados indicaram melhorias significativas em todas as variáveis analisadas entre os grupos de intervenção, com destaque para o grupo de treino sensório motor, que obteve diferenças estatisticamente significativas ($p < 0.001$) em variáveis como SSWL, SSL, FF e RBBL. Os tamanhos de efeito oscilaram entre pequenos e moderados, confirmando a relevância funcional destas adaptações no contexto do envelhecimento ativo.

O teste TUG (Podsiadlo & Richardson, 1991) demonstrou particular sensibilidade na deteção de melhorias na mobilidade funcional. Os participantes submetidos ao treino sensório motor apresentaram reduções significativas nos tempos de execução ($p < 0.001$), refletindo ganhos evidentes em coordenação e equilíbrio dinâmico. Estes resultados sustentam a evidência de que este tipo de treino potencia mecanismos de neuroplasticidade, promovendo respostas mais rápidas e eficazes a estímulos externos (Freire & Seixas, 2024). Segundo Bianco et al. (2014), programas que estimulam especificamente o tempo de reação são os mais eficazes na redução do risco de quedas, uma vez que reforçam a capacidade de resposta motora imediata face a desafios ambientais.

No teste SSWL, os GC e pilates apresentaram desempenhos inferiores, com tempos de execução mais longos, o que sugere défices de força e de equilíbrio funcional



— aspetos frequentemente observados em adultos mais velhos sedentários (Cameron et al., 2016; Maki & McIlroy, 2006). Em contrapartida, os grupos sensório motor e de hidroginástica revelaram melhorias significativas, indicando ganhos na coordenação intermuscular e na força dos membros inferiores.

No teste FF (Rikli & Jones, 1999), apenas os grupos sensório motor e de hidroginástica evidenciaram melhorias significativas, ao contrário dos grupos de controlo e pilates, cujos resultados permaneceram estáveis. A prática do TSM parece potenciar a força muscular do tronco e dos membros superiores, associada a um melhor recrutamento neuromuscular e a uma maior eficiência dos mecanismos propriocetivos. Por outro lado, a hidroginástica, através da resistência natural da água, favorece o reforço da força muscular sem sobrecarga articular, justificando os resultados positivos observados (Song & Oh, 2022)

Em relação à flexibilidade, avaliada pelo teste *Sit and Reach*, o grupo sensório motor apresentou resultados significativos, embora este não seja o foco principal da modalidade. Os exercícios dinâmicos e de estabilidade presentes no TSM contribuem indiretamente para uma melhor mobilidade articular e para uma maior elasticidade muscular (Pšeničnik Sluga & Kozinc, 2024). Estes ganhos, embora menos pronunciados do que os obtidos com o pilates, são relevantes para a manutenção da amplitude funcional dos movimentos do quotidiano.

A mobilidade dos ombros, medida pelo RBB, apresentou melhorias moderadas no grupo de TSM (Ahmad et al., 2020; Freire & Seixas, 2024) e resultados significativamente superiores no grupo de hidroginástica, nomeadamente no lado esquerdo. Este último efeito pode ser atribuído às propriedades físicas da água, que reduzem o impacto articular e permitem maior amplitude de movimento com menor desconforto, reforçando a importância do treino aquático em populações com limitações articulares (Tsourlou et al., 2006).

Apesar das melhorias observadas, algumas variáveis apresentaram tamanhos de efeito negativos, o que pode dever-se a erros de medição, à variabilidade interindividual ou a um declínio real do desempenho, exigindo investigação adicional. Entre as limitações metodológicas identificadas incluem-se o tamanho amostral reduzido em alguns grupos (por exemplo, pilates, N = 22), a predominância de mulheres (>70%), que limita a generalização dos resultados, a ausência de seguimento longitudinal e a falta de controlo de fatores confundidores (alimentação, medicação, condição física basal).



Apesar das diferenças entre modalidades, todos os programas produziram melhorias significativas na aptidão física funcional, sugerindo que intervenções multicomponentes e periodizadas podem representar uma estratégia particularmente eficaz para o envelhecimento ativo. A combinação estruturada destas modalidades poderá maximizar benefícios complementares, potenciando ganhos globais em funcionalidade, mobilidade e prevenção de quedas.

6.6.3. Efeitos psicossociais: qualidade de vida, prazer e bem-estar

Para além das adaptações físicas, os RCTs indicaram melhorias significativas em dimensões psicossociais, incluindo a QVRS, o prazer associado à prática de exercício e o bem-estar subjetivo. Os participantes relataram maior satisfação pessoal, redução de sintomas de ansiedade e depressão, bem como um aumento do sentimento de pertença social, sugerindo que o TSM influencia positivamente mecanismos psicológicos e sociais que contribuem para o envelhecimento ativo.

A utilização de escalas como o PACES (Teques et al., 2020) permitiu quantificar o prazer percebido na AF, revelando altos níveis de adesão e motivação ao longo das 24 semanas de intervenção. Estas descobertas estão em concordância com a literatura, que associa o prazer na prática de exercício à manutenção de hábitos de vida ativos e à redução do sedentarismo em adultos mais velhos (Chia et al., 2023; McGowan et al., 2021)

O estudo avaliou 124 adultos mais velhos, com características similares de idade, peso e altura. O IMC indicou classificação de pré-obesidade (sobrepeso) em ambos os sexos. Após a intervenção, observou-se uma redução do IMC, mais pronunciada no grupo de exercício. Observou-se ainda uma maior adesão feminina (>70%), alinhada com evidências que sugerem que mulheres mais velhas participam mais frequentemente em programas estruturados de exercício físico, possivelmente devido a uma maior consciência de saúde, apoio social e motivação para manter a independência funcional.

A análise do PACES revelou diferenças mínimas no prazer global entre o GC e o grupo de exercício, sem alterações estatisticamente significativas. Apenas o item *Not invigorating / Very invigorating* apresentou tamanho de efeito moderado, sugerindo que alguns participantes percecionaram a atividade como mais revigorante, embora essa percepção não tenha sido consistente em todas as dimensões de prazer.

A literatura sugere que o prazer na AF está intimamente ligado à motivação intrínseca, conforme a teoria da autodeterminação de Ryan & Deci (2020). Segundo a teoria da autodeterminação, a motivação intrínseca surge quando três necessidades



psicológicas básicas são satisfeitas: autonomia, competência e relacionamento social. No presente estudo, a estrutura do treino poderá não ter proporcionado escolha suficiente de atividades (autonomia), reconhecimento claro de progressos (competência) ou interação social significativa (relacionamento), limitando a emergência de motivação intrínseca e, por consequência, do prazer na prática.

O IPAQ (Lee et al., 2011) evidenciou alterações positivas nos NAF entre a avaliação inicial e a avaliação pós-24 semanas. A atividade de caminhada apresentou diferença estatisticamente significativa e grande tamanho de efeito, indicando um aumento expressivo da mobilidade funcional no grupo de exercício. As variáveis *Moderate Activity* e *Total Physical Activity* mostraram tamanhos de efeito moderados, sugerindo melhorias mais modestas no volume total de AF. Estes resultados corroboram estudos prévios que destacam a caminhada como uma forma de exercício acessível e sustentável para adultos mais velhos, especialmente quando combinada com programas de treino de força e equilíbrio (Hung et al., 2023; Pahor et al., 2014; Tomioka et al., 2011).

A análise do SF-36 (Aguirre et al., 2022), instrumento de avaliação do bem-estar e saúde geral, revelou diferenças pequenas entre as avaliações inicial e final, sem significância estatística entre GC e grupo de exercício. Todos os tamanhos de efeito foram reduzidos, sugerindo um impacto limitado do TSM na percepção subjetiva da qualidade de vida ao longo de 24 semanas. Estes resultados estão em consonância com revisões sistemáticas que apontam que os ganhos físicos nem sempre se traduzem em melhorias percebidas na QVRS, particularmente em programas de curta duração ou em populações com níveis de bem-estar já moderados a elevados (Rejeski & Mihalko, 2001; Stewart et al., 2001).

Os resultados relativos ao prazer na prática de exercício sugerem que, embora o TSM seja percebido como estimulante e funcionalmente relevante, a ausência de estratégias estruturadas de promoção da autonomia, competência e interação social poderá ter limitado o impacto motivacional global. Assim, intervenções futuras deverão integrar componentes comportamentais e psicossociais adicionais, de modo a potenciar a adesão e os efeitos sustentados da prática de exercício.

6.6.4. Impacto no controlo postural

O controlo postural constitui um dos pilares centrais da capacidade funcional no envelhecimento, sendo determinante para a autonomia e para a prevenção de quedas. Nos RCTs analisados, o TSM revelou efeitos positivos evidentes sobre a estabilidade corporal,



reduzindo significativamente a oscilação postural e melhorando a capacidade de resposta a desequilíbrios externos.

A análise do controlo postural foi realizada através de métodos lineares e não-lineares, permitindo uma compreensão mais aprofundada das adaptações neuromusculares decorrentes da intervenção. Enquanto os métodos lineares avaliam a magnitude da oscilação corporal, os não-lineares quantificam a complexidade e a estrutura temporal dos ajustes posturais — um aspeto crucial para compreender a eficiência, a estabilidade e a adaptabilidade do sistema de controlo motor.

6.6.4.1. Métodos lineares

Os métodos lineares (como a amplitude média de oscilação, a velocidade média do CoP e a área elíptica de deslocamento) demonstraram reduções consistentes nos valores após a intervenção, refletindo maior estabilidade postural e menor variabilidade. Num estudo de seis meses, com 86 adultos mais velhos aleatorizados em GE e GC, foram analisadas variáveis espaço-temporais, posicionais e dinâmicas do CoP, em ambas as direções AP e ML, utilizando métodos tradicionais e avançados.

Embora os resultados da ANCOVA indiquem que o desempenho inicial influenciou substancialmente os resultados pós-teste, o padrão de alterações intra-grupo e a representação em *forest plot* oferecem uma perspetiva clinicamente relevante. Os aumentos acentuados em rangeRatio_OF (0.58 [0.90; 0.25]) e sway_deg_OF (0.48 [0.79; 0.16]) observados no GC são consistentes com maior variabilidade e menor consistência postural, particularmente em condições de OF. Em contraste, o GE apresentou alterações mínimas ou negativas nessas mesmas métricas (rangeRatio_OF = -0.03 [-0.27; -0.33]; sway_deg_OF = -0.01 [-0.29; -0.31]), sugerindo uma estabilização relativa do comportamento postural após a intervenção. Assim, mesmo na ausência de diferenças estatisticamente significativas entre grupos após ajustamento, a intervenção pode ter tido um efeito protetor ao atenuar a deterioração evidenciada no GC.

Do ponto de vista mecanístico, o treino sensório motor visa melhorar a integração propriocetiva, o contributo vestibular e a coordenação neuromuscular, promovendo estratégias posturais mais consistentes e eficientes (Kumar et al., 2023). Os adultos mais velhos tendem frequentemente a adotar estratégias rígidas e cautelosas que reduzem a amplitude de oscilação, mas aumentam a suscetibilidade a perturbações (Mongold et al., 2025; Varjan et al., 2024). Na nossa amostra, os aumentos nos parâmetros de oscilação no GC — especialmente nos índices de variabilidade ML e direcional — provavelmente



refletem perda de controlo postural, mais do que flexibilidade funcional. Por outro lado, a manutenção relativa das métricas do CoP no grupo treinado, particularmente em condições de OF, sugere uma melhor utilização de inputs sensoriais não visuais e uma possível melhoria na adaptabilidade sensório motora (Low et al., 2017; Peterka, 2002).

A interpretação de aumentos na oscilação requer cautela. Um aumento em algumas medidas de oscilação pode refletir exploração funcional da base de suporte e redução da rigidez associada ao medo (Johansson et al., 2019; Quijoux et al., 2021); contudo, aumentos grandes e direcionalmente inconsistentes são mais plausivelmente interpretados como instabilidade. A ausência dessas alterações no GE pode indicar prevenção bem-sucedida da desestabilização ou que os efeitos do treino foram insuficientes para produzir melhorias mensuráveis além da variação natural e dos efeitos de aprendizagem. Melhorias na oscilação AP (rangeAP_OA) e nas distâncias máximas de oscilação (maxAP_OA, maxR_OA) podem refletir maior flexibilidade postural e confiança (Quijoux et al., 2021), apoiando uma estratégia postural dinâmica e adaptável.

Clinicamente, estes resultados salientam dois pontos importantes. Primeiro, o ajustamento estatístico convencional para diferenças basais (ANCOVA) deve ser reportado e interpretado juntamente com as alterações Intra grupo: a ausência de diferenças significativas entre grupos após ajustamento não implica necessariamente que a intervenção não tenha valor prático. Segundo, programas sensório motores podem ser particularmente valiosos como estratégias preventivas que mantêm a função do equilíbrio e limitam a deterioração, especialmente em condições de desafio sensorial (OF), fortemente associadas ao risco de queda. O padrão observado reforça esta perspetiva (Bacha et al., 2016; Cho et al., 2014a; Costa et al., 2012; Rezende et al., 2012; Sadaqa et al., 2023; Sung & Lee, 2025).

Embora as comparações ajustadas pela ANCOVA não tenham mostrado diferenças estatisticamente significativas entre os grupos após o controlo dos valores basais, o padrão geral sugere que seis meses de treino sensório motor podem ajudar a preservar o controlo postural em adultos mais velhos e prevenir a deterioração observada nos pares não treinados, particularmente em condições de OF. Estes resultados sustentam a utilidade clínica das intervenções sensório motoras como parte de programas de prevenção de quedas e manutenção do equilíbrio em populações envelhecidas (Cho et al., 2014b; Johansson et al., 2019; Kumar et al., 2023; Low et al., 2017; Mongold et al., 2025; Rezende et al., 2012; Sadaqa et al., 2023; Sung & Lee, 2025; Varjan et al., 2024).



6.6.4.2. Métodos não-lineares

Os resultados obtidos suportaram parcialmente a hipótese de que a intervenção sensoriomotora promoveria melhorias nas características não lineares do controle postural, incluindo alterações na regularidade e estabilidade dos padrões de oscilação. Estes resultados estão em consonância com estudos prévios que reportam um melhor controle do equilíbrio em indivíduos treinados comparativamente a indivíduos sedentários (Bacha et al., 2016; Costa et al., 2012; Rezende et al., 2012). Os participantes do GE evidenciaram melhorias seletivas na organização da oscilação ML em condição de OA (EnAp_ML_OA) e na estabilidade dinâmica local, avaliada através do expoente de Lyapunov, em condição de OF (LyE_AP_OF; LyE_ML_OF). Em contraste, outras medidas não lineares, como a DFA, não apresentaram diferenças significativas entre os grupos. Estes resultados mistos poderão estar relacionados com a curta duração da intervenção e com a ausência de um acompanhamento longitudinal.

O presente estudo diferencia-se da literatura existente ao aplicar um enquadramento analítico não linear consistente, com procedimentos padronizados de pré-processamento dos sinais do centro de pressão (centragem do CoP e filtragem passa-baixo a 10 Hz) e métricas de desfecho uniformes (Entropia Aproximada, Expoente de Lyapunov e DFA). Esta consistência metodológica reforça a comparabilidade dos resultados, tanto internamente como com estudos anteriores (Figueiredo et al., 2018; Shokouhyan et al., 2020). Ainda assim, a ausência de medidas funcionais limita a extrapolação direta dos resultados para contextos de risco real, como a prevenção de quedas.

Foram observadas reduções significativas da entropia aproximada (EnAP) no GE em ambas as condições visuais, indicando padrões de oscilação mais regulares e previsíveis. Valores mais baixos de entropia poderão refletir um maior controle neuromuscular (Roerdink et al., 2011), em linha com evidência prévia sobre os benefícios do treino sensório motor em adultos mais velhos (Costa et al., 2012; Rezende et al., 2012). Contudo, importa considerar que a filtragem dos sinais a 10 Hz poderá ter contribuído para a atenuação de flutuações de alta frequência, influenciando as medidas relacionadas com a entropia (Lubetzky et al., 2018). Investigações futuras deverão analisar o impacto de diferentes estratégias de filtragem nos resultados não lineares.

As melhorias observadas na DFA nas direções AP e ML, em condição de OF, sugerem uma redução da intensidade da oscilação postural, em consonância com estudos que associam valores mais baixos de DFA a uma melhor estabilidade postural (Chiari et al., 2002; Prieto et al., 1996). No entanto, os resultados da ANCOVA não evidenciaram



diferenças significativas entre grupos para esta métrica, indicando que a intervenção induziu melhorias seletivas, em vez de alterações globais no comportamento postural. Neste contexto, as métricas associadas à direção AP pareceram particularmente sensíveis à intervenção, reforçando a importância desta componente para o equilíbrio funcional (Maki et al., 1994; Peterka et al., 2018).

A literatura não linear aplicada ao envelhecimento apresenta resultados heterogêneos, com estudos a reportarem tanto aumentos como diminuições da entropia, propriedades fractais e expoentes de Lyapunov (Cavanaugh et al., 2007; Duarte & Sternad, 2008; Kędziołek & Błażkiewicz, 2020; Manor et al., 2010). Estas discrepâncias salientam o carácter dependente do contexto destas métricas e a necessidade de interpretações cautelosas. Neste enquadramento, as reduções seletivas observadas no presente estudo poderão refletir uma maior eficiência e estabilidade do sistema de controlo postural, em vez de uma melhoria uniforme em todas as dimensões da oscilação.

Do ponto de vista neurofisiológico, os efeitos observados são consistentes com os princípios da neuroplasticidade, segundo os quais o treino sensorio motor favorece estratégias motoras mais eficientes através da estimulação sensorial direcionada (Kumar et al., 2023). As melhorias no expoente de Lyapunov e na entropia, particularmente em condição de OF, sugerem um reforço dos mecanismos compensatórios quando a informação visual é limitada (Matur & Oge, 2017). As reduções do LyE em ambos os eixos sob condição de OF indicam um aumento da estabilidade dinâmica local, um fator determinante para a resposta a pequenas perturbações e para a prevenção de quedas (Mehdizadeh, 2018).

Apesar destas tendências favoráveis, foi observada uma considerável variabilidade interindividual, com alguns participantes a apresentarem respostas divergentes da média do grupo. Este aspeto sugere que fatores como a estabilidade basal, as estratégias motoras individuais ou variáveis não avaliadas poderão influenciar a resposta à intervenção (Kędziołek & Błażkiewicz, 2020), reforçando a necessidade de abordagens mais individualizadas.

As métricas não lineares revelaram-se particularmente sensíveis à deteção de alterações subtis que poderiam não ser captadas por medidas lineares ou instrumentos clínicos convencionais. Este resultado é consistente com evidência proveniente de sistemas de avaliação avançados, que demonstram que pequenas melhorias, mesmo quando não clinicamente evidentes, podem ter impacto funcional relevante (Simmatis et al., 2020). Assim, a utilização combinada de medidas lineares e não lineares revela-se



fundamental para captar a natureza multidimensional do controlo postural e os efeitos específicos do treino sensório motor.

Do ponto de vista teórico, a dinâmica não linear oferece um enquadramento robusto para compreender o controlo postural como um sistema adaptativo e auto-organizado, que opera em múltiplas escalas temporais. Métricas como a entropia e os expoentes de Lyapunov refletem a complexidade e flexibilidade do sistema, permitindo interpretar as alterações observadas como adaptações funcionais, e não simplesmente como melhorias ou deteriorações do equilíbrio (Riley & Turvey, 2002; Stergiou & Decker, 2011).

Em termos clínicos, os resultados sugerem que um treino sensório motor estruturado poderá contribuir para melhorias da estabilidade postural e para a redução do risco de queda em adultos mais velhos, particularmente em indivíduos com diabetes. No entanto, devem ser reconhecidas algumas limitações, incluindo a dimensão reduzida da amostra, a curta duração da intervenção e os constrangimentos logísticos associados à pandemia de COVID-19, bem como a ausência de dados sobre o historial de quedas dos participantes. Estes fatores limitam a generalização dos resultados e a avaliação da sustentabilidade dos efeitos observados.

6.7. Integração dos resultados: perspetiva global

A integração dos diferentes níveis de evidência analisados revela uma elevada coerência conceptual e empírica, sustentando de forma consistente a eficácia do TSM como intervenção multidimensional no envelhecimento ativo. Em conjunto, os resultados demonstram que o TSM produz efeitos positivos não apenas ao nível físico, mas também em domínios funcionais, cognitivos e psicossociais, contribuindo para a manutenção da autonomia, da funcionalidade e da qualidade de vida dos adultos mais velhos.

A convergência entre os dados quantitativos e qualitativos reforça a validade externa das conclusões, enquanto a complementaridade metodológica dos diferentes estudos permite uma compreensão integrada e abrangente do fenómeno, articulando evidências provenientes de revisões sistemáticas, análises bibliométricas, ensaios clínicos randomizados e estudos de caso. Esta abordagem multinível fortalece a robustez científica dos resultados e minimiza as limitações inerentes a cada desenho metodológico isolado.

Do ponto de vista clínico, o TSM afirma-se como uma estratégia eficaz de reabilitação funcional e prevenção, com impacto direto na redução do risco de quedas e na preservação da independência funcional. No plano social, promove a participação



ativa, a integração comunitária e a mitigação do isolamento, enquanto, no plano científico, contribui para o aprofundamento do conhecimento sobre os mecanismos neurofisiológicos e adaptativos associados ao envelhecimento, consolidando o TSM como uma intervenção relevante e baseada em evidência.

6.8. Forças do estudo

Esta investigação apresenta várias forças que reforçam a sua relevância científica e aplicabilidade prática. Destaca-se, em primeiro lugar, a abordagem multidimensional que integrou diferentes níveis de evidência, incluindo revisões sistemáticas, análises bibliométricas, ensaios clínicos randomizados e estudos de caso, permitindo uma análise abrangente e articulada do fenómeno em estudo.

O foco específico no treino sensório motor constitui outra mais-valia significativa, dado tratar-se de uma área emergente e ainda pouco explorada no contexto português, particularmente no domínio do envelhecimento ativo. Acresce a análise integrada de parâmetros físicos, cognitivos e psicossociais, que proporciona uma visão holística dos efeitos do exercício físico na população idosa, ultrapassando abordagens centradas exclusivamente em indicadores fisiológicos.

Por fim, a elevada relevância prática dos resultados representa uma força adicional do estudo, uma vez que as evidências produzidas podem ser diretamente transpostas para contextos clínicos, comunitários e institucionais, sustentando a implementação de programas de exercício físico baseados em evidência científica.

6.9. Limitações gerais da investigação

Apesar dos contributos relevantes, esta investigação apresenta algumas limitações que devem ser consideradas na interpretação dos resultados. Entre as principais destacam-se a heterogeneidade das amostras e dos instrumentos de avaliação utilizados nos diferentes estudos, bem como a dimensão da amostra reduzida em alguns trabalhos, particularmente nos estudos de caso e estudos piloto, o que pode limitar a generalização dos resultados.

Adicionalmente, as restrições linguísticas e de bases de dados nas revisões realizadas podem ter introduzido viés de publicação, ao excluir estudos relevantes não indexados ou publicados noutras línguas. A limitação geográfica de alguns ensaios, conduzidos exclusivamente em Portugal, constitui igualmente um fator a considerar, reduzindo a extrapolação dos resultados para outros contextos socioculturais.



Não obstante, estas limitações não comprometem a consistência global dos resultados. Pelo contrário, reforçam a necessidade de futuras investigações multicêntricas, com desenhos longitudinais, amostras mais amplas e diversificadas, e integração de marcadores clínicos e psicossociais adicionais, de modo a aprofundar e consolidar a evidência científica sobre os efeitos do treino sensório motor no envelhecimento ativo.



Capítulo 7 | Conclusão

7.1. Artigo 1 – Instrumentos de avaliação sensório motora no envelhecimento

Este artigo permitiu sistematizar e clarificar os principais instrumentos utilizados na avaliação das capacidades sensório motoras em adultos mais velhos, evidenciando a diversidade metodológica existente na literatura. Apesar da ausência de consenso quanto aos instrumentos *gold standard*, os resultados demonstram que a combinação de medidas funcionais, biomecânicas e psicossociais oferece uma avaliação mais abrangente do envelhecimento funcional. Esta revisão constitui um contributo relevante para investigadores e profissionais de saúde, ao apoiar a seleção informada de instrumentos adequados aos objetivos de intervenção e investigação.

7.2. Artigo 2 – Risco de quedas e benefícios do treino físico

Os resultados reforçam que o aumento do risco de quedas nos adultos mais velhos está fortemente associado à redução da força muscular, da densidade óssea e do controlo postural, frequentemente agravada pelo sedentarismo. Programas estruturados de treino físico e psicológico revelaram-se eficazes na melhoria da funcionalidade, da autonomia e da qualidade de vida, destacando o papel central do exercício físico como estratégia preventiva e terapêutica no envelhecimento.

7.3. Artigo 3 – Sedentarismo e envelhecimento: análise bibliométrica

Este estudo evidenciou um crescimento exponencial da produção científica relacionada com o sedentarismo no envelhecimento, particularmente nas últimas décadas. Os resultados confirmam a relevância crescente da AF como determinante da qualidade de vida e da saúde cardiovascular, sublinhando a necessidade de programas regulares, frequentes e sustentados de promoção da AF para contrariar os efeitos do sedentarismo ao longo do envelhecimento.

7.4. Artigo 4 – Atividade física, capacidade funcional e tendências de investigação

Os resultados demonstram que a AF contribui para a manutenção da capacidade funcional, da saúde psicológica e do bem-estar social dos adultos mais velhos. A análise bibliométrica revelou um aumento consistente da produção científica desde o final da



década de 1990, com especial destaque para a área da Gerontologia Geriátrica. Estes resultados reforçam a importância académica e clínica deste domínio e identificam oportunidades para investigação futura.

7.5. Artigo 5 – Programa Reforma Ativa

Este estudo destaca o potencial de programas de reforma ativa na melhoria da composição corporal, da condição física, da QVRS e da redução do risco de quedas. Constitui um passo fundamental para a validação de intervenções estruturadas dirigidas a adultos mais velhos, integrando múltiplas dimensões da saúde.

7.6. Artigo 6 – Variabilidade da marcha e análise fractal

Este estudo pioneiro em Portugal demonstrou que adultos mais velhos apresentam uma menor escala fractal da marcha, refletindo maior aleatoriedade e menor organização do padrão locomotor, características associadas ao envelhecimento, a patologias neurológicas e ao aumento do risco de quedas. Os resultados evidenciam ainda o potencial da tecnologia móvel (smartphones) como ferramenta válida, acessível e inovadora para a avaliação da marcha em contexto clínico e comunitário.

7.7. Artigo 7 – Treino sensório motor em mulheres idosas com DM2

Os resultados confirmaram os benefícios do TSM na melhoria da agilidade, força, flexibilidade e propriocepção em mulheres idosas com DM2, contribuindo para a prevenção de quedas e a manutenção da independência funcional. Apesar das limitações metodológicas, o estudo reforça o potencial do TSM como estratégia eficaz e adaptável em populações clínicas específicas.

7.8. Artigo 8 – Efeitos do TSM na aptidão física e funcional

Este estudo demonstrou que o TSM promove melhorias significativas no equilíbrio, força e função física global, quando comparado com grupos de controlo. Os resultados sustentam a integração do TSM em programas comunitários, de reabilitação e de prevenção de quedas, salientando a importância de avaliações funcionais regulares para ajustar as intervenções às necessidades individuais.



7.9. Artigo 9 – Comparação entre TSM, hidroginástica e pilates

Os resultados indicaram que diferentes modalidades de exercício produzem benefícios específicos, com o TSM a destacar-se na melhoria global do equilíbrio, coordenação e força. Estes resultados reforçam a importância de abordagens multimodais e personalizadas na prescrição do exercício para adultos mais velhos.

7.10. Artigo 10 – TSM, composição corporal, atividade física e qualidade de vida

Apesar de nem todas as variáveis terem atingido significância estatística, os resultados revelaram tendências clinicamente relevantes a favor do GE, nomeadamente na redução do IMC, no aumento dos NAF (particularmente caminhada) e em indicadores de qualidade de vida. Estes dados sustentam o valor clínico do TSM como promotor de estilos de vida mais ativos.

7.11. Artigos 11 e 12 – Controlo postural e métricas lineares e não lineares

Estes estudos demonstraram que o TSM contribui para a preservação e melhoria seletiva do controlo postural, particularmente em condições sensoriais desafiantes. A utilização de métricas não lineares revelou-se essencial para captar adaptações subtis, mas funcionalmente relevantes, reforçando a importância de abordagens analíticas avançadas na investigação do equilíbrio e do envelhecimento.

Conclusão geral da tese

O presente trabalho teve como principal objetivo o desenvolvimento, implementação e validação de um programa de TSM, designado “Reforma Ativa”, dirigido a adultos entre os 55 e os 80 anos, com a duração de 24 semanas, visando a melhoria das capacidades sensório motoras, da coordenação, da adaptação motora e da qualidade de vida.

De forma consistente, os resultados provenientes de revisões sistemáticas e bibliométricas, estudos de caso e ensaios clínicos randomizados demonstram que o TSM constitui uma estratégia eficaz, segura e adaptável, com benefícios significativos nas dimensões física, funcional, neuromotora e psicossocial do envelhecimento. A



convergência entre métodos quantitativos e qualitativos reforça a robustez das evidências obtidas e valida o TSM como uma abordagem multidimensional de promoção da saúde.

Do ponto de vista físico-funcional, o programa “Reforma Ativa” evidenciou melhorias na força dos membros inferiores, agilidade, flexibilidade, equilíbrio e controlo postural, traduzindo-se numa maior eficiência neuromotora e numa redução do risco de quedas — fator determinante para a autonomia funcional e independência nas atividades da vida diária.

A utilização de métodos lineares e não lineares permitiu demonstrar que o TSM promove uma reorganização adaptativa do sistema de controlo postural, restaurando padrões de variabilidade fisiológica saudável, associados à plasticidade neural, à integração sensorial e à propriocepção.

No domínio psicossocial, observaram-se ganhos moderados no prazer associado à prática de exercício, motivação intrínseca e bem-estar subjetivo, ainda que os efeitos na QVRS tenham sido mais discretos. Estes resultados sugerem a necessidade de reforçar as componentes sociais e motivacionais do treino em futuras implementações.

A comparação entre diferentes modalidades de exercício revelou que o TSM apresenta vantagens claras na melhoria do equilíbrio, coordenação e propriocepção, complementando os benefícios específicos de outras modalidades, como o pilates e a hidroginástica. Estes resultados apoiam uma abordagem integrada e personalizada na prescrição do exercício físico para adultos mais velhos.

Em termos clínicos e comunitários, o programa “Reforma Ativa” apresenta elevada viabilidade, baixo custo e facilidade de implementação, constituindo uma ferramenta relevante para a promoção do envelhecimento ativo, saudável e autónomo.

Apesar dos resultados promissores, reconhecem-se limitações relacionadas com a dimensão da amostra, a duração das intervenções e a ausência de seguimento longitudinal. Futuras investigações deverão explorar os efeitos do destreino, a sustentabilidade dos ganhos ao longo do tempo, a integração de variáveis cognitivas e emocionais e a realização de estudos multicêntricos com maior diversidade populacional.

Em síntese, esta tese confirma que o treino sensório motor representa uma abordagem inovadora, eficaz e multidimensional para a promoção da funcionalidade, da autonomia e da qualidade de vida em adultos mais velhos. O programa “Reforma Ativa” contribui para a evolução do paradigma do envelhecimento, deslocando o foco da limitação para a capacidade, participação ativa e bem-estar global ao longo da vida.



Implicações práticas e futuras linhas de investigação

Os resultados obtidos nesta investigação apresentam implicações diretas para a promoção do envelhecimento ativo e saudável. O TSM revelou-se uma intervenção de baixo custo, altamente eficaz e de fácil implementação, aplicável tanto em contextos clínicos como comunitários. Recomenda-se a integração de programas de TSM em centros de dia, unidades de saúde e programas municipais direcionados a adultos mais velhos, assim como a formação de profissionais especializados na prescrição de exercício sensório motor.

A incorporação de tecnologias digitais e móveis, como sensores de movimento, plataformas de força portáteis e aplicações móveis, permitirá monitorizar parâmetros de marcha, equilíbrio e adesão, facilitando a personalização do treino e o acompanhamento remoto. Esta abordagem também pode contribuir para manter a motivação e a segurança dos participantes, especialmente em contextos de intervenção à distância.

Futuramente, será fundamental avançar com estudos longitudinais e multicêntricos que avaliem os efeitos sustentados do TSM ao longo do tempo, considerando não apenas os ganhos durante a intervenção, mas também a duração e magnitude da manutenção dos benefícios após a cessação do treino. Esta análise é particularmente relevante para adultos mais velhos que, por limitações físicas ou de saúde, possam deixar de participar ativamente nos programas, permitindo compreender até que ponto os efeitos benéficos do TSM permanecem e quais estratégias podem prolongar esses benefícios.

Além disso, será importante investigar a interação do TSM com fatores genéticos, ambientais e comportamentais, bem como o impacto em diferentes subpopulações, incluindo indivíduos com fragilidade ou condições crónicas. Apesar de já se saber que o exercício físico melhora equilíbrio, força, mobilidade e bem-estar psicossocial em adultos mais velhos, o futuro da investigação deve centrar-se em estudos de implementação, procurando transformar resultados comprovados em programas sustentáveis, escaláveis e capazes de promover mudanças de comportamento a longo prazo.

Estas perspetivas têm relevância transversal:





Figura 29- Relevância transversal.

A investigação futura poderá assim contribuir para a criação de protocolos padronizados de treino baseados em evidência, sustentando a implementação do TSM como uma intervenção de saúde pública eficaz e integrada.



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Apêndice 1

Apresentações orais:

Cabo, C. A., Parraça, J. A., Santos, S., Alegrete, J., & Fernandes, O. (2022). *Assessment of spatiotemporal characteristics of gait, through the Phyphox® APP* [Apresentação oral]. TAPAS 2022: International Conference on Technology in Physical Activity and Sport.



Figura 30- Certificado de apresentação oral no congresso TAPAS. Esta apresentação foi convidada para ser publicada como um artigo.



Cabo, C. A., Fernandes, O., Mendoza-Muñoz, M., Barrios-Fernandez, S., Muñoz-Bermejo, L., Gómez-Galán, R., & Parraca, J. A. (28 de marzo de 2023). *Efectos de la aplicación de un programa de entrenamiento sobre la estimulación del sistema sensorio motor*. [Apresentação oral]. VI Congreso Internacional Estudiantil En Ciencias De La Actividad Física Y Deporte.



Figura 31- Certificado de apresentação oral no VI Congreso Internacional Estudiantil En Ciencias De La Actividad Física Y Deporte.



Cabo, C. A., Fernandes, O., Mendoza-Muñoz, M., Barrios-Fernandez, S., Muñoz-Bermejo, L., Gómez-Galán, R., & Parraca, J. A. (17 de abril de 2023). *An Active Retirement Programme, a Randomized Controlled Trial of a Sensorimotor Training Programme for Older Adults: A Study Protocol*. [Apresentação oral]. European Healthcare Summit 2023.



Figura 32- Certificado de apresentação oral no European Healthcare Summit 2023.

Cabo, C. A., Fernandes, O., Murillo-García, A., Lllamas, J. L. L., & Parraca, J. A. (8 de maio de 2023). *Effects of linear and non-linear methods on postural control throughout the aging process*. [Apresentação oral]. 3ème Congrès International des Sciences du Sport Sport, Sciences et Santé.



Figura 33- Certificado de apresentação oral no 3ème Congrès International des Sciences du Sport Sport, Sciences et Santé.



Cabo, C. A., Fernandes, O., Mendoza-Muñoz, M., & Parraca, J. A. (16 de maio de 2023). *Jubilación activa: efectos de la aplicación de un programa de entrenamiento para estimular el sistema sensorio motor*. [Apresentação oral]. III Congreso Internacional Innovación Docente.



Figura 34- Certificado de apresentação oral no III Congreso Internacional Innovación Docente.

Cabo, C. A., Fernandes, O., Mendoza-Muñoz, M., & Parraca, J. A. (31 de maio de 2023). *Efeitos da aplicação de um programa de treino na estimulação do sistema sensorio motor*. [Apresentação oral]. V Congresso Nacional de Educação para a Saúde.



Figura 35- Certificado de apresentação oral no V Congresso Nacional de Educação para a Saúde.



Cabo, C. A., Fernandes, O., Santos, S., & Parraca, J. A. (12 de outubro de 2023). *Análise do controlo postural através de métodos lineares e não lineares ao longo do processo de envelhecimento*. [Apresentação oral]. Algarve Social Development Summit.



Figura 36- Certificado de apresentação oral no Algarve Social Development Summit.



Cabo, C. A., Fernandes, O., Santos, S., Espada, M. C., & Parraca, J. A. (30 de maio de 2023). Reforma Ativa: Efeitos da aplicação de um programa de treino na estimulação do sistema sensório motor. In A. Figueiredo, A. Pereira, A. Azevedo, C. Vasconcelos, F. Mendes, J. L. Esteves, & P. Eira (Eds.), *Livro de Resumos do 4.º Fórum da REDESPP – Desporto, Comunidades e Qualidade de Vida* (p. 30). REDESPP e Escola Superior de Educação – Instituto Politécnico de Viseu. DOI: <https://doi.org/10.34633/978-989-35325-3-9>.



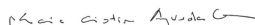
Certificado

Certifica-se que **Carolina Alexandra Cabo** apresentou em comunicação oral o estudo intitulado *Reforma Ativa: Efeitos da aplicação de um programa de treino na estimulação do sistema sensório motor*, da autoria de **Carolina Alexandra Cabo, Sara Santos, Mário Espada, Orlando Fernandes, José Alberto Parraca**, no 4º Fórum da REDESPP Desporto, Comunidades e Qualidade de Vida", que decorreu no Instituto Politécnico de Viseu nos dias 30 e 31 de outubro de 2023.

Escola Superior de Educação de Viseu, 22 de novembro de 2023

A Presidente da Escola

O Presidente da REDESPP





(Maria Cristina Azevedo Gomes)

(José Rodrigues)

(Professora Coordenadora)



Figura 37- Certificado de apresentação oral na REDESPP.



Cabo, C. A., Fernandes, & Parraca, J. A. (31 de maio de 2023). Evaluation of gait complexity in elderly women after twenty four weeks of sensory-motor training. In A. Figueiredo, A. Pereira, A. Azevedo, C. Vasconcelos, F. Mendes, J. L. Esteves, & P. Eira (Eds.), *Livro de Resumos do 4.º Fórum da REDESPP – Desporto, Comunidades e Qualidade de Vida* (p. 31). REDESPP e Escola Superior de Educação – Instituto Politécnico de Viseu. DOI: <https://doi.org/10.34633/978-989-35325-3-9>.



Figura 38- Certificado de apresentação oral na REDESPP.



Cabo, C. A., Hernández-Beltrán, V., Fernandes, Santos, S., Martin Gamonales, J., Espada, M. C., & Parraca, J. A. (15 de noviembre de 2024). Evaluation of gait complexity in elderly women after twenty four weeks of sensory-motor training. In A. Figueiredo, A. Pereira, A. Azevedo, C. Vasconcelos, F. Mendes, J. L. Esteves, & P. Eira (Eds.), *Libro de resúmenes del V Congreso Internacional "HEALTHY-AGE: Envejecimiento Activo, Ejercicio y Salud"* – Desporto, Comunidades e Qualidade de Vida (p. 27). Facultad de Ciencias del Deporte Universidad de Murcia. ISBN-13: 978-84-09-66866-3



SE CERTIFICA
la presentación del trabajo titulado

Assessing the Effects of Sensorimotor Training on Physical Abilities in Older People

Cuya autoría pertenece a Cabo, CA; Hernández-Beltrán, V; Fernandes, O; Santos, S; Gamonales, JM; Espada, MC; Parraca, JA, bajo el formato de Comunicación Oral en el "V Congreso Internacional HEALTHY-AGE: Envejecimiento Activo, Ejercicio y Salud".

Congreso organizado por la Facultad de Ciencias del Deporte de la Universidad de Murcia y la Red HEALTHY-AGE, en colaboración con el Consejo Superior de Deportes (CSD), Universidad de Almería (UAL) e Instituto Universitario de Investigación en Envejecimiento (IUIE), en la localidad de San Javier (Murcia), durante los días 14 y 15 de noviembre de 2024 con 15 horas de formación.

Y, para que así conste, a petición del interesado, se certifica su contribución a los efectos oportunos en San Javier (Murcia).

Fdo. J. Arturo Abalades Valeiras Fdo. Raquel Vaquero Cristóbal
Directores del V Congreso Internacional HEALTHY-AGE: Envejecimiento Activo, Ejercicio y Salud

Firmado Electrónicamente. La información de verificación del documento se encuentra disponible en los márgenes del certificado

Código seguro de verificación: RUXFMmw-piEY9Cal-D6GPIKt0-vUyUdCQg

Copia Electrónica - Página 1 de 1

Este es una copia electrónica legible de un documento administrativo electrónico aprobado por la Universidad de Murcia, según el artículo 27.3 c) de la Ley 39/2015, de 1 de octubre. Su autenticidad puede ser contrastada a través de la siguiente dirección: <https://sede.ucm.es/validador/>

Figura 39- Certificado de apresentação oral no V Congresso Internacional Health-Age: Envejecimiento Activo, Ejercicio y Salud.



Cabo, C. A., Fernandes, O., Santos, S., & Parraca, J. A. (14 de dezembro de 2024). *Sensorimotor Training in Pre-Retired and Retired Populations: Enhancing Physical Function and Quality of Life through a Practical Workshop*. [Apresentação oral]. XVII International Human Motricity Congress “Approaches in Enhancing Physical Activity and Quality of Life in the Older Adults: A Scientific Perspective Course”.



Figura 40- Certificado de apresentação oral no XVII International Human Motricity Congress “Approaches in Enhancing Physical Activity and Quality of Life in the Older Adults: A Scientific Perspective Course”.



Cabo, C. A., Fernandes, & Parraca, J. A. (14 de dezembro de 2024). *Melhorar a saúde, a qualidade de vida e o bem-estar: O papel do exercício físico no processo de envelhecimento*. [Apresentação oral]. III Jornadas Internacionais em Prescrição do Exercício e Promoção da Saúde.



Certificado

Para os devidos efeitos certifica-se que

CAROLINA CABO

apresentou a Comunicação intitulada: **Melhorar a saúde, a qualidade de vida e o bem-estar: o papel do exercício físico em idosos**, da autoria de Carolina Alexandra Cabo, Mário Cunha Espada, José Alberto Parraca, Orlando Fernandes, nas **III JORNADAS INTERNACIONAIS EM PRESCRIÇÃO DO EXERCÍCIO E PROMOÇÃO DA SAÚDE**, realizadas nos dias 13 e 14 de dezembro de 2024, organizadas pelo Curso de Mestrado em Prescrição do Exercício e Promoção da Saúde, na Escola Superior de Educação e Ciências Sociais do Politécnico de Leiria.

O Diretor da ESECS – Instituto Politécnico de Leiria



Campus 1 - Rua Dr. João Soares - Apartado 4045 2411-901 Leiria - Portugal - NIF: 506 971 244

Figura 41- Certificado de apresentação oral nas III Jornadas Internacionais em Prescrição do Exercício e Promoção da Saúde.

Cabo, C. A., Fernandes, O., Espada, M. C., Hernández-Beltrán, V., Santos, S., & Parraca, J. A. (14 de dezembro de 2024). *Impacto do treino sensório motor nas capacidades físicas das pessoas ao longo do envelhecimento*. [Apresentação oral]. III Jornadas Internacionais em Prescrição do Exercício e Promoção da Saúde.



Certificado

Para os devidos efeitos certifica-se que

CAROLINA CABO

apresentou a Comunicação intitulada: **Impacto do treino sensório-motor nas capacidades físicas dos idosos**, da autoria de Carolina Alexandra Cabo, Orlando Fernandes, Mário Cunha Espada, Víctor Hernández-Beltrán, Sara Santos, José Alberto Parraca, nas **III JORNADAS INTERNACIONAIS EM PRESCRIÇÃO DO EXERCÍCIO E PROMOÇÃO DA SAÚDE**, realizadas nos dias 13 e 14 de dezembro de 2024, organizadas pelo Curso de Mestrado em Prescrição do Exercício e Promoção da Saúde, na Escola Superior de Educação e Ciências Sociais do Politécnico de Leiria.

O Diretor da ESECS – Instituto Politécnico de Leiria



Campus 1 - Rua Dr. João Soares - Apartado 4045 2411-901 Leiria - Portugal - NIF: 506 971 244

Figura 42- Certificado de apresentação oral nas III Jornadas Internacionais em Prescrição do Exercício e Promoção da Saúde.



Cabo, C. A., Fernandes, O., Parraca, J. A., Santos, S., & Espada, M. C. (8 de fevereiro de 2025). *Shaping the future of sports physical training programs improve sensorimotor skills in older adults: With relevance to covid-19*. [Apresentação oral]. Sprint Congress.



Figura 43- Certificado de apresentação oral no Sprint Congress.



Cabo, C. A., Parraca, J. A., Santos, S., Espada, M. C., & Fernandes, O. (8 de fevereiro de 2025). *Processo de melhoria do controlo postural em adultos mais velhos após um programa de treino sensório motor de 24 semanas*. [Apresentação oral]. XI Congresso Nacional de Biomecânica.



Figura 44- Certificado de apresentação oral no XI Congresso Nacional de Biomecânica.



Cabo, C. A., Espada, M. C., Santos, S., Fernandes, O., & Parraca, J. A. (28 de fevereiro de 2025). *Evolution of research related to how a sedentary lifestyle influences the aging process*. [Apresentação oral]. III International Congress CIEQV.



Figura 45- Certificado de apresentação oral no III International Congress CIEQV.

Cabo, C. A., Parraca, J. A., Santos, S., Espada, M. C., & Fernandes, O. (3 de abril de 2025). *Process of improving postural control in the older people after a 24-week sensorimotor training program*. [Apresentação oral]. Curso Simpósio sobre Melhoria da Qualidade de Vida do Idoso: Teoria e Prática “NexAge”.



Certificado

Carolina Cabo

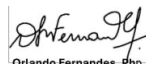
Apresentou a comunicação “**Postural Control before and after a sensorimotor program in elderly people: non-linear methods**”: Carolina Cabo, José A. Parraça, Mário Espada, Sara Santos e Orlando Fernandes

Integrada no painel temático “Exemplos Práticos (Parte II) - Dinâmicas Não Lineares nos Sistemas de Envelhecimento, do Curso Simpósio sobre Melhoria da Qualidade de Vida do Idoso: Teoria e Prática “NexAge”.

Vila Viçosa, Portugal, 3 e 4 de abril de 2025


José Alberto F. M. Parraça, PhD.

Presidente Comissão
Organizadora


Orlando Fernandes, PhD.

Presidente Comissão
Científica



Figura 46- Certificado de apresentação oral no Curso Simpósio sobre Melhoria da Qualidade de Vida do Idoso: Teoria e Prática “NexAge”.



Cabo, C. A., Parraca, J. A., Santos, S., Espada, M. C., & Fernandes, O. (3 de abril de 2025). *Process of improving postural control in the older people after a 24-week sensorimotor training program*. [Apresentação oral]. Curso Simpósio sobre Melhoria da Qualidade de Vida do Idoso: Teoria e Prática “NexAge”.



Certificado

Carolina Cabo

Apresentou a comunicação

"Process of improving postural control in the older people after a 24-week sensorimotor training program", integrada no painel temático "Exemplos Práticos (Parte I) - Dinâmicas Não Lineares nos Sistemas de Envelhecimento, do Curso Simpósio sobre Melhoria da Qualidade de Vida do Idoso: Teoria e Prática "NexAge".

Vila Viçosa, Portugal, 3 e 4 de abril de 2025


José Alberto F. M. Parraça, PhD.

Presidente Comissão
Organizadora


Orlando Fernandes, PhD.

Presidente Comissão
Científica



Figura 47- Certificado de apresentação oral no Curso Simpósio sobre Melhoria da Qualidade de Vida do Idoso: Teoria e Prática “NexAge”.



CIDEES is funded by FCT (UID/04045)



This is to certify that the scientific work entitled **"The Impact of a Sensorimotor Training Program on Physical Fitness in Older Women with Diabetes"** authored by **Carolina A. Cabo, José A. Parraça, Orlando Fernandes, Sara Santos and Mário C. Espada** was presented as an oral presentation at the CIOESD 2025 International Congress*, held at the University of Beira Interior, Covilhã, Portugal, from June 5th to 7th, 2025.

Daniel Marinho
Chair of Scientific Committee CIDEFO 2025

Henrique Neiva
Chair of Organizing Committee CIOFSD 2025



*Certified by the Portuguese Institute of Sport and Youth (IPDJ) with 3.2 ECTS credits for TPTEF/DT and TPTD, and by the Portuguese Scientific-Pedagogical Council of Continuing Education for Teachers (codes 260 and 620) with 16 hours.

Cabo, C. A., Parraca, J. A., Santos, S., Espada, M. C. & Fernandes, O (22 de setembro de 2025). *Effects of a Sensorimotor Training Program on Gait, Balance, and Mobility in Older Adults*. [Apresentação oral]. 6th Comprehensive Health Research Centre Annual Summit.



Figura 49- Certificado de apresentação oral no Comprehensive Health Research Centre Annual Summit.



Cabo, C. A., Parraca, J. A., Santos, S., Espada, M. C. & Fernandes, O. (13,14 e 15 de novembro de 2025). *Impacto de um Programa de Treino Sensório-Motor na Marcha*. [Apresentação oral]. 4º Congresso AGE.COMM.



CERTIFICADO

Certifica-se que

Carolina Alexandra Cabo

participou no **4º Congresso Internacional AGE.COMM**, que decorreu na Escola Superior de Tecnologia de Castelo Branco, nos dias 13, 14 e 15 de novembro de 2025, e apresentou uma comunicação intitulada: **Impacto de um Programa de Treino Sensório-Motor na Marcha, Equilíbrio e Mobilidade em idosos.**

Autores: **Carolina Alexandra Cabo; José Alberto Parraça; Sara Santos; Mário Cunha Espada; Orlando Fernandes.**

We certify that

Carolina Alexandra Cabo

has participated in the **4th International Congress AGE.COMM**, which took place at the Castelo Branco School of Technology on November 13, 14 and 15, 2025, and presented a communication entitled: **Impacto de um Programa de Treino Sensório-Motor na Marcha, Equilíbrio e Mobilidade em idosos.**

Presidente da Comissão Organizadora

Prof. Doutora Lucinda Sofia Almeida Carvalho

Coordenadora da Age.Comm/IPCB

Prof. Doutora Maria João Guardado Moreira



Figura 50- Certificado de apresentação oral no 4º Congresso AGE.COMM.



Posters:

Cabo, Carolina Alexandra; Parraça, José Alberto; Santos, Sara; Fernandes, Orlando. (3 e 4 de novembro de 2022). *The effects of a sensorimotor exercise program for elderly on postural control* [Apresentação Poster]. 3rd Annual Summit of the Comprehensive Health Research Centre (CHRC), Universidade de Évora, Évora, Portugal.



Figura 51- Certificado poster do 3rd CHRC Summit.

Cabo, Carolina Alexandra; Parraça, José Alberto; Fernandes, Orlando. (25 e 26 de maio de 2022). *Analysis of postural control through linear and non-linear methods throughout aging* [Apresentação Poster]. 4th Annual Summit of the Comprehensive Health Research Centre (CHRC), Universidade de Évora, Évora, Portugal.



Figura 52- Certificado poster do 4th CHRC Summit.



Cabo, Carolina Alexandra; Parraça, José Alberto; Fernandes, Orlando. (23 e 24 de setembro de 2024). *Body Composition, Physical Activity and Health-related Quality of Life throughout Aging* [Apresentação Poster]. 5th Annual Summit of the Comprehensive Health Research Centre (CHRC), Universidade de Évora, Évora, Portugal.



Figura 53- Certificado poster do 5th CHRC Summit.

Cabo, Carolina Alexandra; Parraça, José Alberto; Santos, Sara; Espada, Mário C.; Fernandes, Orlando. (23 e 24 de setembro de 2024). *Postural control in retired & pre-retired before and after 12 weeks of sensorimotor training* [Apresentação Poster]. 5th Annual Summit of the Comprehensive Health Research Centre (CHRC), Universidade de Évora, Évora, Portugal.



Figura 54- Certificado poster do 5th CHRC Summit.



Cabo, Carolina Alexandra; Fernandes, Orlando; Santos, Sara; Espada, Mário C.; Parraça, José Alberto. (2 e 3 de abril de 2025). *Effectiveness of Sensorimotor Training on Postural Control in Older Adults: A CoP Variation Study* [Apresentação Poster]. Behaviour Change Conference 2025 Health & Sustainability, Universidade NOVA, Escola Nacional de Saúde Pública, Lisboa, Portugal.



Figura 55- Certificado poster do Behaviour Change Conference 2025 Health & Sustainability.



Cursos:



Certificado

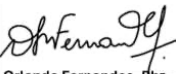
Carolina Cabo

Participou no **Curso Simpósio sobre Melhoria da Qualidade de Vida do Idoso: Teoria e Prática "NexAge"**, com um total de 14h.

Vila Viçosa, Portugal, 3 e 4 de abril de 2025


José Alberto F. M. Parraça, PhD.

Presidente Comissão
Organizadora


Orlando Fernandes, PhD

Presidente Comissão
Científica



Figura 56- Curso simpósio sobre melhoria da qualidade de vida do idoso.



Docência:

Cabo, Carolina A. (11 de setembro de 2023 a 06 de julho de 2024). [Aula de PhD].
Sistemática Actividades Desportivas e Expressivas I, Universidade de Évora, Évora,
Portugal.



Nº 178/2024

DECLARAÇÃO

A pedido da interessada para os devidos efeitos, declara-se que a mestre **Carolina Alexandra Alípio Mourata do Cabo**, exerceu funções como assistente convidada a título gracioso (0%), em regime de contrato de trabalho em funções públicas, no departamento de Desporto e Saúde da Escola de Saúde e Desenvolvimento Humano, desta Universidade, no período 11/09/2023 a 06/07/2024, para lecionar a unidade curricular de Sistemática Atividades Desportivas e Expressivas I.

Universidade de Évora, 9 de julho de 2024.

A Chefe da Divisão de Gestão de Recursos Humanos



Serviços Administrativos – Divisão de Gestão de Recursos Humanos
Largo da Sra. da Natividade | Apartado 94 | 7002-554 Évora | drhsc@uevora.pt | tel. +351 266 760 969

Figura 57- Certificado de docência na Licenciatura em Ciências do Desporto da Universidade de Évora.



Cabo, Carolina A. (18 de setembro de 2024 a 05 de julho de 2025). [Aula de PhD].
Sistemática Atividades Desportivas e Expressivas I e Teoria e Método de Treino
Desportivo Específico, Universidade de Évora, Évora, Portugal.



UNIVERSIDADE
DE ÉVORA

Nº 268/2025

DECLARAÇÃO

A pedido da interessada para os devidos efeitos, declara-se que a mestre **Carolina Alexandra Alípio Mourata do Cabo**, exerceu funções como assistente convidada a título gracioso (0%), em regime de contrato de trabalho em funções públicas, no departamento de Desporto e Saúde da Escola de Saúde e Desenvolvimento Humano, desta Universidade, no período 18/09/2024 a 05/07/2025, para lecionar as unidades curriculares de:

- Sistemática Atividades Desportivas e Expressivas I;
- Teoria e Método de Treino Desportivo Específico.

Universidade de Évora, 15 de setembro de 2025.

A Chefe da Divisão de Gestão de Recursos Humanos



Serviços Administrativos – Divisão de Gestão de Recursos Humanos
Largo da Sra. da Natividade, s/n | 7000-810 Évora | drhsc@uevora.pt | tel. +351 266 760 969

Figura 58- Certificado de docência na Licenciatura em Ciências do Desporto da Universidade de Évora.



Cabo, Carolina A. (16 de novembro de 2024). *Reforma Ativa* [Aula de PhD]. Seminário de Doutoramento em Motricidade Humana, Universidade de Évora, Évora, Portugal.



CERTIFICADO

Certifica-se que a Professora Carolina Cabo colaborou na lecionação de uma aula da Unidade Curricular de Seminários em Motricidade Humana 2 no âmbito do Doutoramento em Motricidade Humana da Universidade de Évora, com o tema "*Reforma Ativa*", que decorreu no dia 16 de novembro de 2024.

Direção do Doutoramento em Motricidade Humana

Assinado por: **Armando Manuel de Mendonça Raimundo**
Num. de Identificação: 08534902
Data: 2024.12.20 10:33:50 +0000



(Professor Doutor Armando Raimundo)

A Docente da Unidade Curricular

A handwritten signature in blue ink, reading "Ana Isabel Rodrigues de Morais".

(Professora Doutora Ana Morais)

Figura 59- Certificado de docência no seminário de Doutoramento em Motricidade Humana da Universidade de Évora.



Cabo, Carolina A. (1 de abril de 2025). *Reforma Ativa* [Aula de bacharelato]. Licenciatura de Ciências Biomédicas, Universidade de Évora, Évora, Portugal.



Declaração

Declara-se para os devidos efeitos que a professora **Carolina Alexandra Alípio Mourata do Cabo**, estudante do Doutoramento em Motricidade Humana na Universidade de Évora (Portugal) com Bolsa FCT, colaborou no ano letivo de 2024/25 com a Escola de Saúde e Desenvolvimento Humano da Universidade de Évora na Unidade Curricular de *Exercício na Saúde e na Doença (DES14338L)* da Licenciatura em Ciências Biomédicas e da Saúde (cód. 747), 3º ano / Par.

Nomeadamente na docencia associada a programas de treino na estimulação do sistema sensório motor em diferentes populações.

Évora, Portugal

O responsável pela Unidade Curricular

José Alberto Parraça, PhD

Figura 60- Certificado de docência na Licenciatura de Ciências Biomédicas da Universidade de Évora.



Cabo, Carolina A. (3 e 4 de abril de 2025). *Curso simpósio sobre melhoria da qualidade de vida do idoso: Teoria e Prática*. NexAge, Vila Viçosa, Portugal.



Certificado

Carolina Cabo

Foi membro do Comité Organizador do **Curso Simpósio sobre
Melhoria da Qualidade de Vida do Idoso: Teoria e Prática**
“NexAge”.

Vila Viçosa, Portugal, 3 e 4 de abril de 2025

José Alberto F. M. Parraça, PhD.

Presidente Comissão
Organizadora

Orlando Fernandes, PhD.

Presidente Comissão
Científica



Figura 61- Certificado de docência no Nexage, Vila Viçosa.



Cabo, Carolina A. (5 de dezembro de 2025). *Apresentação do projeto de doutoramento “Reforma Ativa: Efeitos da aplicação de um programa de treino na estimulação do sistema sensório motor”*. Universidade de Évora, Évora, Portugal.



UNIVERSIDADE DE ÉVORA

Certificado

Certifica-se que a **Professora Carolina Cabo** realizou a apresentação do seu projeto de doutoramento com o tema “**Reforma Ativa: Efeitos da aplicação de um programa de treino na estimulação do sistema sensório motor**”, no âmbito da visita da Comitiva da Universidade de Kairouan (Tunísia). Como resultado desta colaboração, foi elaborado um acordo que visa a cooperação entre as instituições para promoção e cooperação em educação e investigação.

Évora 05 de dezembro de 2024.

José Parraça

Responsável acompanhamento da Comitiva da Universidade de Kairouan,

Figura 62- Certificado de apresentação do projeto de doutoramento: *Reforma Ativa: Efeitos da aplicação de um programa de treino na estimulação do sistema sensório motor*.



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Data de Apresentação	29-01-2025
Data do Pedido	29-01-2025
Modalidade	não aplicável
Fase Atual	REGISTO CONCEDIDO 
Início da Fase	30-04-2025
Fim Previsto	---
Situação de Taxas	NÃO HÁ RENOVACÕES A PAGAMENTO
Início da Situação	13-05-2025
Fim Previsto	31-07-2034
Taxas Periódicas	Pagas 1 Devidas 0
BPI 1ª Publicação	06/02/2025
Data do Despacho	24-04-2025
BPI do Despacho	30/04/2025
Início de Vigência	29-01-2025
Limite de Vigência	---
Titulares	UNIVERSIDADE DE ÉVORA
Mandatário	---
Classificação de Nice	44
Processo em Tribunal?	NÃO
Tribunal	---
Data do Envio	---
Senioridade	---



REFORMA ATIVA

Tipo de Sinal: MISTO

Subtipo de Sinal: Normal

[Anterior](#)

Figura 63- Patente da imagem do projeto Reforma Ativa no Instituto nacional da propriedade industrial.



ANALYSIS OF PHYSICAL TRAINING PROGRAMS IMPROVE SENSORIMOTOR SKILLS IN ELDERLY POST-COVID-19: SYSTEMATIC REVIEW

Carolina A. Cabo ^{1*}; Orlando Fernandes ^{1,2}; María Mendoza-Muñoz ^{1,3} & Jose A. Parraca ^{1,2*}

ABSTRACT

CABO, C.A.; FERNANDES, O.; MENDOZA-MUÑOZ, M.; PARRACA, J.A. Physical training programs improve sensorimotor skills in older adults: Systematic Review with relevance to COVID-19. **Online Perspectives: Biology & Health**, v.14, n.49, p. 29-44, 2024.

An unforeseen public health challenge was brought forth by the COVID-19 outbreak. Globally, steps were taken to slow the virus's transmission in order to prevent overburdening the healthcare system. As a result, engaging in physical activity helps to boost immunity, which is advantageous for both preventing and treating viral infections and chronic illnesses. This systematic review's main goal was to provide information on how exercise programs impact sensorimotor abilities as people age, with a focus on the COVID-19 pandemic. Method: The Preferred Reporting Items for Systematic Reviews and Meta Analysis (PRISMA) guidelines were followed in the conduct of this systematic review. Databases were searched starting in May 2022 for articles that addressed physical training regimens to enhance sensorimotor

skills in older adults over 50. A total of approximately 895 people aged 60 to 85 years were included in this review. Specific findings support the positive benefits of exercise programs during COVID-19 to improve physical, cognitive, social, and psychological health skills in older adults. Improvements in mood, anxiety, and quality of life in relation to health are among the results; however, they present an increase in body fat due to reduced daily physical activity (PA) and changes in daily diet. These results will update healthcare professionals and researchers on how to target a specific group. Therefore, it was imperative to maintain physical activity during COVID-19, using specific voluntary and motivating skills that overcome the obstacles unique to COVID-19 and increase motivation and success in physical exercise.

Keywords: COVID-19; Elderly; Falls; Gait; Postural Control.

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ANÁLISE DOS PROGRAMAS DE TREINAMENTO FÍSICO MELHORAM HABILIDADES SENSORIO-MOTORAS EM IDOSOS PÓS-COVID-19: REVISÃO SISTEMÁTICA

Carolina A. Cabo ^{1*}; Orlando Fernandes ^{1,2}; María Mendoza-Muñoz ^{1,3}; and Jose A. Parraca ^{1,2*}

RESUMO

CABO, C.A.; FERNANDES, O; MENDOZA-MUÑOZ, M.; PARRACA, J.A. Programas de treino físico melhoram as habilidades sensório-motoras em adultos idosos: Revisão Sistemática com relevância à COVID-19. *Perspectivas Online: Biológicas & Saúde*, v.14, n.49, p. 29-44, 2024.

Um desafio imprevisto de saúde pública foi trazido pelo surto de COVID-19. Globalmente, foram tomadas medidas para retardar a transmissão do vírus, a fim de evitar a sobrecarga do sistema de saúde. Como resultado, a prática de atividade física ajuda a aumentar a imunidade, o que é vantajoso tanto para prevenir como para tratar infecções virais e doenças crônicas. O objetivo desta revisão sistemática foi fornecer informações sobre como os programas de exercícios impactam as habilidades sensório-motoras à medida que as pessoas envelhecem, com foco na pandemia de COVID-19. As diretrizes Preferred Reporting Items for Systematic Reviews and Meta Analysis (PRISMA) foram seguidas na condução desta revisão sistemática. As bases de dados foram pesquisadas a partir de maio de 2022 em busca de artigos que abordassem regimes de treinamento físico para melhorar as habilidades sensório-motoras em idosos com mais de 50 anos. Um total de

aproximadamente 895 pessoas com idade entre 60 e 85 anos foram incluídas nesta revisão. Descobertas específicas apoiam os benefícios positivos dos programas de exercício durante a COVID-19 para melhorar as competências de saúde física, cognitiva, social e psicológica em adultos mais velhos. Melhorias no humor, ansiedade e qualidade de vida em relação à saúde estão entre os resultados; entretanto, apresentam aumento da gordura corporal devido à redução da atividade física (AF) diária e às mudanças na dieta diária. Estes resultados irão atualizar os profissionais de saúde e investigadores sobre como atingir um grupo específico. Portanto, era imperativo manter a atividade física durante a COVID-19, utilizando habilidades voluntárias e motivadoras específicas que superassem os obstáculos exclusivos da COVID-19 e aumentassem a motivação e o sucesso no exercício físico.

Palavras-chave: COVID-19; Adultos idosos; Quedas; Marcha; Controle postural.

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1. INTRODUCTION

The paradigm of the twenty-first century is demographic aging, with an increasing proportion of the population becoming older adults. In the Office of Statistics National Institute's central forecast scenario, between 2015 and 2080, there will be 2.8 million more older persons than there were in 2.1 million. (INE, 2017). The primary risk factor for functional decline in older persons is aging, making it crucial for public health to comprehend and prevent impairment in this population (Anton et al., 2020).

The natural aging process is defined as continuous and irreversible and is associated with a decline in the physical and cognitive functions of the human body and an increased risk of falls (Wong et al., 2019). Aging-related loss of strength causes a decline in functional ability, including impaired walking and balance (Rosa, 2012). When walking, older persons typically exhibit a wider gait, more postural sway, and greater gait variability (Ready, 2019).

The sensory system is crucial for motor function, and when it malfunctions or operates poorly, it might affect the functions required to detect the surroundings. This is an aptitude that starts to diminish with age. According to Suzuki et al. (2019), this loss may cause a significant biomechanical alteration in gait. Decreased muscle strength, impaired balance, and reduced mobility are some of the elements that lead to dependency and a loss of autonomy (Bacha et al., 2016). Although sensorimotor training helps older persons balance better and develop their gait more confidently, it might not have a direct impact on this function's biomechanical elements (Rezende et al., 2012).

Health is impacted by the world's population's lack of physical activity (Hernández-Beltrán et al., 2023). It is well known that physical activity has an impact on healthy aging and that chronic diseases have been linked to inactivity (Park et al., 2020). According to recent research on sedentary behavior, a sedentary lifestyle is a unique health risk factor that is associated with successful aging, morbidity, and death in addition to physical inactivity. According to Dhuli et al. (2022) and Donoghue et al. (2016) a sedentary lifestyle is a substantial risk factor for a variety of health problems, including overweight, obesity, and the related metabolic disorders. According to physical activity recommendations published by the World Health Organization (WHO), more than a quarter (27.5%) of the world population does not perform at least 150 minutes of moderate PA or 75 minutes of vigorous PA per week.

Whether at a provincial, national, continental, or global level, some historical events leave an indelible impression on generations. 2020 will surely be remembered for the COVID-19 epidemic and its effects over the world (Ribeiro et al., 2020). During a COVID -19 pandemic, the older adults, who are at excessively high risk for viral infections, are confined to their homes. A viable strategy to reduce daily PA loss and inactivity is home-based physical activity programs (Chaabene et al., 2021). In this context, as new studies have since been published and considering the need to clarify the association between PA and COVID-19, the objective of this systematic review was to investigate the effects of physical training on sensorimotor skills in the aging process during the COVID-19 pandemic.

2. MATERIALS AND METHODS

The Preferred Reporting Items for Systematic Reviews and Meta Analyses (PRISMA) guidelines provided guidance in the development of the systematic review methodology. The



study was registered with PROSPERO (www.crd.york.ac.uk/PROSPERO) with the registration number of CRD4202233326 on 18/05/2022, available from: https://www.crd.york.ac.uk/prosperto/display_record.php?ID=CRD4202233326 and with title of "Physical training programs improve sensorimotor skills in older people: Systematic Review with relevance to COVID-19" (Cabo et al., 2022).

Weaknesses that are identified by the systematic review surface during a narrative review (Tranfield et al., 2003). To address the subject at hand, a systematic literature review entails multiple stages of planning, carrying out, documenting, and sharing information. This stage has been split up into seven sections: Search approach, eligibility requirements, study selection, data extraction, result, data synthesis, and bias risk.

2.1. Search Strategy

The research strategy started in May 2022 through the analysis of documents published in the last 5 years. Bibliographic databases, keywords and search strategy are determined at this stage. The following databases were considered: Science Direct, Scielo, PubMed/Medline and Scopus.

In the search strategy stage, we used the International Registry of Systematic Reviews, PROSPERO, to identify any recent or previous systematic reviews that meet the selection criteria (i.e., investigating the physical training programs improve sensorimotor skills in older people).

The keywords that make up the investigate process remained intentionally broad to ensure that we have many articles associated to gait and motor control. Therefore, the keywords "exercise", "neuromuscular training", "strength training", "resistance training", "strength training" and "balance training" were used. In this way, different combinations of keywords were tested: 'fitness', 'strength', 'flexibility', 'power', 'balance' and 'endurance'. To obtain the most specific sample of documents for analysis, the words "older", "healthy" and "COVID-19" were introduced. The following Boolean operators and terms were used as a search strategy: (exercise OR "neuro-muscular training" OR "strength training") AND (strength OR agility OR power) AND older adults AND healthy AND COVID-19. In addition, we applied two filters to the PubMed database: "randomized control trial" and "5 years".

2.2. Eligibility Criteria

The following inclusion criteria were used to select the articles for this systematic review: (a) research involving older adults; (b) studies assessing sensorimotor resources; (c) complete papers published in journals with peer review and indexing; and (d) publications written in English. The individuals' gender was not a criterion for disqualification. Furthermore, publications that involved individuals with mobility impairments, psychological diseases, neurological disorders, and other addictions, reviews, or duplicate articles were disqualified (Pereira et al., 2023; Sterne et al., 2016).



Table 1: Table with the PICOS strategy

Initials	Description	Analytics
P	Participants	A total of approximately 895 people aged 60 to 85 years.
I	Interventions	Physical training programs and their effects on sensorimotor skills in older people, with relevance to COVID-19.
C	Comparisons	In the analysis of the different studies, we will compare the intervention groups, in order to understand the benefits of each intervention, not comparing with groups that did not receive any physical intervention.
O	Outcomes	Individuals with mobility impairments, psychological diseases, neurological disorders, and other addictions.
S	Study design	The study types to be included in the review were randomized controlled trials, published within the last 5 years.

2.3. Selection of studies

The search results were downloaded into a Zotero database. The main reviewer checked the titles, abstracts, and content of the documents for selection, as well as the full texts of relevant articles to ensure that the eligibility criteria were met. Two reviewers independently verified the titles and abstracts of all studies, retaining those that met the inclusion criteria. Studies included based on title and abstract were then peer-reviewed in full text, again independently by the two reviewers. Any disagreements were resolved by discussing with a third reviewer. Finally, we checked the reference lists of the selected articles for other relevant studies.

The studies allowed the collection of the following data: name of the first author, year of publication, country of origin, research objectives, study population (number of participants, gender, and age), type of study, instruments used, and main results. The initial bibliographic search yielded a total of 94 articles, of which 3 were duplicates. Of the remaining 91 articles, 48 were excluded because the title and abstract were not related to the topic, and 21 because they were reviews. Twenty-two articles were selected for full-text reading, but 11 were excluded because they did not study healthy people, 2 because they did not study older people, and 3 because the sample was not stratified by different age groups. Six studies were ultimately selected. Subsequent documents were read in full to assess attention to a likely increase in falls and reduced quality of life for those affected. In this way, we obtained a final sample of 22 documents

2.4. Data Extraction

Independent reviewers took data on studies out of the Zotero database. The following data extraction was done: 1) Publication information: writers and year of release; 2) Nation: participants' nationality; 3) Goals: research aims; 4) Sample: includes the quantity of

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participants and demographic details (such as gender and age over 50); 5) Intervention: comprises the nature and attributes of the training program; 6) Results: research findings.

2.5. Outcomes

The results of this review will first identify whether physical activity programs are a viable strategy to reduce daily physical activity loss and inactivity. Furthermore, will also examine possible effects of the practice of these same programs in times of a pandemic, covid-19, considering the restrictions applied.

2.6. Data synthesis

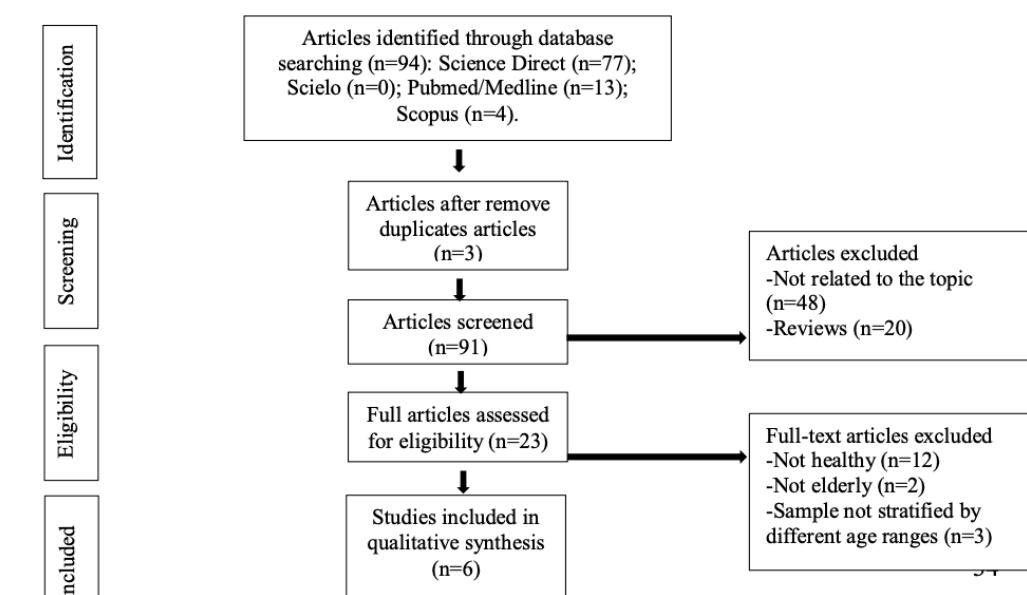
Data extracted from eligible studies were synthesized using a narrative approach. The synthesis aimed describe the existing body of literature, identifying any strengths and gaps in the analysis of different physical training programs in the older adults. Findings are further summarized below in a narrative interpretation focused on the main objective of this review, to synthesize evidence on whether physical activity programs are a viable strategy to reduce daily physical activity loss and inactivity in the older adults.

2.7. Risk of Bias

The methodological quality of randomized control trials was assessed using the Evidence Project assessment for risk of bias (Vitale et al., 2020). Using this tool, you can get an overall score (0–8) by answering yes (1) or no (0) to eight questions from three distinct areas. A higher score reduces the possibility of prejudice.

3. RESULTS

The results are presented in this section. The aim is to analyze the content of the sample in detail and to provide data for the creation of the investigate question. The initial bibliographic search of the files resulted in a total of 94 articles, of which only six studies were selected because they met the inclusion criteria for the systematic review (Figure 1).



Perspectivasonline: biol. & saúde, Campos dos Goytacazes, 49 (14) 29–44 –2024
<https://ojs3.perspectivasonline.com.br/>



Figure 1: Study selection flowchart.**3.1. Study Characteristics**

The main characteristics of the selected studies are summarized in Table 1. All articles were written in English and published in the last five years. About the study sites, one was conducted in Italy (Verghese et al., 2021), one in USA (Corley et al., 2021), one in Scotland (Das & Bhattacharyya, 2021), one in India (Thiel et al., 2021), one in Germany (Dupuy et al., 2021) and one in Canada (Ferrucci et al., 2016). Of the selected articles, four were longitudinal studies and four were cross-sectional studies. In general, the studies examined 895 participants aged between 60 and 90 years.

3.2. Outcomes Measures**3.2.1. Variables**

The study revealed numerous instruments measuring the outcomes of physical activity pro-grams during the COVID-19 pandemic (Table 2). The most frequently reported variables were physical, psychological, sleep quality, and psychosocial health related to COVID-19. Personal factors such as health-related quality of life, spasticity in muscle tone functions, gait pattern, and aerobic capacity in exercise tolerance were also frequently examined by the authors (Table 2).

Other variables under study were muscle strength, balance, gait assessment and body composition. Some authors evaluated the functionality and disability of the older adults, among other tests that analyze several dimensions related to mobility, home life and lifestyle habits in general.

Table 2: Description of selected studies.

Author	Country	Objectives	Sample	Intervention	Results
Corley et al. (2021)	Scotland	The aim of the study is to examine whether during COVID-19 self-reported physical and mental well-being in older adults was associated with the use of home gardens.	n=171; age: 84 ± 0.5 years	Around two months after the initiation of COVID-19, 171 participants were asked to complete an online questionnaire. The survey comprised 145 questions about demographics, knowledge and experience of COVID-19 and physical, psychological, and psychosocial health.	The study results assert that associations can be bidirectional and that home gardens can be a positive health resource during the COVID-19 pandemic.
Das et al. (2021)	India	The aim is to develop volunteer services, counseling, awareness plans and policies to make coping strategies more viable to combat this unforeseen crisis.	n=15; age: >60 years	The intervention of the participants is made through telephone calls, to follow all the rules of social distance.	The primary sources of social networks remain instrumental in reciprocal and emotional support. This support helps to alleviate stress, depression and promotes well-being among participants.
Dupuy et al. (2021)	Canada	The aim is to document the effects of 6 months of isolated home exercise versus home exercise combined with cognitive training on cognitive and physical functions.	n=122; age: > 50 years	All participants will be evaluated in four test sessions, by videoconference and online questionnaires over a period of 7 to 10 days at the beginning of the study, 3 months, and 6 months thereafter. At 12 months, an assessment was performed to explore the potential for maintaining the effects of the intervention.	The primary outcome is cognition. The secondary result is physical functions. Exploratory results include anxiety, mood, and health-related quality of life.
Thiel et al. (2021)	Germany	This paper aims to describe the study objectives, design, methods, assessment types, collection schedules and considerations for examining the data within on facilitators and barriers for PA promotion in nursing homes.	n=200	We designed this participatory intervention study with a mixed methods assessment approach in selected nursing homes. The data collected will be used to develop and evaluate an integrated method to physical activity promotion combining environment-oriented and individual counseling.	This study allowed us to increase our knowledge of how to reach a group characterized by inactivity, multimorbidity and a high prevalence of dementia, through physical exercise in nursing homes.

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Vitale et al. (2020)	Italy	The objective was to evaluate, during home confinement caused by the COVID-19 pandemic, the effect of a home resistance training program on muscle health and physical performance in older adults for 6 months.	n=9 age: $\pm$ 68 years	The intervention involved elders divided into two groups, an experimental group that performed exercises for six months (EXE) and a control group (CON). Participants were assessed for muscle strength, balance, gait assessment, and body composition by dual-energy X-ray absorptiometry and magnetic resonance imaging, at baseline (PRE) and after 6 months (POST).	The home-based resistance training program determined only improvements in lower-limb muscle strength. Home confinement due to COVID-19 reduced the daily PA regimen and changed people's eating patterns, which may partially explain the increase in total body fat.
Verghese et al. (2021)	USA	The objective was to see if there are improvements in walking for people aged 70 and over through a computerized cognitive remediation program.	n=378 age $\Rightarrow$ 70 years	The intervention consists of applying brain games, that is, a computer program of progressive intensity and complexity for 8 weeks.	Participants obtained a change in walking speed at normal pace and in walking conditions during speech.

3.2.2. Instruments

We identified 20 instruments to measure the above variables. The instruments referred to were (a) Hospital Anxiety and Depression Scale subscale (HADS) (Das & Bhattacharyya, 2021), with scores ranging from 0 to 21, and a higher score indicating more signs; (b) a computerized programs, known as brain games (Corley et al., 2021), that has progressive intensity and complexity to improve walking in older adults; (c) dual-energy X-ray absorptiometry and magnetic resonance (Verghese et al., 2021), to assess muscle strength, balance, gait, and body composition; (d) Interview guide (Thiel et al., 2021), allows you to understand their understanding of the pandemic situation, the types of difficulties they face and their concerns about the future; (e) Strength testing on a cycle ergometer (Verghese et al., 2021); (f) The 30-second chair stand test (CST) (Verghese et al., 2021), was conducted to assess lower limb strength; (g) Hand Grip Strength Test (HGS) is a widely used measure because it is easy to apply and economical, and allows you to assess the maximum isometric force that a hand can press; (h) Montreal Cognitive Assessment (MoCA) score (Ferrucci et al., 2016), to assess cognition as well as executive functions, processing speed and episodic memory; (i) one-leg stance test (Ferrucci et al., 2016), to assess physical functions and balance; (j) timed up and go (TUG) (Ferrucci et al., 2016), to assess gait performance and mobility; (k) 5 times standing up (Ferrucci et al., 2016), to assess leg muscle strength; (l) Matthews questionnaire (Ferrucci et al., 2016), to assess cardiorespiratory fitness; (m) geriatric depression scale 30 items (Ferrucci et al., 2016); (n) perceived stress scale (Ferrucci et al., 2016); (o) State-Trait Anxiety Inventory 36 items (Ferrucci et al., 2016); (p) Perseverative Thinking Questionnaire (Ferrucci et al., 2016); (q) Connor - Davidson Resilience Scale 10 (Ferrucci et al., 2016); (r) GAIT Rite® system (Dupuy et al., 2021), assesses PA patterns and interactions and PA -related nursing home infrastructure testing; (s) ACTi Graph wGT3x- BT, Pensacola, F are accelerometers that allow us to assess individual resident physical activity behaviors (Dupuy et al., 2021); (t) Physical exercise Scale for the Older adult (PACE) (Dupuy et al., 2021), interview-administered questionnaires.

The interventions analyzed with the presented assessment tools were questionnaires (Ferrucci et al., 2016), interviews (Thiel et al., 2021), followed by training programs (Verghese et al., 2021), physical tests (Dupuy et al., 2021; Ferrucci et al., 2016; Verghese et al., 2021), and scales (Das & Bhattacharyya, 2021; Dupuy et al., 2021; Ferrucci et al., 2016). Many studies have investigated gait training (Corley et al., 2021; Dupuy et al., 2021; Ferrucci et al., 2016; Verghese et al., 2021). Two studies focused on evaluating the effectiveness of home-based programs, one involving an exercise program (Verghese et al., 2021), and the other examined the use of home gardens in relation to self-reported physical and mental well-being in older adults (Das & Bhattacharyya, 2021). Some authors have examined areas such as social therapy (Corley et al., 2021; Das & Bhattacharyya, 2021; Dupuy et al., 2021; Ferrucci et al., 2016; Thiel

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et al., 2021; Verghese et al., 2021), cognitive training (Ferrucci et al., 2016), computerized programs (Corley et al., 2021), and alternative therapies (Das & Bhattacharyya, 2021). Finally, (Vitale et al., 2020) examined dual-energy X-ray absorptiometry and magnetic resonance imaging.

Regarding physical training interventions, in the study by Corley et al. (2021), a questionnaire consisting of 145 questions on demographics, knowledge and experience of COVID-19 and physical, psychological, and psychosocial health was applied. The questionnaire took about 30 to 45 minutes to complete. Participants were also asked to retrospectively assess how they felt before COVID-19, to assess the change in health perception after the pandemic. In the study by Das and Bhattacharyya (2021), the intervention consisted of telephone interviews, between April 7, 2020, and April 14, 2020, lasting approximately 30 minutes. In the study by Dupuy et al. (2021), the study design included six months of intervention. All participants were evaluated at baseline, 3 months, and 6 months. At each point in time, four test sessions were conducted remotely using video conferencing supervision and online questionnaires over a period of 7 to 10 days.

At twelve months, a follow-up assessment was performed to explore the potential maintenance of intervention effects. Participants were encouraged to perform a physical exercise at home using video capsules available on Facebook or YouTube. The videos lasted approximately 15 minutes and included a 3–5-minute warm-up, followed by a 10-minute workout, and finally a 2-minute cool-down period. The exercises did not require any equipment and included aerobic, muscle strengthening, flexibility and/or balance exercises. Participants were asked to perform exercise sessions at least 5 times a week. Participants rated their exercise intensity using the modified Borg Perception of Effort (RPE) scale. Participants were also encouraged to undertake cognitive training lasting at least three sessions per week.

In the study by Thiel et al. (2021), questionnaires were applied to obtain information on self-reported physical activity, as well as the individual's activity prerequisites regarding reasons for participating in exercise, exercise-specific self-efficacy, and activity restriction for fear of falling. To assess individual residents' physical activity behavior, we used accelerometer-based devices. We recorded the residents' total physical activity in everyday life over seven consecutive days. The primary outcome measure was steps per day recorded by ankle-mounted accelerometers. For additional secondary analyses, minutes per day with sedentary behavior.

In the study by Vitale et al. (2020), the intervention involved elderly people divided into two groups, an experimental group that performed exercises (EXE) and a control group (CON). Participants were assessed for muscle strength, balance, gait assessment, and body composition by dual-energy X-ray absorptiometry and magnetic resonance imaging, at baseline (PRE) and after 6 months (POST).

The EXE subjects were instructed and familiarized with the execution of the training protocol. The first session of the resistance training program was performed at home under the supervision of the researchers. Therefore, EXE performed four at-home resistance training sessions per week for 24 weeks. Each session consisted of 5 min of warm-up, 45 min of resistance exercise intervention and 5 min of cool-down. In detail, the warm-up included light, dynamic movements, and exercises. The core part of the training included resistance exercises for both the lower and upper body muscles. The exercises were performed in 3–4 sets, 12–15 repetitions and with a rest period of 60 to 90 seconds. The cool-down phase consisted of light

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static stretching exercises, lasting between 25 and 40 seconds.

In the study by Verghese et al. (2021), the intervention consists of the application of brain games, that is, a computer program of progressive intensity and complexity for 8 weeks. Participants were divided into groups of up to eight participants and performed training sessions three days a week for 8 weeks. Each session lasted approximately 50 minutes and was divided into three blocks, the first two blocks included training tasks in the cognitive domain and an assessment task that monitored performance and increased the difficulty of the task in future sessions, and the third block specifically targeted the executive functions training and related processes. Participants in the control group also trained for about 150 minutes every week for 8 weeks. Each session consisted of interactive computer-based health education classes and a low-complexity, non-progressive program.

3.3. Risk of Bias

As indicated in Table 3, item 1, the mean risk of bias analysis score using the Evidence Project tool was 5.88 out of 8 with a standard deviation of 1.31. The scores ranged from 5 to 7. Merely two individuals made it to item 2. Item 3 was not met by two investigations. However, the results of the assessment of the individuals' representativeness are more inconsistent. All studies satisfied item 4, which evaluated the "random assignment of participants to the intervention." Item 5 ("random selection of participants for evaluation") was not met by any publication, nevertheless. Ultimately, every study satisfied items 6, 7, and 8.

Table 3: Risk of bias analysis with the Evidence Project tool.

	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7	Item 8	
Study	Study Design		Participant Representativeness		Equivalence of Comparison Groups		Total Score		
Corley et al. (2021)	Yes	No	No	Yes	No	Yes	Yes	Yes	5/8
Das et al. (2021)	Yes	No	No	Yes	No	Yes	Yes	Yes	5/8
Dupuy et al. (2021)	Yes	No	Yes	Yes	No	Yes	Yes	Yes	6/8
Thiel et al. (2021)	Yes	No	Yes	Yes	No	Yes	Yes	Yes	5/8
Verghese et al. (2021)	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	7/8
Vitale et al. (2020)	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	7/8

4. DISCUSSION

This review systematically examined physical exercise programs aimed at improving sensorimotor skills in older adults, focusing on how aging and COVID-19 affect variables like sleep, stress, anxiety, strength, gait, and balance. These programs not only enhance sensorimotor abilities but also help older adults stay active, improving their quality of life, health, and well-being. However, only six studies evaluated physical training programs in older adults after the onset of the COVID-19 pandemic.

Twenty distinct measures were discovered in the review, none of which were used repeatedly in various studies to assess quality of life, physical, cognitive, mental, or social capacities. To evaluate strength and balance, well-known instruments like the cycle ergometer, the 30-second chair stand test (CST), the Hand Grip Strength Test (HGS), and the one-leg



standing test were frequently employed. Studies have indicated that exercising with a cycle ergometer can help avoid cardiovascular illnesses and improve metabolic responses in older persons. It also improves cognitive function, muscular strength, and functional status. Based on this information, medical professionals can offer cycle ergometer training with confidence to older adults, enabling them to preserve their independence in everyday activities and reap the health benefits (Bouaziz et al., 2015; Carballeira et al., 2021). A popular sit-to-stand evaluation in clinical and laboratory settings is the 30-second chair-stand test (30s-CST). This test has a moderately high test-retest reliability and is easy to score (Rikli & Jones, 1999; Roongbenjawan & Siriphorn, 2020).

One popular physical fitness test that is especially useful for community-based evaluations is handgrip strength (HGS). Physical restrictions have been associated with a reduction in HGS in persons 60 years of age and older. A correlation between low HGS and higher mortality was found in a pooled examination of 6,426 older persons who lived in the community. Because of this, HGS is a clinically meaningful measure of older persons' health state. Because of this, the HGS test can be used independently to effectively evaluate physical fitness levels in older persons who live in the community, offering insightful, unbiased data. (Pan et al., 2022). The one-leg standing test is a helpful indicator of frailty in older people who live in communities. Enhancing balance, resistance, strength, and endurance through interventions has the potential to improve one-leg standing times (Michikawa et al., 2009).

Furthermore, to monitor muscle activity, dual-energy X-ray absorptiometry and magnetic resonance imaging were employed in our investigation. Dual-energy X-ray absorptiometry (DXA) is a relatively new technique in an aging culture, yet it is regarded as the gold standard for diagnosing sarcopenia in terms of limb muscle mass measurement. Furthermore, in terms of measuring limb muscle mass, bioelectrical impedance analysis (BIA), which has been widely utilized in clinical settings recently and assesses body composition, shows a strong association with DXA (Fujimoto et al., 2019).

The timed up and go (TUG) test, which is particularly user-friendly, was the sole one used by the authors to evaluate dynamic balancing. According to guidelines released by the American Geriatric Society and the British Geriatric Society, the TUG is advised as a regular screening test for falls. In order to reduce falls in the elderly population, the National Institute of Clinical Evidence (NICE) guidelines also support the use of the TUG for gait and balance assessments (Barry et al., 2014).

Cognitive capacities were measured using the Montreal Cognitive Assessment (MoCA) and an automated algorithm. The MoCA has a sensitivity of 90% and 100% in identifying MCI and Alzheimer's disease (AD), respectively, and is intended to aid in the detection of mild cognitive impairment (MCI). The MoCA is a screening tool that can also be used to test cognitive function across various domains, including attention and visuospatial ability, and so serve as an indicator of total global cognitive ability (Cardoso et al., 2021). Accelerometers, guided interviews, and the Physical Exercise Scale for the Older Adult (PACE) were used to measure physical activity. Numerous self-report questionnaires have been employed to measure older individuals' daily physical activity levels. The Physical Activity Scale for the Elderly (PASE), which is used extensively, is intended to evaluate the quantity, frequency, intensity, and length of physical activity that people 65 years of age and older complete over the course of seven days. This instrument offers a low-cost approach to tracking physical activity and health, making it appropriate and valuable for field research (Logan et al., 2013).



Other physical abilities, such as muscle strength, gait, and cardiorespiratory fitness, were also well assessed in the selected studies. Dual-energy X-ray absorptiometry and magnetic resonance were used to assess muscle strength. For gait analysis, the authors suggested dual-energy X-ray absorptiometry and magnetic resonance imaging, timed up then go (TUG), GAIT Rite® system and accelerometry. Gait was the most assessed physical ability in the different studies (Corley et al., 2021; Das & Bhattacharyya, 2021; Ferrucci et al., 2016) analyzed. For cardiorespiratory fitness the authors proposed the Matthews' questionnaire. Can we stop the mobility failure that accompanies the older adults? And all the physical and biological changes associated with aging? These are the questions we attempt to answer in this article. In the last decade, new information has highlighted the complexity of walking and shown that it affects several systems can have a dramatic impact on mobility and function in older people. In addition, new findings directly link functional capacity to various biological and behavioral factors (Ferrucci et al., 2016).

The social and psychological abilities such as anxiety, depression, and stress were examined in the selected studies. To measure anxiety, the authors used the Hospital Anxiety and Depression Scale (HADS) and the State-Trait Anxiety Inventory. To measure depression, the geriatric de-pression scale was used. To measure stress, the Perceived Stress Scale was used. To assess the social component, the authors used the GAIT Rite® system and guided interviews. Sousa et al., (2017) indicate that among older Portuguese persons, anxiety prevalence is 9.6% and depression prevalence is 11.8%. Seniors who suffer from anxiety or depression are more likely to self-report having a lower quality of life and a higher degree of physical infirmity. Anxiety and despair are prevalent among older Portuguese individuals. These prevalence rates indicate that there is a critical need to prevent mental disease in the senior population. The well-being of the elderly can be effectively increased by a well-thought-out preventative plan.

Elderly people who engage in physical activity (PA) benefit from many different sources, such as the prevention of physical deterioration and improvements in psychological health and social perception. By assisting people in developing and reinforcing the movement patterns necessary for daily activities, physical activity enhances quality of life. A higher sense of social and personal well-being results from this. It is possible to lower the risk of disease, cardiovascular problems, and the detrimental effects of a sedentary lifestyle in older persons by maintaining excellent functional ability. Programs or tactics that promote regular PA should be created in order to support this, with a recommended frequency of at least three days per week (Cabo et al., 2024).

According to the results of our work, the studies with the highest score (7/8) use tests and the studies with the lowest score (5/8) in the analysis of risk of bias use questionnaires. One hundred percent of the articles analyzed (6 articles) scored five or more of the eight points, so we can consider them to be good quality clinical trials and protocol studies and therefore good measures of physical activity intervention programs for older people. The good quality of the studies suggests that the way the instruments were used was probably appropriate to achieve the results; however, the analysis regarding the appropriateness of the instruments used should be more precise in future studies. This work includes many articles that may be of importance considering that the COVID-19 pandemic is recent, and we all need studies that are fundamental to understanding the relationship with exercise.

The review highlighted that while the studies generally scored well in quality, there were limitations. Only English-language articles indexed in specific databases were included, and



the studies varied in the equipment used, making data comparison difficult. Additionally, the cross-sectional nature of most studies introduced a moderate risk of bias. Despite these challenges, the review provides valuable insights into the relationship between physical activity and COVID-19 in older adults, emphasizing the importance of continued research in this area. The pandemic has underscored the need for self-care and the protection of vulnerable elderly populations, highlighting the critical role of physical activity in maintaining health and well-being.

Finally, the review acknowledges the need for further research to determine which assessment tools are most reliable and sensitive for older adults, particularly in the context of COVID-19. Despite the study's limitations, it offers significant data on the relationship between physical activity and aging, particularly in the wake of the pandemic.

5. CONCLUSIONS

Physical activity programs have garnered the attention of physiology researchers due to their impact on aging-related changes and the effects of the COVID-19 pandemic. Physical, social, and psychological abilities are significantly influenced by aging, which in turn affects daily functionality and quality of life. Engaging in physical exercises, social therapies, cognitive training, computer programs, and alternative therapies can improve sensorimotor abilities in older adults. This relationship can aid healthcare professionals and study participants in enhancing their sensorimotor skills, thereby preventing a decline in functionality and quality of life. Various instruments have been used in studies to assess sensorimotor abilities in older adults. Although there is some disagreement on the best tools to evaluate these variables, this article provides an overview of the instruments employed by researchers in the field of physiology

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Evolution of research related to how a sedentary lifestyle influences the aging process: a bibliometric review

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Abstract

Aim The world's population suffers greatly from sedentary lifestyles, which are becoming more common as a result of factors such as a lack of easily accessible places to exercise, a rise in sedentary work practices such as office work, and the pervasive use of television and video devices. Consequently, associated health problems are escalating. The primary goal of this study was to examine the state and features of current trends in international publications regarding the effects of sedentary behavior on the elderly.

Subject and methods A bibliometric analysis spanning the years 1994–2022, identifying a total of 311 documents, was carried out using the Web of Science Core Collection.

Results The findings showed an exponential increase of 79% from 1997 to the present. The most productive journal categories, authors, and countries were Geriatrics & Gerontology and Public, Environmental & Occupational Health; authors S. Amagasa, N. Fukushima, S. Inoue, and H. Kikuchi; and the United States, respectively. Considerable variation was found in the keywords; “aging” and “sedentary lifestyle” were the most frequent terms, with 97 and 37 instances, respectively.

Conclusion Maximum investment in programs promoting physical activity is necessary to improve quality of life as people age. Participants' mental health will improve as a result of these programs, and their risk of illness will decrease.

Keywords Aging · Health · Life quality · Physical activity · Sedentary lifestyle

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Introduction

Aging is defined as a natural physiological process that progressively follows the life cycle (Anton et al. 2020). In addition to complications in the psychosocial sphere, physical losses occur, leading to slower thinking, depression, functional incapacity, loss of resistance, inactivity, and physical degeneration (Murman 2015; Wong et al. 2019).

Functional changes inherent to the aging process, such as decreased mobility and muscle strength, can lead to imbalance and, consequently, increase the risk of falling in elderly individuals (Giovannini et al. 2022; Rodrigues et al. 2022; Steadman et al. 2003). Aging is often associated with a decline in quality of life due to factors such as limited mobility and autonomy, and the appearance of various chronic diseases (Rasche et al. 2018).

Aging and metabolism are linked, and many age-related changes in body composition, including increased central adiposity and sarcopenia, are related to fundamental aging processes (Palmer and Jensen 2022). Sarcopenia is one of the main issues associated with the process of aging. Characterized by muscle mass loss, it is triggered by several conditions, including sedentary habits and negative net protein balance. According to the World Health Organization, a 38% increase in sarcopenia is expected in older individuals by 2025 (Rogeri et al. 2021).

The lack of physical activity among the world's population has an impact on global health (Hernández-Beltrán et al. 2023a, b). It is common knowledge that physical activity promotes healthy aging and that a lack of activity is linked to chronic diseases (Park et al. 2020). Recent studies on sedentary behavior suggest that, apart from physical inactivity, a sedentary lifestyle is a distinct health risk factor that is linked to aging, morbidity, and death. A sedentary lifestyle is a significant risk factor for a number of health issues, including overweight, obesity, and the associated metabolic disorders (Dhuli et al. 2022; O'Donoghue et al. 2016).

Sedentary lifestyles have a significant negative impact on the general health of the world's population, and they are becoming more prevalent due to factors such as lack of accessible space for physical activity, an increase in sedentary occupational behaviors like office work, and the widespread use of television and video devices. As a result, related health issues are becoming worse (Park et al. 2020).

Any waking behavior, such as sitting or bending, that involves an energy expenditure of 1.5 metabolic equivalents of task (MET) or less is considered sedentary behavior (Tremblay et al. 2010). Thus, sedentary behavior is defined as those activities which have low expenditure requirements (Tremblay et al. 2017); watching television,

playing video games, using a computer, sitting at school or work, and sitting are a few instances of sedentary behavior. One MET is the energy expenditure for a person at rest (Ainsworth et al. 2011). By this proposed measure, sedentary behavior is characterized as being between 1.0 and 1.5 METs, light activity is 1.6–2.9 METs, moderate activity is 3–5.9 METs, and strenuous activity is 6 METs or greater (Newton et al. 2013).

Sedentary conduct is a health concern and increases the likelihood of developing a number of diseases. The majority of physical activity instruction provided by health professionals places a greater emphasis on increasing physical activity levels than on decreasing sedentary behavior (Katzmarzyk 2010). Linked to this, cardiovascular disorders, certain forms of cancer, and type 2 diabetes mellitus are also diseases which appear due to sedentary behavior (Thyfault and Booth 2011), such as sitting time, screen time, and leisure time spent sitting during the day (Patterson et al. 2018). Lifestyles characterized by inactivity are linked to metabolic dysfunction, including increased plasma triglycerides, low levels of high-density lipoprotein (HDL), and impaired insulin sensitivity (Maciel et al. 2022). Additionally, they harm the health of the vascular system (Onambele-Pearson et al. 2019; Park et al. 2020).

As a result, both sedentary behavior and physical activity should be considered when assessing the health of the elderly. By reducing sedentary behavior and increasing physical activity, it is possible to improve public health (Garcia Meneguci et al. 2021; Niklasson et al. 2023). Considering the importance of physical activity in the aging process, the main purpose of this study was to analyze the status and characteristics of current trends in global publications regarding the influence of sedentary behavior in the elderly.

Materials and methods

Design

Following the Montero and León (2007) proposal, this study adopts an ex post facto retrospective analytical approach. It presents a bibliometric analysis of the development of documents related to the significance of physical activity during the aging process, and how sedentary behaviors influence the quality of life among the elderly.

Data source

The document search was completed in October 2023. For this purpose, documents included in the Web of Science (WoS) Core Collection were selected. WoS is the most popular database for developing this type of review because



it allows one to extract the relevant information from each study (Gutiérrez-Hellín et al. 2023; Hernández-Beltrán et al. 2023a, b). This database houses a great number of documents; it is estimated that 95–99% of the documents indexed in this database can also be found in the Scopus database (Singh et al. 2021). It also allows the documents to be classified according to the main topic, as well as their influence in the scientific field.

Search strategy

The keywords “sedentary lifestyle” and “aging” were used to search the documents, using the filter “topic” in order to obtain those documents which contained these terms in the title, keywords, or abstract. First, a search of the documents was carried out by V.H.-B. and J.M.G. to identify and select the most relevant documents. Next, M.C. and C.A.C. reviewed the process and the studies included, with the aim of including the documents most relevant to the topic and deleting those that were not relevant. This process was carried out by reading the title and abstract. Finally, a total of 311 documents published up to 31 December 2022 were selected and included in the study (Fig. 1).

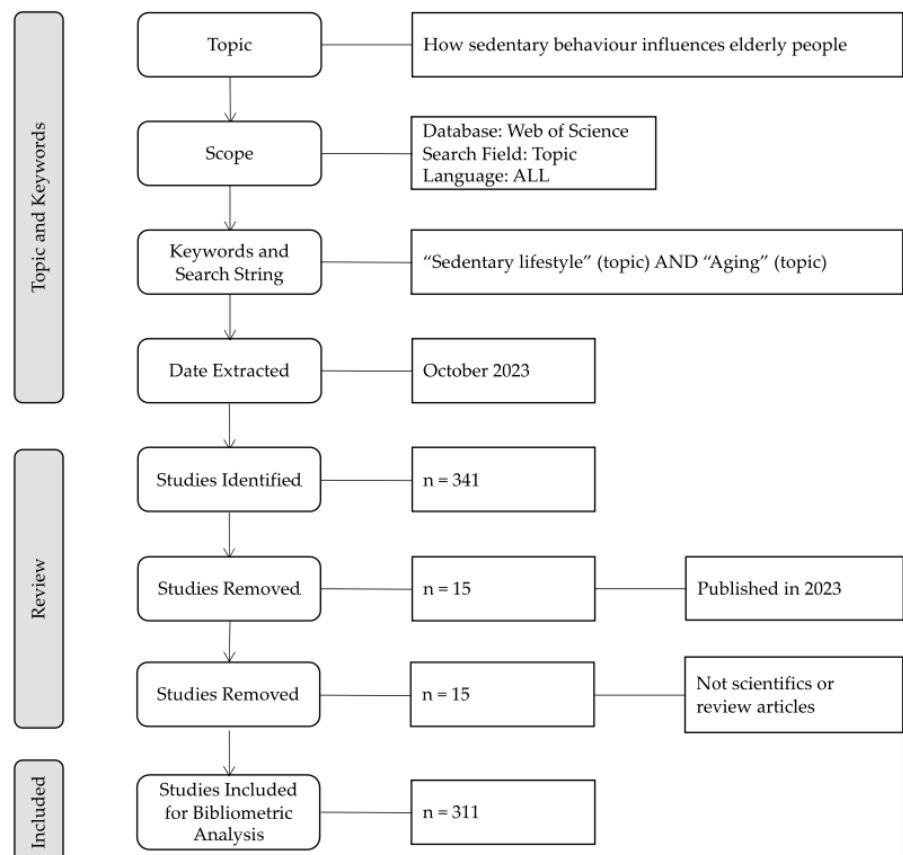
Statistical analysis

After identifying and selecting the documents related to the topic under study, a bibliometric analysis was carried out under the following bibliometric laws:

- De Solla Price’s law: Using the R^2 coefficient, it is possible to determine the exponential growth in the documents (Dobrov et al. 1979; Price 1976) and the interest of the scientific community according to a specific theme.
- Lotka’s law: This law was used to determine the most significant authors and co-authors (Coile 1977). Through the h-index, the authors with the highest number of citations and documents are identified (Crespo and Simoes 2019).
- Zipf’s law: This law was used to select the keywords most frequently used by the authors (Piantadosi 2014).

The data were analyzed using Excel® (2006 version; Microsoft Corporation, Redmond, WA, USA) and VOSviewer (v.1.6.19 for macOS, Centre for Science and Technology Studies, Leiden, Netherlands). VOSviewer software was used to develop the analysis and visualization of the figures.

Fig. 1 Flow chart of the process



Results

Annual publication trends and citations

Figure 2 shows the number of documents published in each year and the total number of citations per year according to the documents published. The results show that the first document was published in 1994, but then no documents were published until 1997, which is the first of a continuous series of years with at least one document published. With regard to the number of citations, 2009 is the year with the largest number of citations ($n = 1601$), whereas the largest number of documents is found in 2021 ($n = 36$). Considering 1997 as the first year, the sample shows exponential growth of 79.4% until the present.

To determine the citations of the documents, first, the h-index of the sample of citations per document was identified ($n = 58$). This means that there are at least 58 documents with a minimum of 58 citations of their publication through 31 December 2022. The analysis shows that there are six documents with more than 300 citations. The average number of citations among the 58 documents in first place was 101 (Fig. 3).

Table 1 shows the top 10 most frequently cited documents and the average number of citations per year. This information enables readers to determine which documents are most relevant and have the greatest interest for the scientific community. Analysis of the results revealed that the article by Chodzko-Zajko et al. (2009) had the highest number of citations ($n = 1301$) and the highest average number of citations per year ($n = 92.93$) despite being published in 2009, so it is considered a recent study. With regard to study type, 50% of the studies were classified

as a review, because they carried out a systematic review of the literature according to different types of variables, such as position stand, reserve capacity of the neuromuscular system, or the overconsumption of food. In the same way, Fig. 4 shows the interactions between the most cited authors; a total of 58 authors were included in the analysis. The size of the node corresponds to the number of citations per document.

WoS categories

Considering the WoS categories, the results show that Geriatrics & Gerontology is the category with the highest number of documents ($n = 50$), representing 16% of the total sample. This is followed by Public, Environmental & Occupational Health, with 33 documents, and Sport Sciences with a total of 31 documents. These three categories comprise ~36% of the total documents (Table 2).

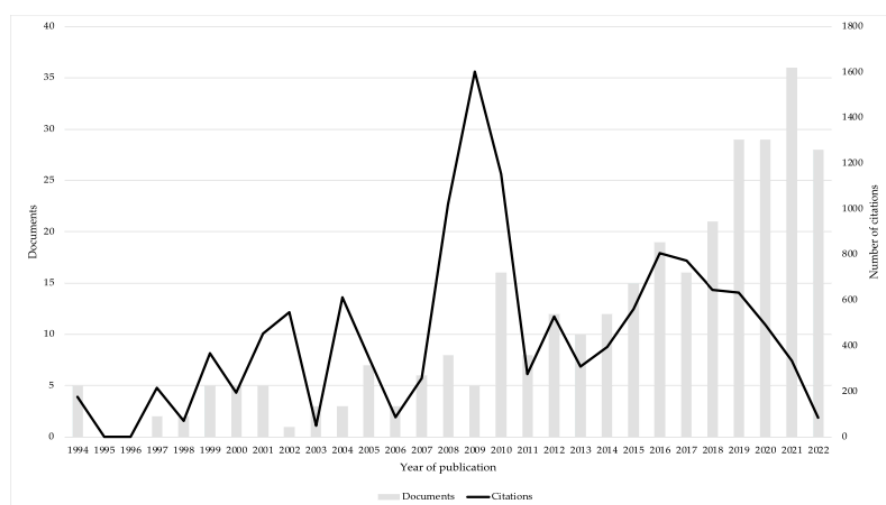
Scientific journals

Table 3 shows the journals with the highest number of documents published related to the selected topic. *PLOS One* had the highest number of documents ($n = 7$), whereas *Medicine & Science in Sports & Exercise* had the highest impact factor (5.4), despite having published only five documents.

Authors and co-authors of the documents

From the 311 documents identified, a total of 1509 authors were selected, with 75 authors having at least two documents, and four authors having at least four documents. The authors with the highest number of published documents related to the selected topic ($n = 4$) were S. Amagasa, N.

Fig. 2 Number of documents and citations per year



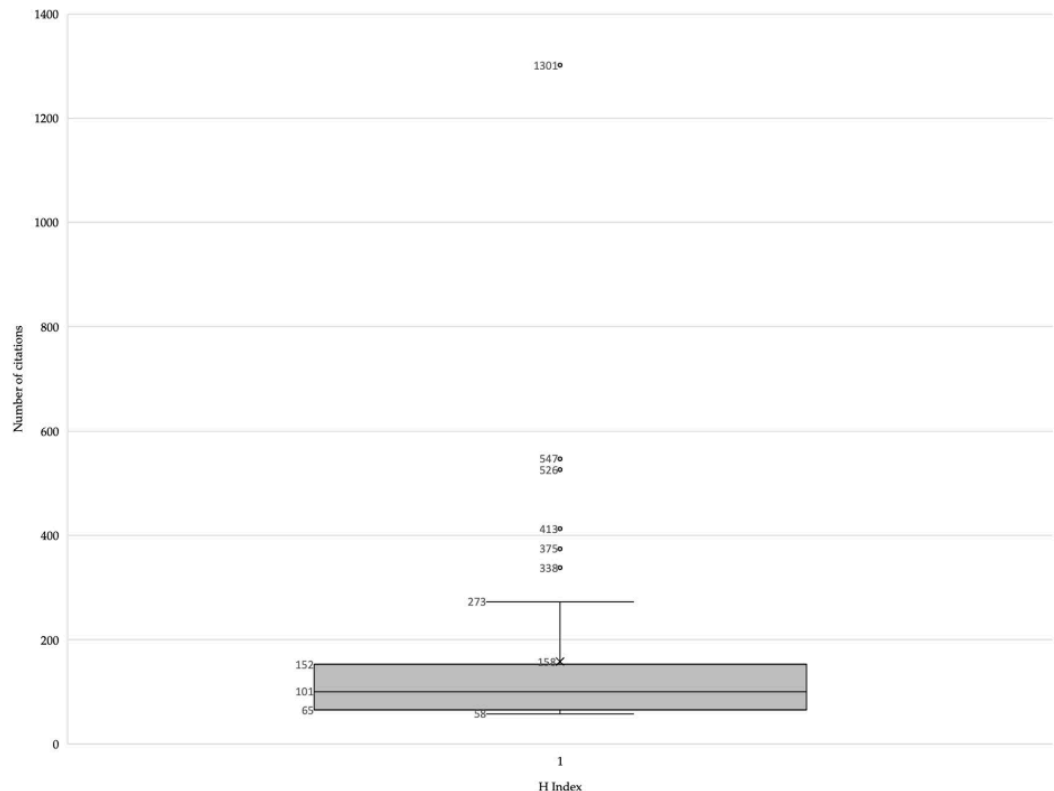


Fig. 3 H-index of the sample of the number of citations

Fukushima, S. Inoue, and H. Kikuchi. To examine the interaction between the authors, they were all included in the co-authorship analysis, as shown in Fig. 5. The size of the node corresponds to the number of documents published, the number of lines in each node to the link strength between authors.

Considering the timing of publication, the results revealed different groups of authors during different periods, with the purple cluster indicating the oldest and the yellow cluster indicating the most recent group, with a recent average of publications. The size of the node corresponds to the number of citations received. Considering the size of the node, the oldest group presents the largest number of citations (Fig. 6).

Publications according to organizations

A total of 630 organizations were detected as collaborators for carrying out the studies. Analysis of the sample showed that only five organizations had at least five documents published. The two most productive, Johns Hopkins University and the University of Lisbon, had eight and six documents published, respectively. With regard to

citations, Johns Hopkins University presented the highest number ($n = 876$) as shown in Fig. 7, where the size of the node corresponds to the number of documents published for each organization.

Publications by country

A total of 58 countries were identified as collaborators for developing the 311 documents included in the analysis. However, only three had at least 21 documents, and 13 presented at least 10 documents. To obtain reliable results, all the countries were included in the analysis. The USA had the highest number of documents ($n = 100$) and citations ($n = 5749$), as shown in Fig. 8, where the size of the node corresponds to the number of documents published for each country.

Authors' keywords

Considering the occurrence of the key terms used by the authors in each study, 807 keywords were detected, with 34 occurring more than five times. For analyzing and



Table 1 Ten most frequently cited scientific and review articles

Author(s)	Article title	Abstract	Source title	Document type	Publication year	Total no. of citations	Average no. of citations/year
Chodzko-Zajko et al. (2009)	Exercise and physical activity for older adults	This position stand aimed to provide an overview of issues critical to understanding the importance of exercise and physical activity in older adult populations	<i>Medicine & Science in Sports & Exercise</i>	Review	2009	1301	92.93
Vandervoort (2002)	Aging of the human neuromuscular system	Loss of cells from the motor system occurs during the normal aging process, leading to a reduction in the complement of motor neurons and muscle fibers. The latter age-related decrease in muscle mass has been termed sarcopenia and is often combined with the detrimental effects of a sedentary lifestyle in older adults, leading to a significant reduction in reserve capacity of the neuromuscular system	<i>Muscle & Nerve</i>	Review	2002	547	26.05
Mattson et al. (2017)	Impact of intermittent fasting on health and disease processes	Humans in modern societies typically consume food at least three times daily, while laboratory animals are fed ad libitum. Overconsumption of food with such eating patterns often leads to metabolic morbidities (insulin resistance, excessive accumulation of visceral fat, etc.), particularly when associated with a sedentary lifestyle	<i>Ageing Research Reviews</i>	Review	2017	526	87.67



Table 1 (continued)

Author(s)	Article title	Abstract	Source title	Document type	Publication year	Total no. of citations	Average no. of citations/year
Cherkas et al. (2008)	The association between physical activity in leisure time and leukocyte telomere length	Physical inactivity is an important risk factor for many aging-related diseases. Leukocyte telomere dynamics (telomere length and age-dependent attrition rate) are ostensibly a biological indicator of human aging. A sedentary lifestyle (in addition to smoking, high body mass index, and low socioeconomic status) has an effect on leukocyte telomere length and may accelerate the aging process. This provides a powerful message that could be used by clinicians to promote the potential anti-aging effects of regular exercise	<i>Archives of Internal Medicine</i>	Article	2008	413	27.53

Table 1 (continued)

Author(s)	Article title	Abstract	Source title	Document type	Publication year	Total no. of citations	Average no. of citations/year
Arbab-Zadeh et al. (2004)	Effect of aging and physical activity on left ventricular compliance	Left ventricular compliance appears to decrease with aging, which may contribute to the high incidence of heart failure in the elderly. However, whether this change is an inevitable consequence of senescence or rather secondary to reduced physical activity is unknown. A sedentary lifestyle during healthy aging is associated with decreased left ventricular compliance, leading to diminished diastolic performance. Prolonged, sustained endurance training preserves ventricular compliance with aging and may help to prevent heart failure in the elderly	<i>Circulation</i>	Article	2004	381	20.05



Table 1 (continued)

Author(s)	Article title	Abstract	Source title	Document type	Publication year	Total no. of citations	Average no. of citations/year
Palazzo et al. (2016)	Risk factors and burden of osteoarthritis	Osteoarthritis (OA) is one of the most common joint disorders worldwide. Its prevalence is increasing because of the growing aging population in developed and developing countries as well as an increase in risk factors leading to OA, particularly obesity and a sedentary lifestyle. It is responsible for activity limitations, particularly walking, and affects participation and quality of life. Patients with OA are at greater risk of all-cause mortality, particularly for cardiovascular diseases, than the general population	<i>Annals of Physical and Rehabilitation Medicine</i>	Article	2016	375	53.57
Ozçivici et al. (2010)	Mechanical signals as anabolic agents in bone	Aging and a sedentary lifestyle combine to reduce bone quantity and quality, decrease muscle mass and strength, and undermine postural stability, culminating in an elevated risk of skeletal fracture. Concurrently, a marked reduction in the available bone-marrow-derived population of mesenchymal stem cells (MSCs) jeopardizes the regenerative potential that is critical to recovery from musculoskeletal injury and disease	<i>Nature Reviews Rheumatology</i>	Review	2010	338	26.00

Table 1 (continued)

Author(s)	Article title	Abstract	Source title	Document type	Publication year	Total no. of citations	Average no. of citations/year
Vettor et al. (2009)	The origin of intermuscular adipose tissue and its pathophysiological implications	The intermuscular adipose tissue (IMAT) is a depot of adipocytes located between muscle bundles. Several investigations have recently been carried out to define the phenotype, the functional characteristics, and the origin of the adipocytes present in this depot. Among the different mechanisms that could be responsible for the accumulation of fat in this site, the dysdifferentiation of muscle-derived stem cells or other mesenchymal progenitors has been postulated, turning them into cells with an adipocyte phenotype	<i>American Journal of Physiology-Endocrinology and Metabolism</i>	Review	2009	199	14.21



Table 1 (continued)

Author(s)	Article title	Abstract	Source title	Document type	Publication year	Total no. of citations	Average no. of citations/year
Paddon-Jones et al. (2008)	Role of dietary protein in the sarcopenia of aging	Sarcopenia is a complex, multifactorial process facilitated by a combination of factors including the adoption of a more sedentary lifestyle and a less than optimal diet. Increasing evidence points to a blunted anabolic response after a mixed nutrient meal as a likely explanation for chronic age-related muscle loss	<i>The American Journal of Clinical Nutrition</i>	Article	2008	273	18.20
Cesari et al. (2015)	A physical activity intervention to treat the frailty syndrome in older persons—results from the LIFE-P study	Frailty syndrome is a well-established condition of risk for disability. This study explored whether a physical activity (PA) intervention could reduce the prevalence and severity of frailty in community-dwelling elders at risk of disability. Regular PA may reduce frailty, especially in individuals at higher risk of disability. Future studies should be aimed at testing the possible benefits produced by multi-domain interventions on frailty	<i>The Journals Of Gerontology Series A—Biological Sciences and Medical Sciences</i>	Article	2015	239	29.88

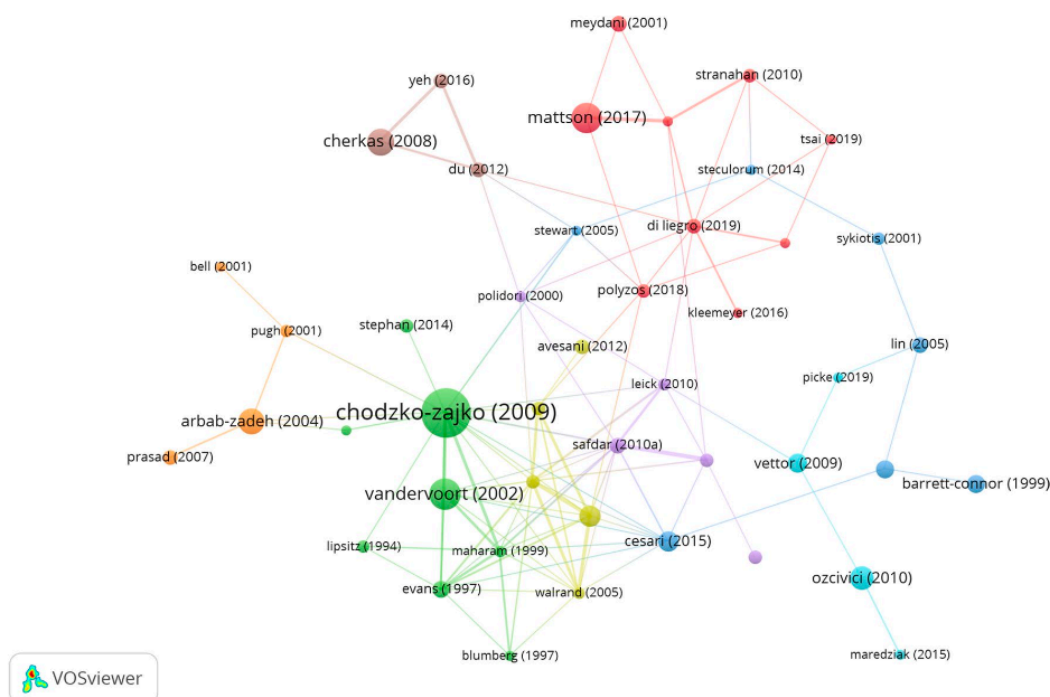


Fig. 4 Bibliographic coupling. (Analysis: Fractionalization; Attraction: 3; Repulsion: -3)

Table 2 WoS categories with the most documents

WOS categories	Documents	%
Geriatrics & Gerontology	50	16.07
Public, Environmental & Occupational Health	33	10.61
Sport Sciences	31	9.96
Endocrinology & Metabolism	28	9.00
Nutrition & Dietetics	20	6.43

identifying the predominant keywords and their interrelationships, all the words that occurred more than four times were included ($n = 49$). Aging, exercise, physical activity, and sedentary lifestyle were the most common terms, with 97, 49, 41, and 37 occurrences, respectively. The pair with the highest link strength were aging and sedentary lifestyles (Fig. 9). Taking into account the timing of publication, a change in the trends of the studies was seen, which were most focused on healthy aging, COVID-19, sedentary

Table 3 Journals with the highest number of documents published

Journal	Documents	%	IF*	Category	Quartile	JIF rank
<i>PLOS One</i>	7	2.25	3.7	Multidisciplinary Science	Q2	26/73
<i>Experimental Gerontology</i>	5	1.60	3.9	Geriatrics & Gerontology	Q2	27/54
<i>International Journal of Environmental Research and Public Health</i>	5	1.60	N/A	Environmental Science	N/A	N/A
<i>Medicine & Science in Sports & Exercise</i>	5	1.60	5.4	Sport Sciences	Q1	14/87
<i>Frontiers in Physiology</i>	4	1.28	4.0	Physiology	Q2	21/79

*Impact factor in the 2022 *Journal Citation Reports*
JIF journal impact factor

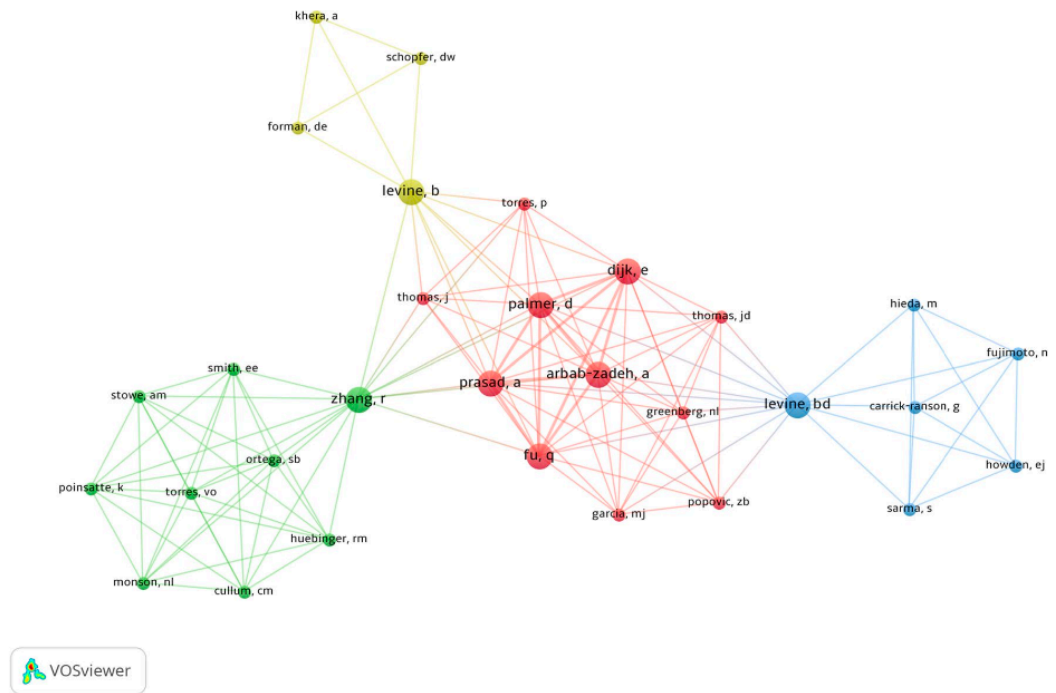


Fig. 5 Co-authorship of the documents. (Analysis: Fractionalization; Attraction: 3; Repulsion: -3)

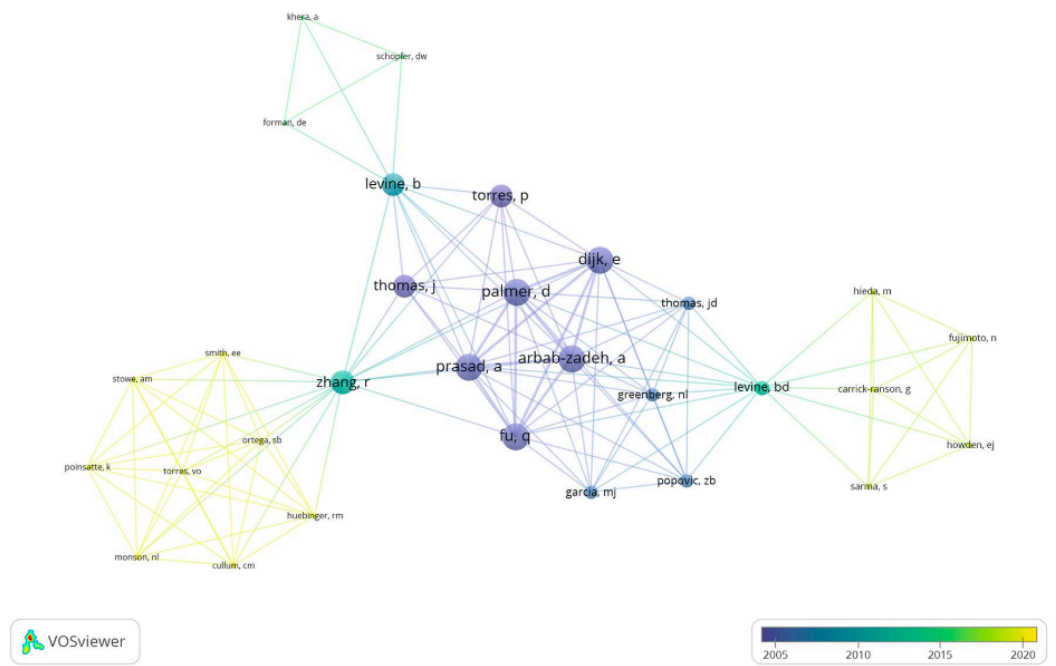


Fig. 6 Overlay visualization regarding the timing of publication. (Analysis: Fractionalization; Attraction: 3; Repulsion: -3)

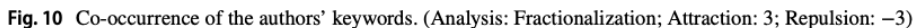






With regard to the individual authors, a total of 1509 authors were identified, among whom only four authors had at least four documents published. S. Amagasa, N.

Considering the WoS categories, the results show that Geriatrics & Gerontology had the highest number of documents ($n = 50$). Public, Environmental & Occupational Health placed second, with 33 documents, followed by Sport Sciences with a total of 31 documents. Following these results, with regard to journals, *PLOS One* had the highest number of documents published related to the



Regarding the organizations that contributed documents, a total of 630 institutions were identified, of which only five organizations had at least five documents published. Johns Hopkins University and the University of Lisbon were positioned at the top of the list, with eight and six documents, respectively. Similarly, Johns Hopkins University presented the highest number of citations ($n = 876$). Related to these results, with regard to countries, the USA was the most prolific region, with a total of 100 documents and 5749 citations. The sedentary lifestyle of a significant proportion of the population has led to an obesity epidemic in the USA (Hu 2023); thus the results obtained in the present study are mainly focused on reality. In addition, a sedentary lifestyle is correlated with the time spent watching TV; individuals who watched television for ≥ 6 h a day had twofold higher all-cause mortality risk than people

Considering the occurrence of the keywords of each document, the results highlighted a total of 807 terms, of which 34 keywords occurred more than five times. Aging, exercise, physical activity, and sedentary lifestyle were the most frequently occurring terms, with 97, 49, 41, and 37 occurrences, respectively. Thus, these results show how the good selection of keywords improves the quality of a study and increases its impact and likelihood of being cited as a reference in future research (Benito-Peinado et al. 2007). With respect to the timing of publication, a change in the publication trend was observed, with terms such as healthy aging, COVID-19, sedentary behavior, and public health being the most frequently used. The results showed that short breaks in sedentary behavior through engagement in moderate to vigorous physical activity will be beneficial for triglyceride levels, waist circumference, and body mass index, because they will be reduced (Park et al. 2020). Sedentary behavior has a negative impact on vascular health. A study in healthy women reported that

56 days of head-down bed rest decreased endothelium-dependent vasodilation while increasing endothelial cell damage. Such alterations in vascular function were prevented through aerobic exercise and muscle training (Lavie et al. 2019; Thosar et al. 2012).

Conclusions

A sedentary lifestyle is a major factor contributing to the obesity epidemic. Thus, this study analyzes the growth and direction of research related to the effects of a sedentary lifestyle during the aging process. The results revealed a significant increase in the number of publications, with an exponential growth of 79% in the last 25 years.

Physical activity directly impacts the quality of life of this population, reducing the risk of illness or cardiovascular disease. To improve the quality of life throughout aging, programs for promoting physical activity must be carried out with the highest frequency. These programs will increase the mental health of the participants and reduce the risk of diseases.

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Author contributions Conceptualization: V.H.-B., M.C.E., and J.M.G.; methodology: V.H.-B., J.M.-J., and J.M.G.; formal analysis: V.H.-B., M.C.E., C.C.F., C.A.C., J.A.P., O.F., and J.M.G.; investigation: V.H.-B., M.C.E., and J.M.G.; supervision: V.H.-B., M.C.E., and J.M.G.; data curation: V.H.-B., M.C.E., and J.M.G.; writing—original draft preparation: V.H.-B., M.C.E., C.C.F., C.A.C., J.A.P., O.F., and J.M.G.; writing—review and editing: V.H.-B., M.C.E., C.C.F., C.A.C., J.A.P., O.F., and J.M.G.; Visualization: V.H.-B., M.C.E., J.M.-J., K.L., C.C.F., J.A.P., and J.M.G.; funding acquisition: M.C.E., C.C.F., and J.M.G. All authors have read and agreed to the published version of the manuscript.

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Data availability The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Institutional review board statement Not applicable.

Informed consent statement Not applicable.

Conflicts of interest The authors declare no conflicts of interest.

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Evolution of documents related to the influence of physical activity and functional capacity throughout the aging process: a bibliometric review

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Physical inactivity can lead to frailty and negative health outcomes in middle-aged to older adults. Sedentary individuals have double the risk of death compared to those who engage in high levels of physical activity (PA). The advantages of practicing PA in older age are significant, with regular, moderate-intensity activity (150 min per week) being consistently linked with a decreased risk of chronic disease, cognitive decline, and mortality. Therefore, the study aimed to carry out a bibliometric review related to the terms "Physical activity," "Functional capacity" and "Aging" including all the documents published in the Web of Science Core Collection until 31st December 2023. The sample was made up of 231 studies related to the topic. The results reported that the first document was published in 1994. However, there was no continuity in the publication of the documents till 1998, which was the first year with at least one document published. Considering 1998 as the first year, it is observed an exponential growth of 77.4%, between the oldest (1997–2008) and contemporaneous studies (2008–2023), in which "Geriatric Gerontology" was the Web of Science category with the highest number of documents (n = 59). The journal "Experimental Gerontology" was associated with the largest number of published documents (n = 7), being indexed in Quartil 2. The years 2009 had the highest number of citations (n = 1811), with a total of 7 documents published and 2018 with the higher number of documents (n = 25). These results reported the importance of PA in elderly people, and how it influences the risk of falls, improving the balance and the functional capacity. Thus, it is important to carry out programmes to promote physical activity to this population and reduce the risk of falls and the presence of diseases.

KEYWORDS

sedentary lifestyle, elderly, trend, co-authorship, journals



1 Introduction

Human beings are prepared to move, but, interestingly, more and more people practice less physical activity (PA). This is related to current lifestyles, which tend to be more sedentary than active (Woessner et al., 2021). Preventing and managing disabilities in the elderly is a significant public health challenge since aging is a risk factor that contributes to functional decline. This process is continuous and irreversible (Wong et al., 2019; Anton et al., 2020).

Physical inactivity is one of the main modifiable risk factors for mortality (Fletcher et al., 2018). Inactivity is linked to weakness and negative health results among middle-aged and older adults. Sedentary individuals are twice as likely to die as those who engage in high levels of PA (Tieland et al., 2018; Ghram et al., 2021).

Exercise and PA are crucial lifestyle choices that support good aging and are regarded as essential treatment approaches for common geriatric syndromes. Attenuating the deterioration in muscle function and cardiorespiratory fitness, retaining functional capacity, and managing chronic disease are among the known clinical benefits of PA (Langhammer et al., 2018; Meredith et al., 2023). The importance of PA and physical exercise nowadays is very important, with varied benefits for improving health, so it is necessary to have a better approach in the evaluation and control of physical exercises to ensure the continuity of our practitioners to the activity, without risk of injuries, withdrawals or even lack of motivation (Warburton et al., 2006). Normally, PA is defined as body movement produced by the contraction of skeletal muscle that increases caloric needs concerning energy expenditure at rest. Physical exercise is defined as a type of PA that is planned, repetitive, and structured that aims to promote improved health and physical condition (Caspersen et al., 1985).

The benefits of PA in old age are vast. Regular, moderate-intensity activity (150 min per week) consistently reduces the risk of chronic disease, cognitive decline, and mortality (McGarrigle and Todd, 2020). Balance and gait impairments significantly affect one's ability to perform daily activities and increase the risk of falls, leading to a lower quality of life (Rashid et al., 2021). Exercise programs that emphasize improving strength and balance reduce falls in older adults (Claudino et al., 2021; Wiedenmann et al., 2023). In the same way, these programs should be focused on the maintenance and improvement of the functional capacity of elderly people (de Paiva et al., 2021).

Considering the European Union countries, Portugal is the country with the highest percentage of citizens who never performed PA (36%), higher results than the European average (14%) (Alvarez-Lourido et al., 2023). Elderly people do not escape this tendency, because they do not practice enough PA, causing a decrease in flexibility, body balance (Eckstrom et al., 2020), and quality of life (Fiorilli et al., 2022). As we age, a decline in functionality is experienced, but this can be minimized through regular physical exercise (Daley and Spinks, 2000). This serves to improve cognitive and functional functions, in addition to reducing the risk of falls (Buckinx et al., 2021). PA can support quality of life, lessen loneliness, increase embodied joys in later life, improve wellbeing, and enhance social interactions (Gamonaes et al., 2021). It is hardly unexpected that PA is encouraged among older adults given the established advantages (Resna et al., 2022).

In this sense, the World Health Organization (WHO) states that there is clear evidence that regular PA produces important benefits for people over 65 years of age. These are usually less active and therefore have illnesses related to inactivity (Milanovic et al., 2013). Mortality rates from cerebrovascular accidents, coronary heart disease, diabetes, and hypertension, among others, are lower among elderly people who are more active than among those who are less active, consequently they have a better quality of life (Palma et al., 2014). Furthermore, psychological consequences such as low self-esteem, anxiety, depression and, as a social consequence, isolation and negative social image, are determining factors for active aging (Liu et al., 2023). The WHO argues that countries can afford aging if governments, international organizations, and civil society implement active aging policies and programs that improve health, participation, and safety (Guthold et al., 2018; Bull et al., 2020).

Bibliometrics is a statistical method used to analyse scientific publications based on indicators of production, impact, and collaborations. It helps researchers identify potential journals, collaborators, and institutions in specific areas of study (Okubo, 1997). In the same way, the use of bibliometric analysis makes it possible to identify gaps in the literature about research topics. In this way, researchers and scientists will know those aspects that are less worked on, and which can be developed broadly to obtain satisfactory results and conclusions for the scientific community (Gámez-Calvo et al., 2024). This method has been used to explore the scientific production of researchers, institutions, and regions in certain fields. Therefore, the purpose of this research is to analyse the current trends in global publications on the impact of PA and functional capacity during the aging process.

2 Materials and methods

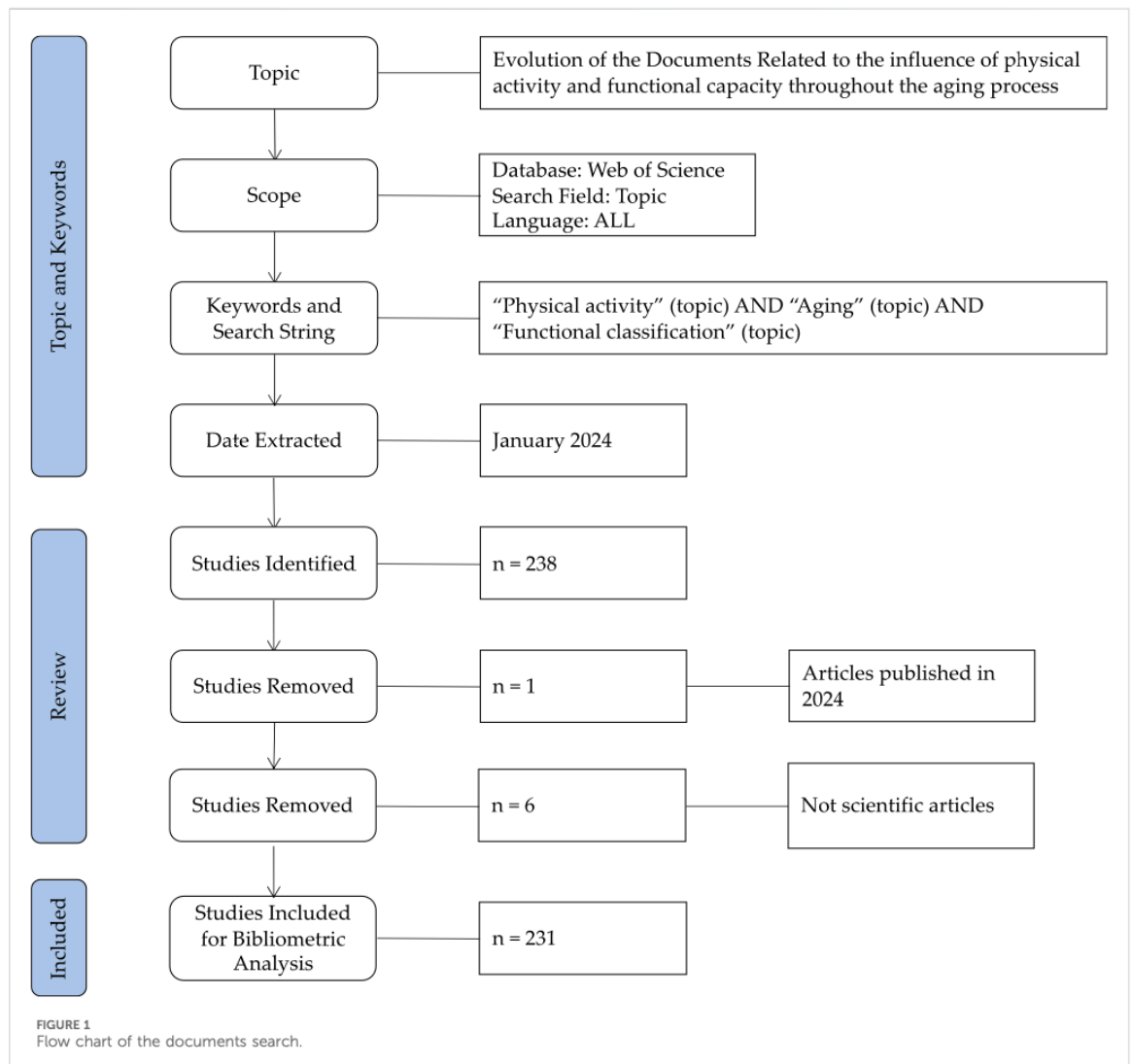
2.1 Design

Considering Montero & León (Montero and León, 2007) proposal, this study fits within the Theoretical research, because the document's main purpose was to carry out a bibliometric analysis of the literature. A bibliometric review allows to analyse the state of the art of a theme and identifies future research lines (Hernández-Beltrán et al., 2023).

2.2 Data extraction

The document search was carried out in the Web of Science (WoS) database, especially, using the WoS Core Collection. This database provides access to a great number of databases, journals, and disciplines (Moral-Muñoz et al., 2020). In the same way, this database was used to reduce the duplicated studies and to standardize the information related to the topic (Herrera & de las Heras-Rosas, 2020), because between 95% and 99% of the studies indexed in the WoS database, are also in another database such as Scopus (Singh et al., 2021). Within the bibliometric analysis, WoS is the most used database (Hernández-Beltrán et al., 2023).





2.3 Search strategy

The terms “Physical activity,” “Functional capacity” and “Aging” keywords were used to search the documents. The filter “topic” was used to identify those documents that contain the previous terms in the title, keywords, or abstract of the document, to increase the reliability of the results. Afterward, a total of 238 documents were identified, after applying the inclusion criteria, the sample was reduced to 231 studies for the bibliometric analysis. The documents were published up to 31st December 2023. Firstly, J.M.G. and V.H.B. carried out the search and selection of the documents. Secondly, if there was any disagreement, M.C.E and C.A.C. discussed whether the study was valid and reliable to be selected for the bibliometric analysis. The title and the abstract of the documents were checked to select the most valid documents related to the

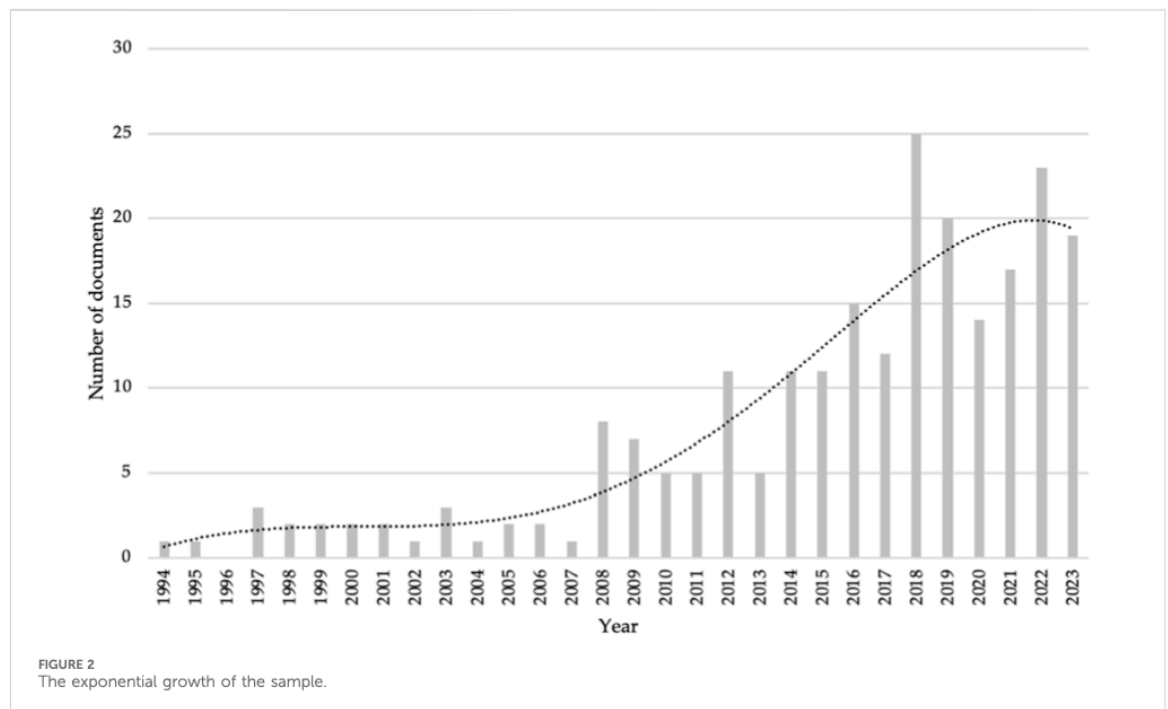
topic and reduce the risk of bias. **Figure 1** shows the process followed in the search of the documents, and the number of studies removed during the phases.

2.3.1 Inclusion criteria

In order to select the most appropriate documents related to the topic, some inclusion criteria were established:

- 1) The documents must be related to the study of PA and functional capacity of elderly people.
- 2) To be written in Spanish, English, or Portuguese.
- 3) The studies must fit such as scientific or review articles (Gamonaes et al., 2018).
- 4) To be published up to 31 December 2023. The documents published in the year 2024 were removed because the year was uncompleted.





2.4 Statistical analysis

In order to analyse the sample and the interactions of the authors, organization, countries, and keywords, some bibliometric laws were used. Firstly, De Solla Price's Law was used to identify the exponential growth of the sample through the R² coefficient (Price, 1976). The growth dynamics study is an important tool for analyzing the state of the art of a topic and evaluating its trend (Teli and Dutta, 2020). Secondly, the Hirsch Index was calculated to identify the most prominent authors and assess the individual impact of each author (Bihari et al., 2023), using Lotka's law (Coile, 1977). Finally, to identify the most prominent terms used in each document (Piantadosi, 2014), Zipf's law was adopted (Zipf, 1932). The key terms are usually used to identify the content of the studies and the trend topics of a research line (Gil-González et al., 2022).

To perform the analysis, data was downloaded in two distinct formats: Excel® (2006 version; Microsoft Corporation, Redmond, WA, United States) and VOSviewer (v. 1.16.19, Center for Science and Technology Studies, Leiden, Netherlands). VOSviewer software was used to carry out the analysis, create, and visualization of the figures. The analysis was accomplished by utilizing the fractionation method, which involved normalization through attraction force (3) and repulsion force (−3).

3 Results

3.1 Annual publication trends

231 documents were selected and included in the analysis. Figure 2 shows the number of documents per year, the x-axis corresponds to the

years and the y-axis corresponds to the number of documents, with the oldest articles published in 1994 (Graves et al., 1994) and 1995 (Green and Crouse, 1995). On the other hand, in 1996 years no document was published. Starting from 1998, at least one publication per year has been identified, with a continuity of publication up until the present day. There has been an exponential growth of 77.4% between older studies (1997–2008) and contemporary studies (2008–2023).

3.2 WoS categories

It has been observed that within the WoS category, “Geriatrics Gerontology” has the highest number of documents (n = 59). Furthermore, “Experimental Gerontology” is the journal that has published the most documents within this category (n = 7). The data are shown in Table 1.

3.3 Scientific journals

Table 2 shows the Top 5 most relevant journals related to the study of PA and functional capacity throughout the aging process. Also, it is shown the Quartile and the Rank of the journal regarding the Impact Factor. This result shows the variability of the journals chosen for publishing these studies.

3.4 Most cited documents

To analyse the citations of the documents, first, the H Index of the sample was identified (n = 44). This value allows to know the

TABLE 1 Documents classified regarding the WOS categories.

WoS categories	Documents	%	Journal name	Documents
Geriatrics gerontology	59	27.44	Experimental gerontology	7
Sport sciences	36	16.74	Journal of aging and physical activity	5
Public environmental occupational health	31	14.41	IJERPH	6
Gerontology	21	9.76	Journal of aging and physical activity	6
Medicine general internal	15	6.97	Preventive medicine	3
Physiology	14	6.51	Frontiers in physiology	3
Nutrition dietetics	13	6.04	Journal of nutrition health aging	3
Rehabilitation	13	6.04	Brazilian journal of physical therapy	3
Cardiac cardiovascular systems	11	5.11	American journal of geriatric cardiology	2
Medicine research experimental	9	4.18	Contemporary clinical trials	3

WoS, web of science. IJERPH, international journal of environmental and public health.

TABLE 2 Journals with most published articles related to the study topic.

Journal	Documents	%	IF ^a	Category	Quartile	JIF rank
Experimental gerontology	7	3.24	3.9	Geriatrics and gerontology	Q2	27/54
IJERPH	6	2.77	N/A	Environmental science	N/A	N/A
Journal of aging and physical activity	6	2.77	1.5	Geriatrics and gerontology	Q4	50/54
Archives of gerontology and geriatrics	4	1.85	4.0	Geriatrics and gerontology	Q2	24/54
Plos one	4	1.85	3.7	Multidisciplinary science	Q2	26/73

^aImpact factor in the 2022 journal citation reports; JIF, rank, journal impact factor ranking; IJERPH, international journal of environmental and public health.

most potential authors related to the topic (Campos-Soto et al., 2019). H Index is explained as the h number of documents which have at least h citations (Crespo and Simoes, 2019).

Figure 3 shows the trend in the publication of documents, and the total of citations per year, the x-axis corresponds to the years and the y-axis corresponds to the number of citations. The results reported that 2009, was the year with the highest number of citations (n = 1811), with a total of 7 documents published. On the other hand, 2018 is the year with the largest number of documents (n = 25). It is observed how the number of citations has been so rare from 2020 till now, due to the articles being so recent, with 2022 was the year with the highest number of citations in the last 4 years (n = 137).

Table 3 shows the Top 10 most cited documents related to the topic selected. The results showed that the article written by Chodzko-Zajko et al. (2009) has the highest number of citations. In the same way, this article has the biggest average of citations per year, with a value of 99.5 citations per year. For analyzing the citations of each document, self-citations have been added.

3.5 Authors and Co-authors of the documents

A total of 1,071 authors were detected, which only eight authors have a minimum of four documents published, and eighty-one

authors with two documents. Figure 4 shows the interaction between the authors and co-authors. The author with the highest number of articles published is Aubertin-Leheudre, M., however, he does not appear in the figure because the interactions between the rest of the authors are so rare.

Figure 5 shows the evolution of the group of authors focused on the influence of the PA and functional capacity in elderly people. It shows that the cluster formed by Thomasini, R.L., Issa Kassab, G.B., Silva, T.J., Perentoni, A.N., Maximo Pereira, L.S., and Maximo Pereira, F.S. are the most recent authors which documents are published from 2020 to nowadays. On the other hand, the authors with a higher number of citations show an average of publications between 2010 and 2014.

3.6 Publications regarding the countries

Considering the countries which have contributed to the production of the studies, 40 have been identified. Twelve countries had a minimum of 5 documents, and nine countries had a minimum of ten articles. Table 4 shows the top 10 most prolific countries, and the number of papers published. As it is seen Brazil and the United States of America (United States) add up a total of 109 documents. In the analysis, the interaction between the countries is illustrated in Figures 6, 7. The country with the highest number of citations is the United States (n = 2,355), followed by Australia (n = 1,410).



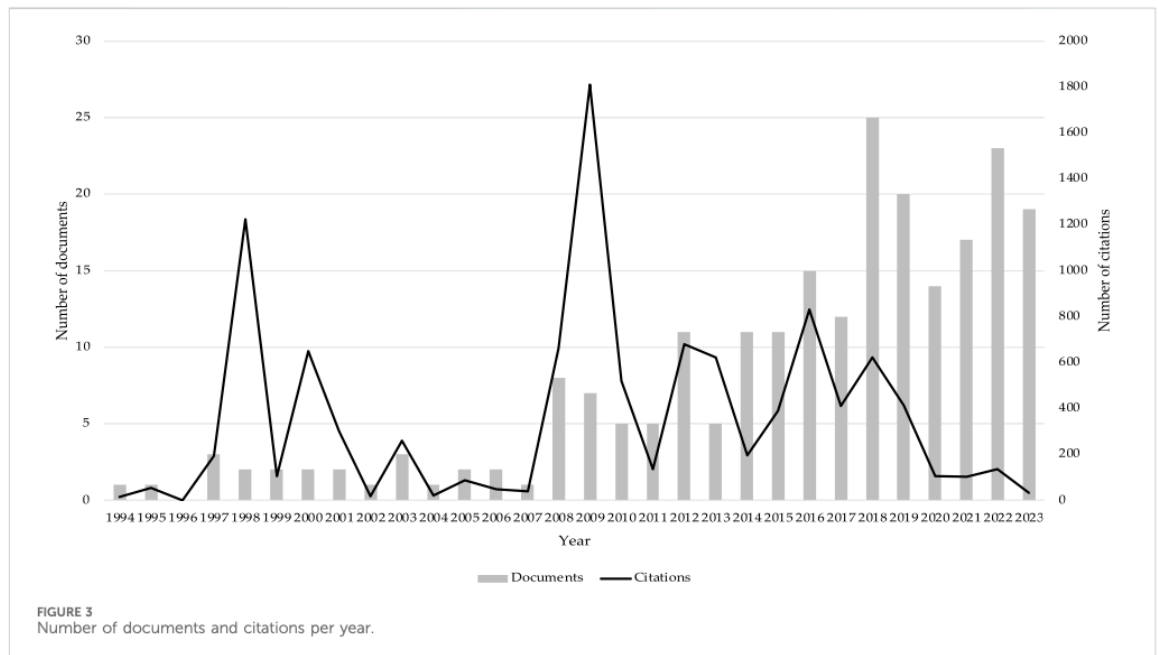
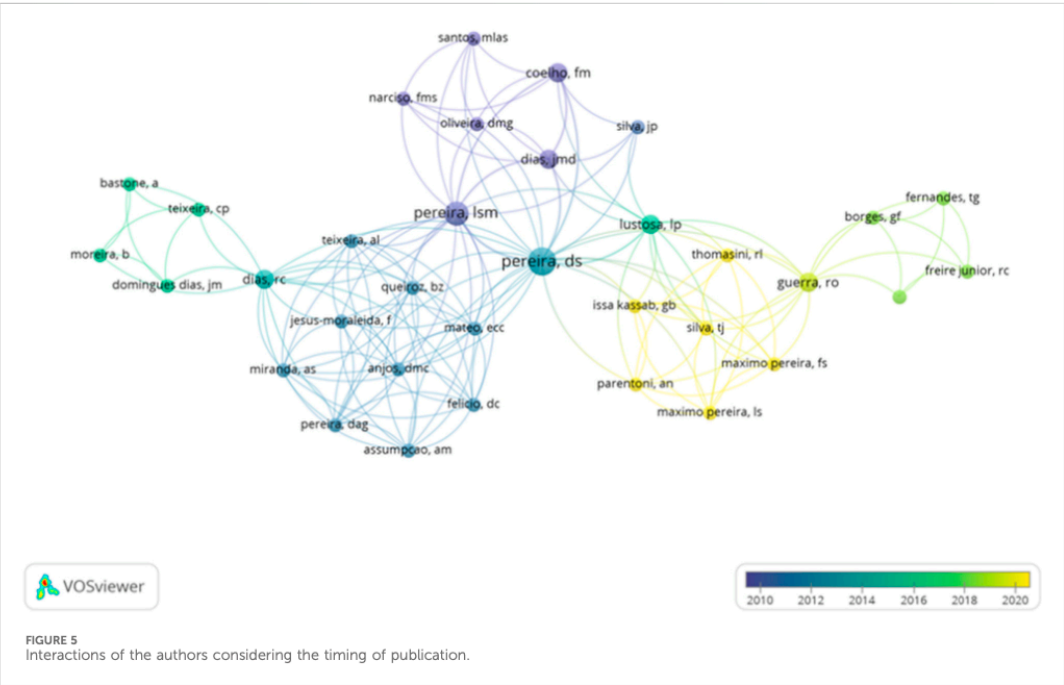
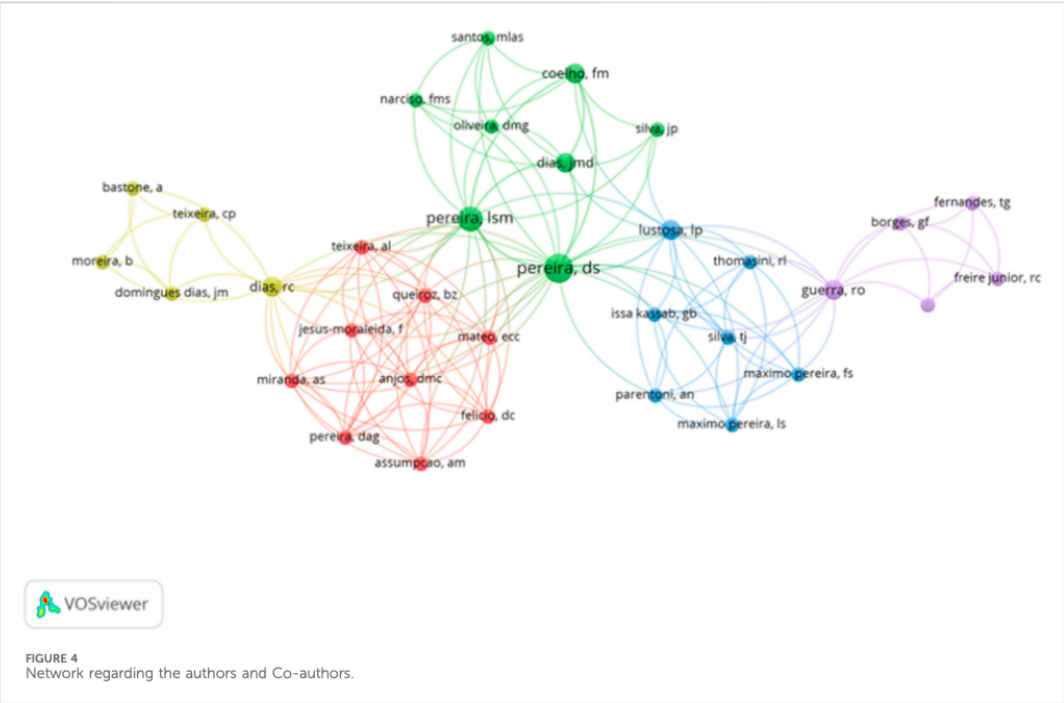


TABLE 3 Ten most cited research documents.

Title	Authors	Publication year	Journal title	Total citations	Average citations per year
Exercise and physical activity for older adults	Chodzko-Zajko et al. (2009)	2009	Medicine and science in sports and exercise	1,293	99.5
ACSM position stand: exercise and physical activity for older adults	Mazzeo et al. (1998)	1998	Medicine and science in sports and exercise	1,072	44.7
Social-cognitive and perceived environment influences associated with physical activity in older australians	Booth et al. (2006)	2000	Preventive medicine	508	23.1
Age-related decrease in physical activity and functional fitness among elderly men and women	Milanovic et al. (2013)	2013	Clinical interventions in aging	414	46.0
Updating the evidence for physical activity: summative reviews of the epidemiological evidence, prevalence, and interventions to promote active aging	Bauman et al. (2016)	2016	Gerontologist	404	67.3
Protecting muscle mass and function in older adults during bed rest	English and Paddon-Jones (2010)	2010	Current opinion in clinical nutrition and metabolic care	313	26.1
The danger of weight loss in the elderly	Miller and Wolfe (2008)	2008	Journal of nutrition health and aging	272	19.4
Aging, exercise, and muscle protein metabolism	Koopman and van Loon (2009)	2009	Journal of applied physiology	254	19.5
Physical work capacity in older adults: implications for the aging worker	Kenny et al. (2008)	2008	American journal of industrial medicine	202	14.4
Fish-oil supplementation enhances the effects of strength training in elderly women	Rodacki et al. (2012)	2012	American journal of clinical nutrition	199	19.9





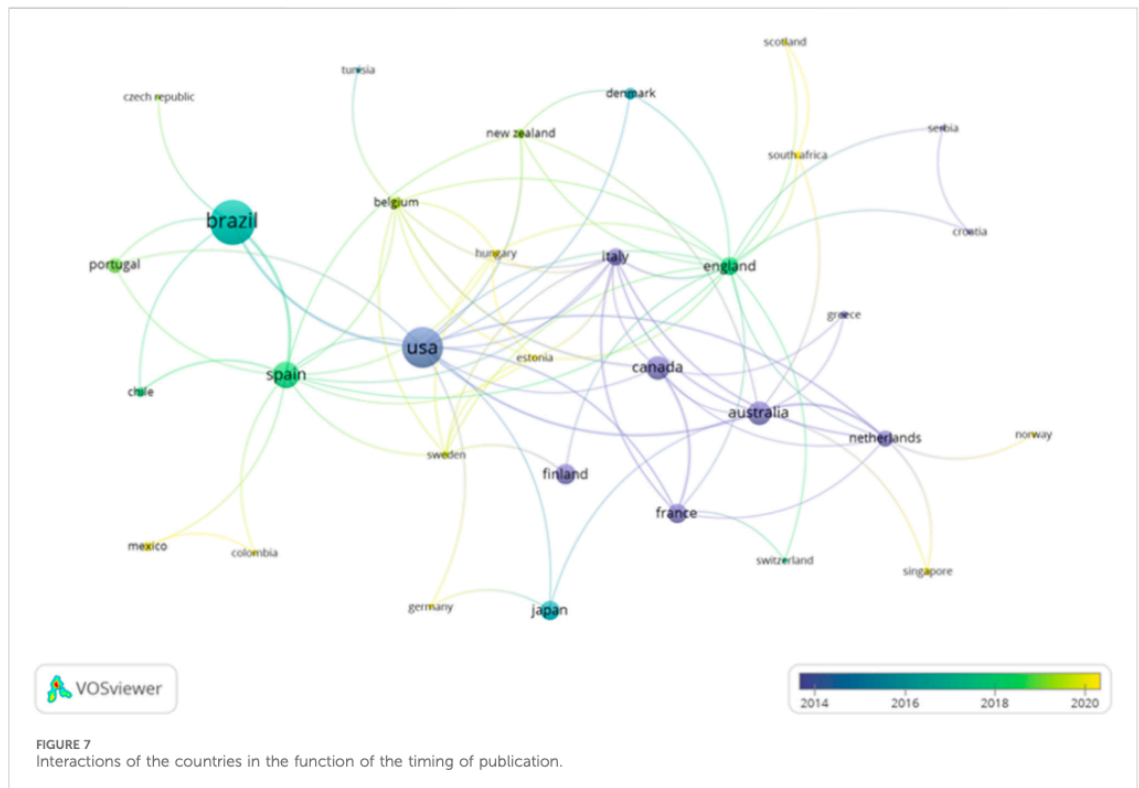
Countries	Documents	%	Citations
Brazil	57	26.51	926
United States	52	24.18	2,355
Spain	21	9.76	434
Australia	16	7.44	1,410
Canada	16	7.44	749
Finland	12	5.58	427
France	11	5.11	360
Japan	11	5.11	187
England	10	4.65	539
Italy	9	4.18	347

3.7 Publications regarding the organisations

relationship between the organizations deeply, only those organizations with a minimum of two documents were included in the analysis ($n = 72$). “Universidade Federal Do Rio Grande Do Sul,” is the most prolific with a contribution of nine documents. In terms of citations, the University of Sydney is in the first position with a total of 890 citations. **Figure 8** shows the interaction between the organizations.

3.8 Author's keywords

FIGURE 6
Interactions of the countries based on the number of documents published.



4 Discussion

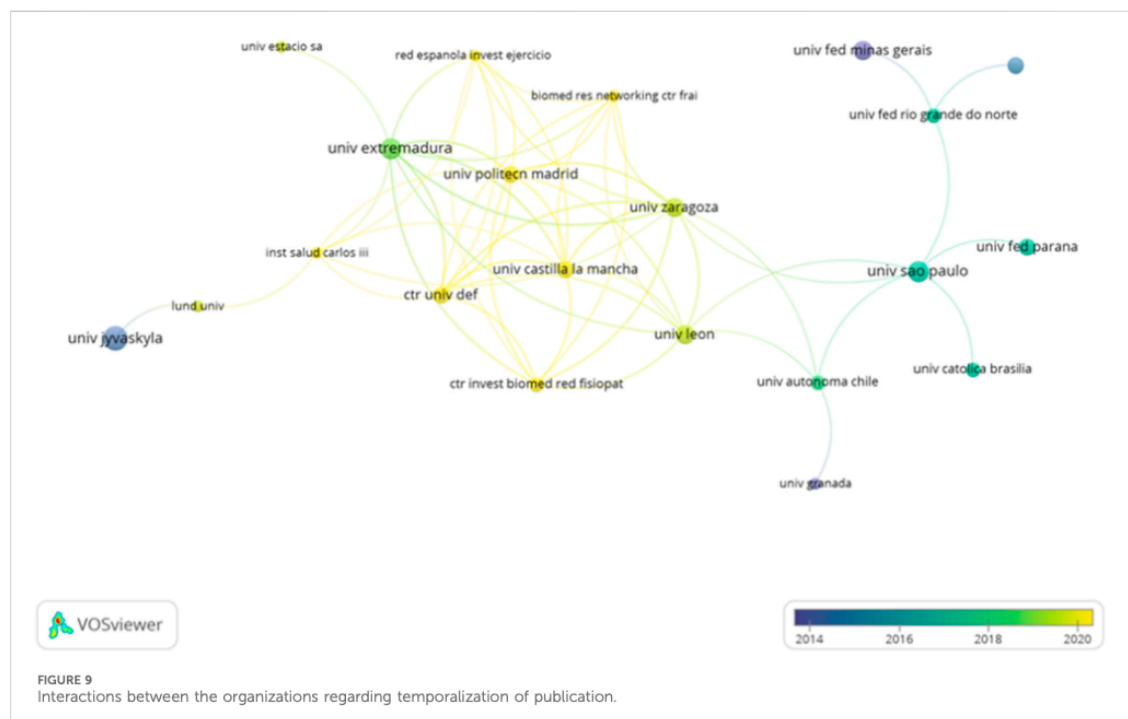
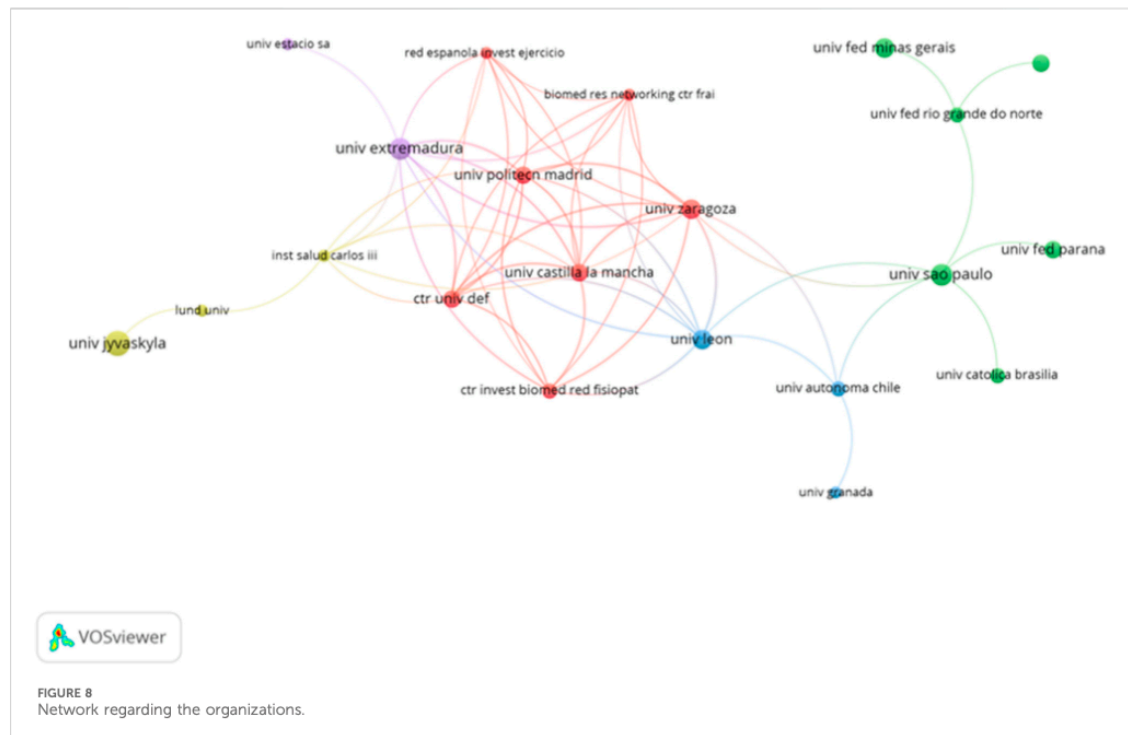
The aim of the study was to conduct a bibliometric analysis of documents related to the study of the impact of PA on functional capacity during the aging process. The results showed that the first document was published in 1994. However, there was no regular publication of such documents until 1998, which was the first year with at least one document published. If we consider 1998 as the starting year, the number of studies has increased exponentially by 77.4% between older studies (1997–2008) and contemporary studies (2008–2023). The WoS category with the highest number of documents was “Geriatric Gerontology.” Within this category “Experimental Gerontology” was the journal with the largest number of documents published. So, these results reported the importance of PA in elderly people, and how it influences the risk of falls, improving the balance and the functional capacity (Thomas et al., 2019). Thus, it is important to carry out programmes to promote PA to this population and reduce the risk of falls and the presence of diseases.

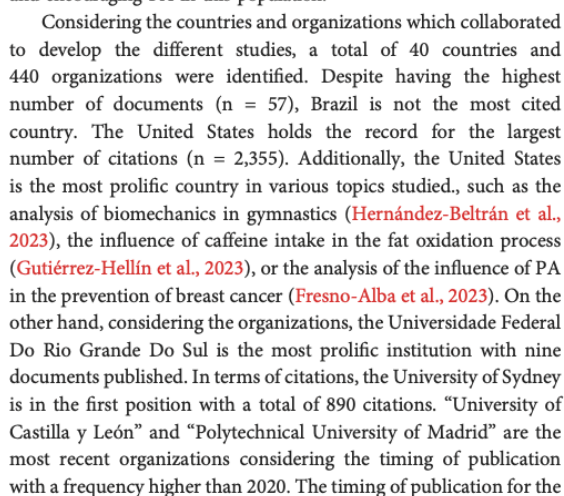
On the other hand, the article with the highest number of citations is indexed in “Medicine & Science in Sports & Exercise” journal, with a total of 1,293 citations (Chodzko-Zajko et al., 2009). Regarding the total of the documents published related to the topic, an H index of 44 was identified. Thus, this means that there are a minimum of 44 documents with at least 44 citations. The second most cited document was published in 1998 with a total of 1,072 citations, it was also published in the “Medicine & Science

in Sports and Exercise” journal. Therefore, it is important to select and publish the document in journals with a high impact factor and use provocative titles (Araujo et al., 2018). In the same way, self-citations play an important role in the increase of the visibility (González-Sala et al., 2019). Self-citations are understood as the number of citations authors make to their own published work. This will increase the number of citations, as well as the visibility of their work, which will allow authors to increase their H-index and 10-index, thereby acquiring greater scientific recognition. These strategies must be followed to increase the visibility of the results and raise the number of citations.

Regarding the authors identified ($n = 1,071$), only four of them have at least 4 documents published. Aubertin-Leheudre, M., is the author with the highest number of documents carried out ($n = 5$). However, the results reported that the cluster composed by Thomasini, R.L., Issa Kassab, G.B., Silva, T.J., Perentoni, A.N., Maximo Pereira, L.S., and Maximo Pereira, F.S. are the most recent authors which documents are published from 2020 to now. On the other hand, considering the number of citations, it is observed that the timing of publication fluctuated between 2010 and 2014. Thus, this highlights that most of the publications are so recent because of the interest of the researchers to prevent the risk of falls and improve the quality of life throughout aging. These factors can be improved through PA, and reduce the anxiety, depression (Zhang et al., 2021) and negative social image (Liu et al., 2023). Regular PA prevents chronic diseases, heart problems and the risk of cancer (Haskell et al., 2007). PA can support quality of life, lessen loneliness, increase embodied joys in later life, improve







This study has certain limitations, such as the number of documents selected, since it assumes the loss of studies that were not indexed in the WoS database, due to the low impact

factor of the journal. In this line, when the first search was carried out a total of 238 documents were selected, of which 7 were deleted due to not fixing the inclusion criteria. Finally, the sample was made up of 231 documents, which is a larger number of documents considering the temporal coverage. Similarly, one of the limitations of the study is the selection of key terms. For the correct development of the study, as well as in the extraction of the results, it is necessary to select those words that are closest to the topic and, in this way, eliminate biases in the results. Therefore, in future work, the right planning and selection of keywords should be carried out to reduce the impact of unrelated studies in the final analysis. On the other hand, one of the strengths of the study is that it allows us to know the trends and co-authorship of the documents regarding the country, organization, or authors. In this way, the evolution in the number of publications analyse the influence of PA on the functional capacity of the elderly is known. For future research lines, it is proposed to analyse the current PA programmes and to extract the main findings and results, to obtain a summarized document of the main studies related to PA and its influence on functional capacity. In essence, this research is crucial for its thorough examination and consolidation of literature that demonstrates the significant effect of PA on the aging process. As well as demonstrating the growing interest in this topic in the scientific community. These findings provide guidance for future investigations, policy creation, and the creation of focused interventions aimed at encouraging a healthier and more active lifestyle among elderly populations.

5 Conclusion

PA in the elderly allows different benefits to be obtained at various levels, such as the prevention of physical deterioration and the improvement of psychological aspects and social image. PA will improve people's quality of life, as they will acquire and strengthen movement patterns typical of daily life activities. It will also make them feel better, increasing their personal and social wellbeing. Therefore, keeping a good functional capacity of older people will reduce the risk of disease, cardiovascular problems and sedentary lifestyles Programmes or strategies should be developed to promote PA in this population, through physical work for at least 3 days per week.

This analysis helps to understand the growth and focus areas within the field of study, identifying gaps and opportunities for future research. The findings revealed that the initial document was published in 1994. However, there were no regular publications of such documents until 1998, which marked the first year with at least one document published. If we take 1998 as the starting point, the number of studies has increased exponentially by 77.4% between older studies (1997–2008) and contemporary studies (2008–2023). The category in WoS with the highest number of documents was “Geriatric Gerontology.” Within this category, the journal “Experimental Gerontology” had the largest number of published documents. This points towards the academic and clinical importance of this research domain, indicating key platforms for disseminating findings and accessing information relevant to the health and wellness of the aging population.

Author contributions

CC: Writing–review and editing, Writing–original draft, Visualization, Supervision, Methodology, Funding acquisition, Formal Analysis. VH-B: Writing–review and editing, Visualization, Methodology, Formal Analysis. JG: Writing–review and editing, Visualization, Methodology, Funding acquisition, Formal Analysis. OF: Writing–review and editing, Visualization, Supervision, Formal Analysis. ME: Writing–original draft, Visualization, Supervision, Funding acquisition, Formal Analysis. JP: Writing–review and editing, Visualization, Supervision, Methodology, Funding acquisition, Formal Analysis.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Protocol

An Active Retirement Programme, a Randomized Controlled Trial of a Sensorimotor Training Programme for Older Adults: A Study Protocol

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Abstract: Research shows that exercise training programmes lead to several improvements in older adults' health-related quality of life (HRQoL) and well-being. This study will examine the effects of an active retirement programme on Portuguese older adults, investigating its effects on body composition, physical fitness, HRQoL, and physical activity level (PAL). Therefore, a parallel-group randomised controlled trial will be conducted, including body composition (height and body weight), physical fitness (strength, flexibility, agility, postural control, and gait), HRQoL, and PAL assessments before and after the application of the programme. The programme will be carried out for six months, two days per week (45 min), plus a year of follow-up. The programme will consist of six circuits with eight physical exercises each. The circuits will change at the end of the four weeks (one monthly circuit). The exercises' difficulty will increase throughout the programme, with alternatives for all the participants. If the effectiveness of the programme is demonstrated, implementation in different services and municipalities could be advised, as the actors involved in health and social services should promote the well-being of their citizens through, among others, health-related physical activity and the prevention of diseases associated with inactivity.

Keywords: elderly; falls; gait; postural control; exercise; quality of life

1. Introduction

Demographic ageing is the paradigm of the 21st century, and the older adult population is trending upwards. According to the central forecast scenario of the Office of Statistics National Institute, the number of older adults will increase from 2.1 to 2.8 million between 2015 and 2080 [1]. Thus, understanding and preventing disability in older adults is an important public health challenge, as ageing is a risk factor contributing to functional decline [2]. Ageing is continuous and irreversible and can be related to physical and cognitive function decline [3].

Physical activity (PA) plays an important role in healthy ageing, extending life, and quality of life, reducing chronic the incidence of physical and mental diseases. Moreover, every additional 15 min of daily PA (up to 100 min/day) reduces the mortality rate from



any cause 4%. Although mechanisms underlying PA's positive effects on health have not been fully revealed, evidence points to inflammatory markers, cellular oxidative stress regulation, and the impact on telomere length that could delay the ageing process [4]. According to the World Health Organization (WHO)'s recommendations [5], more than a quarter of the worldwide population (27.5%) does not perform at least 150 min of moderate or 75 min of vigorous PA per week [6]. Older adults should conduct, at least 150 min of moderate-intensity aerobics, at least 75 min of vigorous-intensity aerobics, or an equivalent combination of moderate- and vigorous-intensity PA throughout the week for substantial health benefits. Older adults should also perform moderate or greater-intensity muscle-strengthening activities that involve all major muscle groups two or more days a week, as these provide additional health benefits. As part of their weekly PA, older adults should practise multicomponent PA, emphasising functional balance and strength training at a moderate or high intensity three or more days a week to prevent falls [5]. In this sense, Gopinath et al. [4] carried out a study for 10 years in Australia, following up with adults over 50 years involved in moderate-vigorous PA (≥ 5000 MET minutes/week), which found that participants doubled their survival probability without chronic diseases, cognitive deficits, or functional incapacity. Moreover, PA levels (PAL) in older people should be higher than those recommended by the WHO (600 MET minutes/week) [5] to reach healthy ageing. There are 2.4 million individuals aged 65 and over in Portugal [7], with only 16.6% following the WHO's recommendations [8]. A lack of PA contributes to the loss of functional fitness in the elderly [9]. Aerobic exercise is important for optimal musculoskeletal performance; however, aerobic capacity gradually declines with advancing age. Likewise, exercised muscles are more sensitive to anabolic stimuli, such as protein ingestion, which allow muscle protein synthesis [10]. As a result, sedentary elderly people have lower muscle mass and reduced bone mass, and, consequently, their ability to perform PA is affected.

Psychosocial factors also impact the functional status of the elderly. Self-efficacy and fear of falling are important factors [11]. Self-efficacy is not only associated with gait speed and physical-function limitations but also with participation in physical exercise programmes. In turn, fear of falling negatively influences sedentary behaviour time. Other psychosocial factors associated with reduced functional fitness are loneliness, depression, and exhaustion [10]. Moreover, physical factors impact the ageing process. A decrease in strength leads to a lower functional capacity, loss of balance, and decreased gait speed [12]: older adults generally have a wider gait, postural sway, and greater gait variability when walking [13]. Moreover, the sensorimotor system incorporates all processing and the afferent, efferent, and centrally integrating components involved in joints' functional stability. As people age, this ability becomes limited, leading to important biomechanical changes in gait [14]. Loss of mobility, decreased muscle strength, and a balance deficit all contribute to dependence [15]. Hence, sensorimotor training improves older adults' balance and provides gait confidence, although it does not affect the biomechanical parameters [16]. Several studies on sensorimotor training reported improvement in performance in clinical balance and mobility [17]: sensorimotor training-induced shortened onset latency in postural muscles [18], decreased onset latency, and enhanced reflex activity [19]. Sensorimotor training also induces an improvement in maximal and explosive-force production of leg extensors' capacity [20] and improves lower-limb strength and power, static and dynamic balance, and mobility [21].

Research on how PA affects health-related quality of life (HRQoL) has shown that PA's benefits regarding quality of life were limited [22,23]. Several studies have evaluated the sensorimotor system in the elderly and obtained strength, mobility, and balance improvements, but these results were not consistent due to the reduced sample [20,21], being short-term (12 weeks or less), or only assessing some abilities [17]. This study will last 24 weeks, and its effects will be measured through gait, postural control, strength, flexibility, balance, and agility. Hence, this study will aim to (1) assess the effectiveness of an active

retirement programme on elderly body composition, physical fitness, HRQoL, and PAL and (2) assess the programme's effectiveness throughout the ageing process (follow-up).

2. Materials and Methods

2.1. Design

A parallel-group randomised controlled trial will be conducted, including a 6-month intervention phase and a 1-year follow-up period. For both groups (control and experimental), assessments will be performed at baseline (before starting the intervention), and after the intervention ends. The study will follow the Consolidated Standards of Reporting Trials Statement (CONSORT) [24].

2.2. Ethics

The Ethics Committee of the University of Évora approved this project (approval number: 21040). The study was registered with the ClinicalTrials.gov PRS Protocol Registration and Results System (Registration Number: NCT05398354; <https://www.clinicaltrials.gov/ct2/show/NCT05398354?term=NCT05398354&draw=2&rank=1> (accessed 12 June 2022)).

2.3. Sample Size

Sample size calculations were performed using the G*Power 3.1.9.4 software (Kiel University, Kiel, Germany), selecting the statistical test to compare the difference between two independent means (two groups). Thus, accepting an alpha risk of 0.05 and a beta risk of 0.2 in a bilateral contrast and assuming a moderate effect size of 0.5, a total of 160 participants (80 subjects in the experimental group and 80 in the control group) were sufficient to reach a minimum potency of 90%.

2.4. Randomisation and Blinding

Participants will be randomly assigned to the experimental (active retirement programme) or control groups. To assign participants to each group (1:1), Research Randomizer software (version 4.0, Geofrey C. Urbaniak and Scott Plous, Middletown, CT, USA; <http://www.randomizer.org>, accessed 12 June 2022) will be used to create a randomisation sequence. A member of the research team, who will not participate in the intervention, will carry out this process. Group assignment will be hidden in a password-protected computer file. Participants will know their group assignment, but outcome assessors and data analysts will not know the participants' group assignment.

2.5. Participants

Participants must meet the following inclusion criteria: (1) be retired; (2) be aged between 55 and 80; (3) show their agreement to participate in the study by providing a signed consent form; (4) be individuals without dentures (except dental prosthesis); and (4) not have undergone surgery for less than six months. Exclusion criteria will be individuals with (1) musculoskeletal diseases; (2) locomotion issues; (3) psychiatric disorders; (4) neurological disorders; and (5) cardiovascular diseases.

2.6. Intervention

Experimental group: This sensorimotor training programme will be carried out for six months, twice per week. As shown in Figure 1, as the programme progresses the load will be progressively increased.

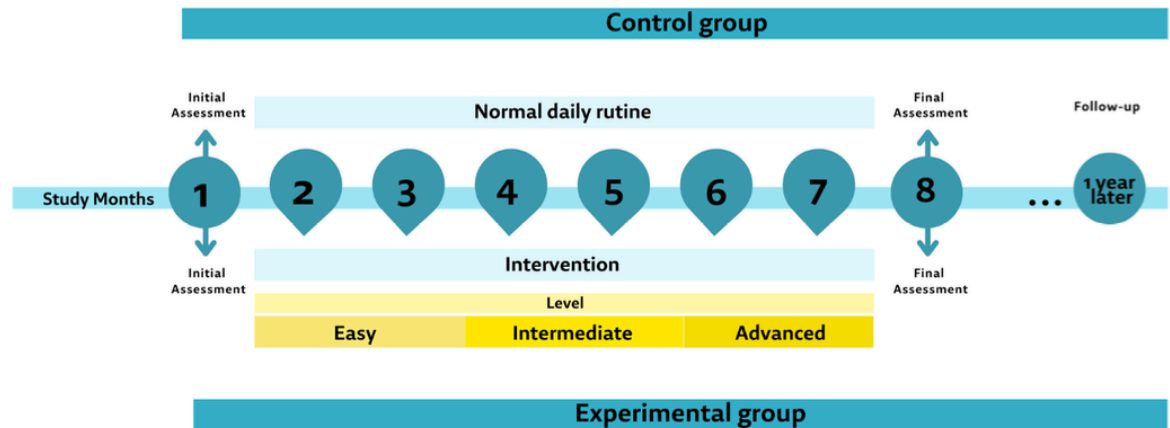


Figure 1. Study timeline graph.

Sessions will be divided into three intensity levels: easy (no external load during the first eight weeks), intermediate (application of external load: elastic bands, shin guards, and free weights, from the 9th week to the 16th week) and advanced (increase in external load for the previous level, from the 17th week to the 24th week). Each month, a different type of session will be developed (Figure 2). Each session will last 45 min and will be divided into three phases: an initial one, consisting of a 5 min walk followed by a joint warm-up (10 min); a fundamental phase (25 min), working on exercises circuits consisting of four cycles, with eight exercises each (50 s on and 15 s off); and a return to calm with muscle stretching (10 min). Additionally, at the end of every session, the intensity will be assessed using the Borg Rating of Perceived Exertion Scale, and the level of satisfaction of the participants will be assessed employing the Physical Activity Enjoyment Scale (PACES) [24].

Control group: Individuals will continue with their normal daily routine, only participating in the assessments. They will be offered to perform the exercise programme when the study ends.

Moreover, to guarantee participants' safety, different strategies will be applied:

- Anamnesis of all participants;
- Hygiene of the material to be used during the sessions;
- Breaks between exercises;
- More than one researcher assisting with the sessions;
- Application of the effort scale.

2.7. Measures

A variety of tools will be used. All measures will be undertaken at baseline, at the end of the intervention, and one year after the end of the intervention (follow-up). Before the first measurement, all participants will go through a familiarisation phase to familiarise themselves with the different instruments and assessments included in this project.

a. **Anthropometrics and body composition.** Bodyweight and height will be assessed. Before the measurements, participants will be asked to remove their shoes, socks, and heavy clothing (coats, sweaters, coats, etc.). They will also be asked to empty their pockets and remove belts and other accessories (bands, pendants, etc.). Height will be measured using a stadiometer (Seca 22, Hamburg, Germany). This instrument must be placed on a vertical surface with the measuring scale perpendicular to the ground. Participants will be positioned in a standing position, with their shoulders balanced, and their arms relaxed along their body. Height will be taken in cm and rounded to the nearest mm. Body weight will be measured using a scale. Body weight will be recorded in kg, and the body mass index (BMI) will be determined using the formula: $\text{weight} \times \text{height}^2$.

b. Physical fitness. Participants will wear tracksuit bottoms and will be asked to remove accessories and any objects in their pockets. The following measures will be carried out (Figure 3): (I) agility and execution speed will be assessed through the Timed Up and Go (TUG) test, which consists of getting up from a chair, walking in a straight line three meters away, and walking back and sitting down again [25]; (II and III) postural control will be tested through a force platform (Ber-tec4060-Columbus; USA). The assessment will consist of measuring the oscillations in a static bipedal position, with eyes open (two minutes) and with eyes closed (two minutes) [26]; (IV) gait will be assessed using the mobile application “Phyphox” on the surface of the skin, at the inner edge of the tibia, to quantify the number of steps and time. Participants will be asked to walk a pre-established route, without slopes or obstacles, for 10 min, at their natural cadence and, later, walk the same route at a pace determined by complex stimuli (auditory metronome—loudspeakers, which allow for hearing beats that correspond to steps) [27]; (V) muscular endurance will be assessed by rising up from the chair or bending and straightening for 30 s, during which the strength of the lower limbs involving the vastus medialis obliquus (VMO) and the vastus lateralis (VL) will also be calculated [28]; (VI) upper limb strength will be determined by the number of times that a weight can be lifted by performing a flexion–extension of the arms for 30 s [28]; (VII and VIII) flexibility will be evaluated by two tests: “the sit and reach” for lower limb flexibility, where participants, from a seated position with one leg extended, will slowly bend down, sliding their hands down the extended leg until they touch (or pass) their toes [28]; and “the behind the back reach” test for upper limbs, assessing the shoulder’s full range of motion, which will consist of measuring with a ruler the distance between (or the overlap of) the middle fingers behind the back [28].

c. HRQoL. This will be assessed using the 36-Item Short-Form Survey (SF-36) [29] in its Portuguese version [30,31], a 36-question tool, which results in 8 dimensions of health status (physical function, physical role, bodily pain, general health, vitality, social function, emotional role, and mental health) and 2 summary components (physical and mental). Dimensions and components are scored from 0 to 100, where 0 is the worst state, and 100 is the best.

d. PAL. This will be assessed using the International Physical Activity Questionnaire Short Form (IPAQ-SF) [32]. This instrument consists of four questions informing on the frequency (days/week) and duration (minutes/day) of daily walks and activities requiring moderate to vigorous physical exertion, as well as the time (minutes/day) spent on sitting activities on weekdays and weekends. PA will be classified into three categories according to the IPAQ consensus group: sedentary (<600 Met-minutes/week), active (≥600 Met-minutes/week), and very active (≥3000 Met-minutes/week). This instrument will be completed by the participants in its Portuguese version [33].

e. Subjective Perception of Effort. This will be assessed through the Borg Rating of Perceived Exertion Scale [34] during the sessions, consisting of 10 items for which participants rate their effort from “not at all” (1) to “maximum” (10).

f. Adherence rate. This will be controlled. For this purpose, following previous studies [35,36] the following parameters will be monitored: proportion of participants completing exercise programmes, proportion of exercise sessions attended, average number of exercise sessions completed per week, class attendance expressed as a proportion of participants reaching certain cutoffs, number of weeks in which exercise was undertaken, and proportion of days on which exercise was undertaken. In addition, recommendations from previous studies will be followed to encourage adherence to the programme, including making instructions to subjects simpler and less demanding, addressing cognitive motivational factors such as self-efficacy and health beliefs, offering social support and reinforcement, and providing reminders [37,38].

g. Level of satisfaction. This will be evaluated through the Physical Activity Enjoyment Scale (PACES) survey, which consists of 8 items that are scored from 1 to 7 points (where 1 = “I enjoy it”, 7 = “I hate it”, and 4 = “neutral”). The total score will be calculated from the sum of the items, with a maximum possible score of 56 points and a minimum

of 8; the higher the score is, the greater the enjoyment is. The Portuguese version will be completed by the participants [24].

2.8. Statistical Analysis

Descriptive statistics and computations will be performed with SPSS (version 25.0; IBM SPSS Inc., Armonk, IL, USA). Personal data will be kept anonymous.

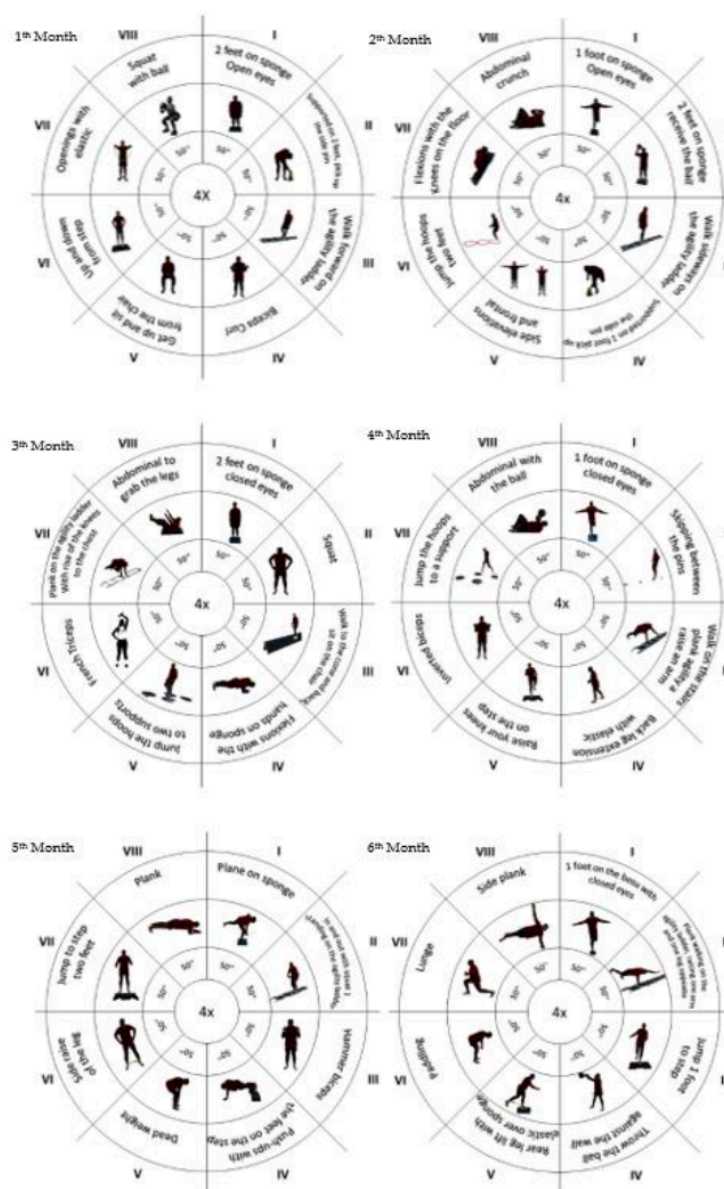


Figure 2. Sessions' main part planning.

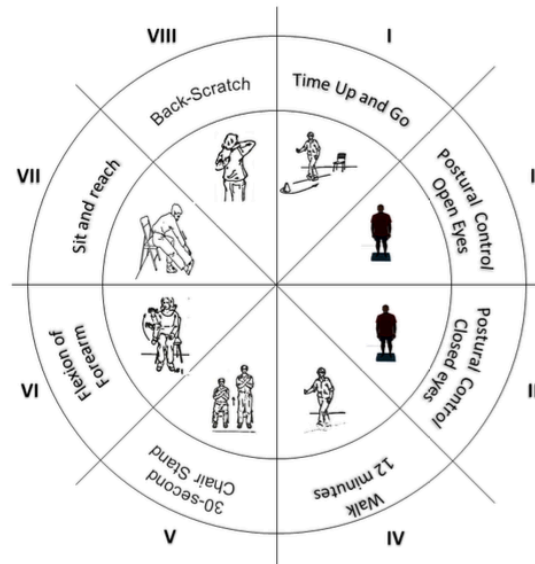


Figure 3. Assessments for physical fitness measurements.

The normality and homogeneity of data will be checked by applying Kolmogorov–Smirnov and Levene’s tests, respectively. Data will be presented as means and standard deviation (SD) (parametric variables) or median and interquartile range (IR) (nonparametric variables). The independent samples t-test (parametric variables) or the Mann–Whitney U test (non-parametric variables) will be used to determine whether the experimental and control groups were comparable at baseline in terms of participant characteristics. Then, repeated measures of ANCOVA will be applied to analyse the intervention effects on the different dependent variables, adjusted by age and baseline outcomes. Cohen’s d (with a 95% confidence interval) will also be included in the results as the effect size. Effect size thresholds will be interpreted as follows: >0.2 , small; >0.5 , moderate; >0.8 , large [36]. Statistical significance will be computed for the effect of time and the interaction group $\times$ time. The alpha level will be fixed at $p \leq 0.05$.

3. Discussion

This project will be the first conducted developing a sensorimotor training programme for 24 weeks using different sensorimotor skills in Portuguese older adults, to test this programme’s effects on HRQoL and fall prevention compared to usual care. Different difficulty levels will be included, facilitating individualisation. This training programme can be applied by multiple agents who might be interested in reaping the benefits of these types of activities, since this training method does not require any specific installation and can be completed indoors or outdoors.

In this sense, Avelar et al. [21] carried out a similar quasi-experimental study, with a similar training period composed of exercise circuits to improve strength, gait, functional reach, and static and dynamic balance, among others. Positive responses in lower limb strength, power, mobility, and static and dynamic balance were found, although the sample was small [20,21,27], compared to the 160 participants expected for our study. Other research [17,18,39] used sensorimotor training programmes on functional capacity and balance for a short time, from two to six weeks. Despite the short period, positive results were obtained concerning balance, mobility, activities of daily living performance, and fall risk. Thus, by improving physical capabilities, fall risk could be lower. Other studies [19–21] have applied 12–13 weeks of sensorimotor training, half of what is proposed in this protocol. There were positive results for mobility and balance and an improved ability to produce the maximum and explosive force of leg extensors. Several of these studies developed

a short-time practical application [39], had a small size [21], or assessed only one or two sensorimotor abilities [17–20]. For all these reasons, no studies with consistent results have produced an advance on this topic, bearing in mind that the percentage of old people practising PA is very low [40], so it is essential to promote PA practise, as sensorimotor skills may be deficient.

The application of this study is expected to obtain an increase in physical capacities such as strength, flexibility, gait, postural control, balance, and agility. In addition, we are also aiming to improve the participants' HRQoL and reduce their fall risk. The programme could be applied to public and private entities. In the public sector, the application of active retirement programmes within the services offered by public health programmes exists at a regional level, as is the case of the "Alma Senior" programme, developed in the Municipality of Almada, Portugal, or the "The Exercise Looks After You" programme, developed in Extremadura, Spain, which increases its cost–benefit ratio for all aspects related to HRQoL and fall prevention in this sector. Likewise, the possibility of implementing this training system in different associations can be studied. In the private sector, a focus group study can include the heads of health and sports centres, focusing on the applicability of sensorimotor training in their centres, with the results of the study able to highlight the potential advantages of private sector application.

The Portuguese population has experienced a substantial increase in average life expectancy in the last four decades. During the same period, there has been a progressive increase in health expenditure [41]. Regarding the relationship between ageing and health expenditure, there does not seem to be a consensus in the literature on the effects of ageing on health expenditure. The literature refutes that population age is a major determinant of health expenditure and other factors, thus considering a strong positive correlation between the two variables. This correlation is not confirmed in the majority of econometric analyses that have been developed in the last two decades in the area of health economics [42]. Thus, PA should be considered an essential item for public health, since, if performed regularly, it is considered an important condition for health promotion and the prevention/remediation of chronic diseases, for different age groups [43].

Regarding limitations, one of the limitations that will exist for the application of this study is being after/during the COVID-19 pandemic. We must take extra care, by adding space and material for the hygienists, to give greater security to the programme. Travel to the space where the programme will be carried out may also be a limitation, considering that the population under study involves people who no longer travel by car; it may be too far away for them to travel on foot, so there will be increased costs due to the necessity of using public transport.

In the future, it would be interesting to evaluate all age groups, in addition to this age group, such as those who are still actively employed, to have a better perception of what happens throughout life in terms of sensorimotor behaviour, not just during the ageing process. This could result in people being able to act from an early age, to improve the capacities analysed in this study. In addition, it would be interesting to add other clinical variables more related to health, such as blood pressure and cholesterol, because, as reported in other studies [44], there were improvements in these variables in the physical condition of participants. We can also analyse the effects of the programme on the number of medical appointments. Finally, applying a pre-participation physical assessment of the participants by a sports physician would be beneficial.

The added value of this study will be the acquired knowledge about sensorimotor training for the elderly, which will present a scientific advancement for PA, HRQoL, and sedentary behaviour prevention. Finally, it will be innovative in creating an intervention manual and a digital library with specific exercises for sensorimotor training, which allow for better adaptation and motor coordination.

4. Conclusions

This study will investigate the effectiveness of an active retirement programme in the elderly on their body composition, physical condition, HRQoL, and fall risk, advancing the knowledge of PA, health, and wellness.

Author Contributions: Formal analysis, J.A.P. and O.F.; investigation, C.A.C. and M.M.-M.; supervision, O.F.; writing—original draft, C.A.C. and S.B.-F.; writing—review and editing, J.A.P., R.G.-G. and M.M.-M.; visualisation, S.B.-F. and L.M.-B.; funding acquisition, L.M.-B. and R.G.-G. All authors have read and agreed to the published version of the manuscript.

Institutional Review Board Statement: The study was approved by the Ethics Committee of the University of Évora (approval number: 21040).

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

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Conflicts of Interest: The authors declare no conflict of interest.

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CASE REPORT

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Assessment of spatiotemporal characteristics of gait, through the Phyphox[®] app: a case series

Carolina A. Cabo^{1,2,3*} , Orlando Fernandes^{1,2}, Sara Santos^{1,2} and Jose A. Parraca^{1,2*}**Abstract**

Background Spatiotemporal characteristics from human locomotion can provide effective clinical metrics to assess motor control and brain function. This case report aims to assess the temporal structure of variability in stride-to-stride time and calculated the intrinsic fractal frame that is hidden below the repetitive structure of physiological gait through the “Phyphox” app. This is an innovative study from the perspective of analyzing gait variables through a mobile app.

Case presentation Five older adults Caucasian (3 women; age = $73 \pm 10,5$ years; body mass = $62,2 \pm 15,1$ kg; height = $1,56 \pm 0,1$ m; 2 men; age = $75,5 \pm 7,8$ years; body mass = $86,3 \pm 18,0$ kg; height = $1,77 \pm 0,1$ m) participated in this study. Five participants were asked to walk with a natural cadence, two of the participants presented a value greater than 80 steps/minute (81.14 ± 0.01 ; 86.67 ± 0.02); and the others had values between 55 and 65 steps/minute (55.20 ± 0.02 ; 55.78 ± 0.05 ; 61.02 ± 0.05). Regarding the coefficient of variation, only one participant presented 10.08%. For the total number of steps, three of the participants had values greater than 1000 steps. The variability of these stride-to-stride time has been quantified through detrended fluctuation analysis; one participant presented a value above 1.

Conclusions This study provides evidence that a smartphone might provide a valid measure to assess the spatiotemporal characteristics of gait.

Keywords Biomechanics, Case report, Fractals, Gait, Smartphone

Background

Aging is defined as a natural and physiological process that progressively accompanies the life cycle and involves complications in the psychosocial and physical spheres, thus generating slow thinking, depression, functional disability, loss of resistance, inactivity, and physical degeneration. The changes in the rhythmically of the stride-to-stride are important to assesses the motor control and is been demonstrated an increase in variability in stride time intervals between elderly population and healthy adults [13]. Research over the last few decades has examined the properties of adaptive and functional biological systems through gait analysis during treadmill and floor locomotion, showing that healthy

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and clinical populations can exhibit similar variability in their rhythms despite having different functional behaviours. All biological rhythms exhibit some level of variability, and while some of these systems remain adaptive and functional, others they are maladaptive and dysfunctional. Consequently, the risk of injury increases if the person is not able to adapt their gait [3].

Active aging contributes to the maintenance of functional capacity, quality of life and independence. The functional changes inherent to the aging process can lead to situations of imbalance and, consequently, increase the risk of falling [10].

Worldwide, falls are the second leading cause of accidental death, with those over the age of 65 experiencing the highest proportion of fatal falls. Injury resulting from falls is associated with reduced physical functioning, loss of independence, and fear of future falls, which in turn can lead to reductions in physical activity and social engagement [7].

It becomes relevant to develop preventive measures relating the risk factors for the occurrence of falls. The clinical approach should contain a good history related to past falls and, in addition, the assessment of muscle strength and range of motion as well as performing gait and balance tests. The application of functional tests is intended to assist the clinical evaluation by providing data on the patient's mobility capacity and revealing possible balance deficits [10].

By providing seniors with appropriate health apps, they can independently and self-determinedly monitor and manage their health. Smartphones have many sensors capable of measuring and tracking vital parameters as well as other health-related data. Healthcare applications analyse and process this data and therefore can provide comprehensive support to healthcare services in the future [8].

More specifically, the rhythmic variability inherent to these systems also exhibited fractal scaling (that is, patterns of variability at one time scale are like those found at other time scales). Thus, more recently, metrics that index the structure of variability have gained favour in the literature because of their ability to quantify the dynamic, time-evolving nature of the locomotor system's rhythmic behaviour [9].

Technological advances allow the updating of techniques and procedures used by health professionals, such as the use of mobile devices as support devices. Smartphones have great potential as they are accessible, practical, and portable devices, which can help from data collection procedures to the diagnosis of diseases [10, 12].

Within the free license applications available for the Android and IOS operating system, Phyphox [12] has

stood out for allowing the use of a variety of sensors to perform various activities, while most applications have its limited use. With interactive graphic resources and real-time measurements, the data obtained is analysed directly in the application, which allows a quick reading even without the use of a computer. The application also offers data export and sharing options, so that they can be processed later and in a more robust program [5].

The Phyphox application was developed at the second Institute of Physics of the Technical University of Aachen, Germany. With this application we can carry out Physics experiments using the smartphone. This is possible because the application allows using the device's sensors to perform evaluations such as detecting the frequency of a simple pendulum using the smartphone's own accelerometer sensor. This application can be used free of charge and can be found for download on its official website (phyphox.org). The basic prerequisites to be able to use the application are some sensors, among them: accelerometer, microphone, light sensor, and proximity sensor. In general, the more sensors the device has, the more experiences can be used, as the greater the scope that can be reached [6].

Phyphox is an application available for Android and IOS. It is possible to use the various sensors existing in smartphones with this application, as it has several functions such as: accessing measurements of acceleration, rotation rate and smartphone location. It is also possible to carry out measurements of magnetic field, pressure, light intensity, and sound intensity [11]. By the application it is still possible to obtain a direct estimate of the gravitational acceleration, performed in real time [5].

Case presentation

Demographic details

A study was carried out to collect data through a practical test. Data was collected between December 2021 and July 2022 through the recruitment of participants who were members of the physical activities group of the Municipality of Almada (MA), more specifically a project called Active Retirement that consisted of promoting the practice of physical activity with stimulation of the sensorimotor abilities of pre-retirees and retirees, protocol between the University of Évora (UE) and the MA.

From the group of participants, we randomly chose five individuals for this pilot study.

Five older adults (3 women; age = $73 \pm 10,5$ years; body mass = $62,2 \pm 15,1$ kg; height = $1,56 \pm 0,1$ m; 2 men; age = $75,5 \pm 7,8$ years; body mass = $86,3 \pm 18,0$ kg; height = $1,77 \pm 0,1$ m) participated in this study. The study was approved by the Ethics Committee of the University of Évora (approval number: 21040). Each participant provided informed consent prior to participation according



to Helsinki for human studies. Prior to any walk test, participants underwent a general health assessment for inclusion criteria and demographics.

Medical history

Participants under 55 years of age were excluded. The inclusion criteria defined were: (1) age over 65 years; (2) people without dentures (except dental prosthesis); (3) people who have not been operated on for less than 6 months; (4) residents in the municipality of Almada. Exclusion Criteria: (1) people with musculoskeletal diseases; (2) people with locomotion problems; (3) psychiatric diseases and neurological disorders; (4) people with a clinical cardiovascular and cardiopathies.

Initially, an anthropometric and body composition assessment was performed, through weight and height analysis. For 5 participants, 3 female and 2 males, we calculated the BMI index using the Centers for Disease Control and Prevention (CDC) adult calculator.

Treatment or intervention

We asked participants to complete a 12-minute walk without stimulation (self-paced walking) and were instructed to walk at their self-selected pace while looking straight ahead.

The first 15 seconds were discarded to avoid any initial adaptation. Likewise, the last 15 seconds have been discarded to avoid cadence slowing effects. The mean and coefficient of variation were calculated for each time series of inter-stride intervals (ISIs). The fractal scale exponent, α , was also calculated from the time series of ISIs. The fractal-scaling exponent, α , was also calculated from the ISIs time series (α -ISIs) using DFA.

The $\log F(n)$ is plotted against $\log n$ (the root mean square versus window sizes). The slope of this graph is the reported α value. If the α value is greater than 0.5, the long-range correlation is positively persistent. This means that increases are likely to be followed by increases and decreases are likely to be followed by decreases. Whereas if the α value is less than 0.5, the long-range correlation is anti-persistent, meaning that increases are likely to be followed by decreases and vice versa. If the α value is greater than 1, the signal is considered brown [1].

In the present study, the stimulus was designed to have an α value of 1, indicating pink noise and fractal complexity in the signal. On the other hand, a lower value indicates loss of complexity. For example, a white noise signal type (that is, highly variable and unstructured) typically has an α value of 0.5. The Detrended Fluctuation Analysis (DFA) window size range selected in the current study was from 16 to $N/8$, where N is the number of pass intervals.

Table 1 Demographics and sample's characteristics

Participant (code)	Age	Weight	Height	BMI
'009	81	73,6	1,72	24,9
'012	84	69,8	1,57	28,3
'106	70	99	1,83	29,6
'111	72	44,8	1,42	22,2
'113	63	71,9	1,69	25,2

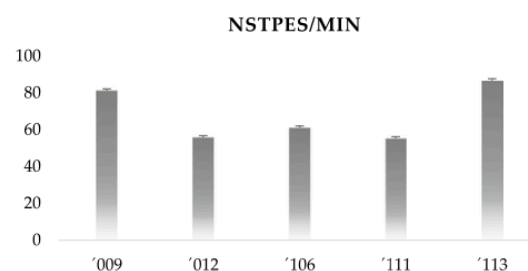


Fig. 1 The total number of steps per minute for each participant

Nonlinear methods were analyzed through number of steps per min, standard variation, coefficient of variation, total number of steps, and the fractal dimension using the trended fluctuation analysis, from five time series of 10 minute' walk.

Results

Five subjects were evaluated, 3 women and 2 men, aged between 60 and 85 years old. According to BMI, we can see that only one of the participants has a normal value, the rest are overweight (Table 1).

Regarding the number of steps per min, two of the participants presented a value greater than eighty steps per min ($81,14 \pm 0,01$; $86,67 \pm 0,02$); and the others had values between 55 and 65 steps per min ($55,20 \pm 0,02$; $55,78 \pm 0,05$; $61,02 \pm 0,05$) (Fig. 1).

Regarding the coefficient of variation, only one participant presented 10.08%, and the others presenting values between 2 and 4%.

The total number of steps, three of the participants had value greater than 1000 steps and the other two approximately 600 steps.

Finally, regarding the fractal dimension, only one participant presented a value above 1, with the remaining values between 0.7 and 0.8 (Table 2).

Discussion and conclusions

This study aimed to assess the temporal structure of variability in stride time and calculated the intrinsic fractal frame that is hidden below the repetitive structure of



Table 2 Summary results for all the studied gait variables in all conditions

nSteps/min	±	sd	%CV	nSteps	Fractal
81,147	±	0,012	2,688	1309	0,712
55,783	±	0,045	4,851	667	1,059
61,028	±	0,051	10,076	1154	0,685
55,203	±	0,019	2,075	646	0,831
86,678	±	0,016	3,282	1188	0,771

physiological gait. To the best of our knowledge, this is the first study to analyse these characteristics in the Portuguese population.

Since there are no studies in Portugal, we discussed our results using information from other countries.

The study population was categorized using the CDC calculator. When we analysed the height and weight of the study participants, we found that only one of the five participants was of normal height and weight, with the rest being overweight and obese [2].

As expected from older adults, we observed in this study a lower fractal scaling as compared to what is typically observed in healthy young adults during overground walking [14, 15]. A mean value of $\alpha=0.81$ indicates that the older adults of the present study present fluctuations in their gait pattern that are more towards randomness ($\alpha=0.5$ is typically observed in white-noise type of signals). This represents a breakdown in the fractal structure ($\alpha \sim 1.0$) of the gait patterns observed in healthy adults. This breakdown has previously been observed as an effect of aging and in the presence of neurological diseases [15].

Likewise, fallers older adults also exhibit a breakdown in fractal scaling compared to non-fallers [4]. Therefore, restoring the fractal structure in older adults can possibly result in other health-related outcomes.

This study provides evidence that a smartphone might provide valid measure to assess the spatiotemporal characteristics of gait and provide gait variability training.

Abbreviations

CDC	Centers for disease control and prevention
DFA	Detrended fluctuation analysis
ISIs	Inter-stride intervals
α -ISIs	ISIs time series
MA	Municipality of Almada
UE	University of Évora

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Author contributions

Formal analysis, JAP, and OF; Investigation, CAC; Supervision, OF; Writing—original draft, CAC; Writing—review & editing, JAP and OF; Visualization, SS. All authors have read and agreed to the published version of the manuscript.

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Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The study was approved by the Ethics Committee of the University of Évora (approval number: 21040).

Consent for publication

Written informed consent was obtained from the patients for publication of this case report and any accompanying images. A copy of the written consent is available for review by the Editor-in-Chief of this journal.

Competing interests

The authors declare that they have no competing interests.

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The impact of sensorimotor training on physical fitness in older women with diabetes: a pilot study

Carolina A. Cabo^{1,2,3,4*}, Jose A. Parraca^{1,2}, Orlando Fernandes^{1,2}, Paulo Nunes^{3,5,6}, Cláudia Mendes^{1,2,7} and Mário C. Espada^{2,3,4,5,8}

Abstract

Aging and diabetes mellitus (DM) are associated with declines in physical fitness, such as reduced muscle strength, balance, and flexibility, increasing the risk of falls and functional limitations. This pilot study used a quasi-experimental design with pre- and post-intervention assessments to evaluate the effects of a 6-month sensorimotor training (SMT) program on physical fitness in older women with type 2 diabetes. Ten women aged 65 and older were divided into an intervention group (IG, $n=5$) and a control group (CG, $n=5$). The IG participated in a twice-weekly SMT program, while the CG maintained their usual routines. Physical fitness was assessed at baseline and after 24 weeks using the Timed Up and Go (TUG) test for agility and dynamic balance; the 30-second sit-to-stand test for lower limb strength; the arm curl test for upper limb strength; and the sit-and-reach and back scratch tests for lower and upper limb flexibility, respectively. The IG showed significant improvements in agility (TUG, $p=0.020$), lower limb flexibility (sit-and-reach, $p=0.049$), and upper limb flexibility on the left side (back scratch, $p=0.023$) compared to the CG. Both groups improved in lower limb strength ($p=0.330$), while upper limb strength showed no significant changes ($p=0.166$). Although the CG also improved in some measures, the IG achieved greater functional gains. These results suggest that SMT enhances neuromuscular control, proprioception, and flexibility—key factors in reducing fall risk and improving independence in older adults with diabetes. SMT appears to be a promising intervention to support physical function, balance, and quality of life in this population.

Trial registration

Clinical trial registry 01/09/2021. Clinical trial number: NCT05398354. Trial Name: Active Retirement: Effects of the Application of a Training Program.

Keywords Exercise therapy, Proprioception, Aging, Diabetes mellitus, type 2, Range of motion, articular, Muscle strength

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Introduction

Aging is a multifactorial process characterized as a natural and physiological process that progressively accompanies the life cycle. In addition to complications within the psychosocial domain, significant physical deterioration also occurs, resulting in cognitive slowing, depression, functional incapacity, diminished resilience, inactivity, and physical degeneration [1]. The functional changes intrinsic to the aging process, such as decreased mobility and muscle strength, may precipitate conditions of imbalance and, consequently, elevate the risk of falls among elderly individuals. Falls in the elderly population are associated not only with the use of medication but also with factors such as frailty and functional decline [2, 3].

The World Health Organization (WHO) states that there is clear evidence that people over 65 years of age who are inactive have several associated diseases and that mortality rates from strokes, coronary heart disease, type 2 diabetes mellitus (T2DM), and hypertension, among others, are higher [4, 5]. T2DM is a growing global health concern, with prevalence expected to triple in the coming decades, particularly affecting older women, who often experience worse metabolic control and greater physical limitations. DM increases the risk of cardiovascular disease, neuropathy, and musculoskeletal impairments. Age-related declines in muscle strength, balance, and coordination, combined with diabetes-related complications such as peripheral neuropathy, heighten the risk of falls and functional limitations in this population [6]. In the coming decades, the number of patients with DM is expected to triple [7].

The WHO states that there is clear evidence that regular physical activity (PA) yields significant benefits for individuals over 65 years of age. These individuals are usually less active and, therefore have diseases related to inactivity, such as DM. This metabolic disease mortality rates are lower among older adults who are more active than among those who are less active [8].

Despite these known benefits, fewer than one-fifth of people with diabetes meet recommended physical activity levels [9]. Exercise is widely recognized as a cornerstone of diabetes management, offering significant benefits for glycemic control, cardiovascular health, and overall well-being. Regular PA has been shown to improve insulin sensitivity, reduce HbA1c levels, and support weight management, which are critical for older women with diabetes. Additionally, exercise enhances muscle strength, bone density, and balance, reducing the risk of falls and osteoporosis, which are common concerns in aging populations. Psychological benefits, including reduced stress and improved mental health, also contribute to a better quality of life for older women managing diabetes [10, 11]. Furthermore,

exercise reduces total daily insulin requirements, stress, and depression while improving the quality of life (QoL) of individuals [12–14].

Recent studies underscore the critical role of education in the self-management of type 2 diabetes, particularly among older adults. A qualitative and quantitative study conducted in Indonesia demonstrated that the implementation of a manual self-management companion book was highly accepted by diabetic patients and health-care providers alike. Most participants—elderly individuals from lower socioeconomic backgrounds—lacked access to digital devices, reinforcing the value of printed educational materials. The manual book served not only as an informational tool but also as a monitoring aid, allowing patients and health professionals to track glycemic levels, HbA1c results, and medication use over time. These findings support the idea that accessible, culturally adapted educational resources are essential for enhancing patients' understanding, compliance, and quality of life [15].

A systematic literature review identified eight core elements of precision health care for patients with diabetes: self-management, interdisciplinary collaborative practice, personalized genetic or lifestyle factors, glycemic targets, patient preferences, glycemic control, patient priority-directed care, and biodata- or evidence-based practice. These components form a comprehensive framework for implementing precision healthcare strategies in clinical settings, offering a structured and patient-centered approach to diabetes care [16].

Sensorimotor training (SMT) was selected for this study due to its unique focus on improving balance, proprioception, and neuromuscular coordination—all critical areas that decline with age and are further compromised by diabetes. Unlike traditional strength or aerobic exercise, which typically focuses on cardiovascular health or muscle strength, SMT directly engages neural and sensory systems essential for physical stability, coordination, and efficient movement [17]. With age and in the context of diabetes, proprioceptive feedback deteriorates due to peripheral neuropathy and neurodegeneration, which compromises balance and increases fall risk [18, 19]. The SMT stimulates the neuromuscular system by activating sensory pathways and motor responses that maintain postural control. This approach is essential for addressing age-specific and diabetes-related declines in physical function [20].

Neuroplasticity is a key mechanism through which SMT exerts its effects. Repetitive sensorimotor stimuli help restore proprioceptive feedback by stimulating mechanoreceptors and strengthening neural circuits involved in postural control and coordination [21]. These adaptations improve reaction times and dynamic



stability, contributing to fall prevention and better mobility in this population.

Skeletal muscle function also benefits from SMT. By activating both slow- and fast-twitch fibers, sensorimotor exercises improve muscular endurance and power, combatting age- and diabetes-related muscle atrophy [22]. Neuromuscular adaptations enhance motor unit synchronization, enabling more efficient movement execution. These physiological effects likely explain the improvements observed in agility and lower limb strength among participants in the intervention group. Increased muscle strength is essential for preserving autonomy and reducing fatigue in daily life [23].

This specific training focuses on improving neuromuscular control, postural stability, and coordination by challenging the body's sensory and motor systems. Research has shown that SMT improves gait, muscle activation, and overall balance in older adults with T2DM [24, 25]. Given that older women with diabetes face higher risks of functional decline, loss of independence, and lower quality of life compared to men [26], implementing SMT as a targeted intervention could offer significant physical and psychological benefits.

Therefore, this study aimed to evaluate the effects of a 6-month SMT program on physical fitness in older women with type 2 diabetes mellitus.

Materials and methods

Design

This investigation is part of a study protocol, registered at ClinicalTrials.gov (Identifier: NCT05398354) under the title "Active Retirement: Effects of the Application of a Training Program." The authors confirm that all ongoing and related trials for this intervention are registered. This is a quasi-experimental, two-arm pilot study with pre- and post-intervention assessments. Participant recruitment occurred from 1 November 2021 to 2 January 2022. This study was developed at the University of Évora, and the measurements were made at two time points: the first on 5 January 2022 and the second on 30 July 2022, both in the municipality of Almada (Portugal).

Participants

Ten elderly women with type 2 DM were selected from the list of registered clinical trials to participate in this pilot study. These 10 women were part of an intervention and control group (IG and CG, respectively) comprising a total of 160 older people. Detailed information about treating diabetic patients typically involves understanding the different approaches tailored to individual needs, including lifestyle modifications, oral anti-diabetic drugs, and insulin administration. In this study, participants were treated with insulin (Fig.1).

Subjects were selected because they have similar characteristics (weight, height, and body mass index - BMI), apart from age, and both suffer from the same pathology DM. All the samples were evaluated at equivalent times. Thus, we analyzed five participants in the IG, who carried out the training program in addition to the assessments, and a second group, the CG, who carried out only the initial and final assessments without having practiced the training program. The selection of participants was random. The inclusion criteria were: (1) women over 65 years of age; (2) diagnosis of type 2 diabetes mellitus; (3) not having undergone recent (<6 months) surgical intervention; (4) no musculoskeletal diagnosis or problems with locomotion; (5) no psychiatric or neurological disorders; and (6) no clinical cardiovascular conditions. Exclusion criteria included: (a) presence of vascular complications related to diabetes—including nephropathy, retinopathy, or polyneuropathy (due to safety concerns and to maintain homogeneity in this initial pilot sample, as neuropathy can significantly alter balance and proprioceptive function); (b) high arterial hypertension; (c) diabetic foot; and (d) other diseases affecting the lower limb's function.

Intervention

The intervention group participated in a 24-week SMT program, delivered twice weekly (Frequency), with each session lasting 45 min (Time). The training intensity was progressive (Intensity) and based on each participant's tolerance and physical condition. The Type of exercise focused on balance, coordination, proprioception, and neuromuscular control. This structure followed the FITT principle (Frequency, Intensity, Time, and Type), a recognized model for prescribing individualized and progressive training programs [27]. The program was structured into three progressive intensity phases:

- Weeks 1–8 (Initial Phase – Easy): Exercises without external resistance, focusing on postural control, balance, and functional movement.
- Weeks 9–16 (Intermediate Phase): Introduction of low-level resistance using elastic bands, ankle weights, and hand-held weights.
- Weeks 17–24 (Advanced Phase): Further increase in load intensity using the same equipment to promote strength and neuromuscular control.

Each session followed a consistent structure:

- Warm-up (10 min): Light walking followed by joint mobility exercises.
- Main training (25 min): Circuit training composed of 4 rounds of 8 exercises (50 s of activity, 15 s of rest).



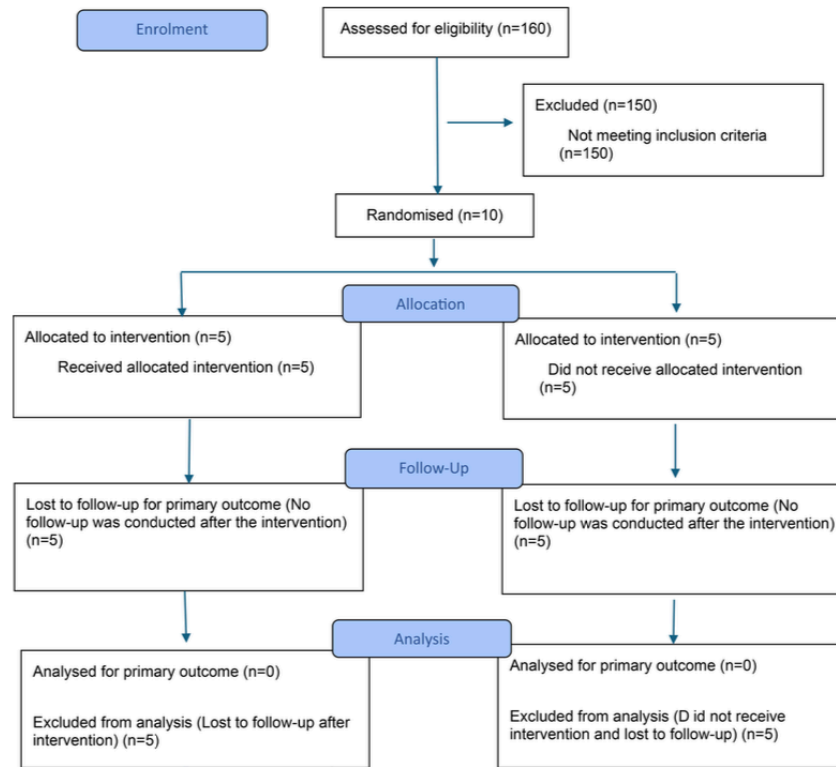


Fig. 1 CONSORT 2025 flow diagram

Exercises targeted balance, coordination, strength, and proprioceptive stimulation.

- Cool-down (10 min): Static stretching and breathing exercises.

Progression was individualized based on performance and tolerance. Post-session perceived exertion was recorded using the Borg Scale, and monthly enjoyment and satisfaction were monitored through the Physical Activity Enjoyment Scale (PACES). Attendance was recorded at every session.

The control group did not receive any structured physical training and continued with their usual activities. They only participated in the baseline and final assessments.

Ethics approval

The Ethics Committee of the University of Évora approved this project (approval number: 21040). In addition, the participants provided written informed consent following the Helsinki Declaration [28].

Sample size

Sample size calculations were performed using the G*Power 3.1.9.4 software (Kiel University, Kiel, Germany), selecting the statistical test to compare the difference between two independent means (two groups). The calculation was based on a power of 0.80, $\alpha = 0.05$, and an estimated moderate-to-large effect size (Cohen's $d = 0.99$), which indicated a minimum of 5 participants per group for this pilot study. The participants were selected to identify clinically relevant differences in physical fitness outcomes.

Instruments

Anthropometry and body mass index

Body weight (scale), height (stadiometer), and BMI were assessed. Before beginning any of the measurements, the participants were asked to remove their shoes, socks, and heavy clothing (jackets, sweaters, coats, etc.). They were also asked to empty their pockets and remove their belts and other accessories (bands, pendants, etc.). Height was measured via a stadiometer (Seca 22, Hamburg, Germany). The instrument was placed on a vertical surface with the measuring scale perpendicular to the ground. The participants stood with their shoulders balanced and



their arms relaxed along the body. Height was measured in cm and rounded to the nearest mm. Body weight was measured on a scale. Body weight was recorded in kg. BMI was determined via the following formula: weight/height².

Physical fitness

To assess physical fitness, two attempts were made for each test applied, including the TUG, strength, and flexibility tests. All instruments and tests used in this study (e.g., TUG, sit-to-stand, arm curl, sit-and-reach, and back scratch) are validated and widely used in older adult populations. Their reliability has been demonstrated in previous studies, with test-retest intraclass correlation coefficients (ICCs) typically ranging from 0.80 to 0.97. Between the two attempts, participants were given a 2-minute rest. The following measurements were then taken:

- I. Agility and speed were assessed using the Timed Up and Go (TUG) test in seconds (s), in which participants were instructed to stand up from a standard chair, walk 3 m, turn around, walk back, and sit down again [29];
- II. (ii and iii) Strength was evaluated through the number of repetitions (reps) performed from two tests. The first consisted of evaluating lower limb strength (SL) by counting how many times the participant could sit down and stand up from a chair for 30 s [30], and the second upper limb strength was determined by the number of times a weight could be lifted by performing flexion-extension of the arms (FA) for 30 s [30];
- III. (iv and v) flexibility was evaluated via two tests. For flexibility of the lower limbs, a “sit and reach” (SA) was performed, where the participants, from a sitting position with one leg extended, slowly lowered themselves, sliding their hands down the extended leg until touching (or passing) their toes [30]. For flexibility of the upper limbs, the “behind the back reach right and left” tests (AD and AE) were carried out, which evaluated the entire range of movement of the shoulder and consisted of measuring the distance between (or the overlap of) the middle fingers behind the back with a ruler [30]. In both cases, the measurement used was in centimeters (cm).

Procedures

A variety of tools were used for the assessments, based on the tests applied. All measures were taken at the

beginning and end of the intervention. Before the first measurement, all the participants went through a familiarization phase to familiarize themselves with the different instruments and assessments included in this project.

Experimental group: The participants enrolled in the SMT program carried out exercises for 6 months, twice a week. As the schedule progressed, the load progressively increased. To this end, the session was divided into three levels of intensity: easy (no external load during the first eight weeks), intermediate (application of an external load: elastic bands, shin guards, and free weights, from the 9th to the 16th week) and advanced (increase in the external load to the previous level, from the 17th to the 24th week). Each month, a different type of session was developed. The duration of each session was 45 min, which was divided into three phases: the initial phase (10 min), consisting of 5 min of walking followed by a joint warm-up; and the fundamental phase (25 min), where we worked on an exercise circuit. This circuit consisted of 4 cycles, with eight exercises each (50s on, 15s off) and a return to calm (10 min), where muscle stretching was performed. In addition, at the end of each session, the intensity was evaluated via the perceived exertion (PSE) scale, and the adherence rate and satisfaction level were measured via the Physical Activity Enjoyment Scale (PACES) [31]. In the CG, the participants continued with their normal daily routine, with only participants in the assessments (Fig.2).

Statistical analysis

Descriptive statistics and calculations were performed using Jamovi (version 1.6) [computer software]. The data are presented as the means and standard deviations ($M \pm SD$). We tested for normality using the Shapiro-Wilk test and for homogeneity using Levene's test. Parametric or nonparametric tests were performed depending on data distribution.

To compare the dependent variables, Student's t-test for paired samples was used within groups, and two-way ANOVA (group $\times$ time) was applied after test for sphericity and homogeneity of variances to evaluate between-group differences. Statistical significance was set at $p < 0.05$. The effect size (ES) was used to analyze the magnitude of change and was interpreted according to Eta squared (η^2): Small effect size (0.01–0.06); Medium effect size (0.06–0.14); Large effect size (> 0.14).

Results

Participant details

Table 1 shows the details of the study participants. According to the results, these ten women were similar in age. In terms of weight and height, they are similar, both being overweight [33].



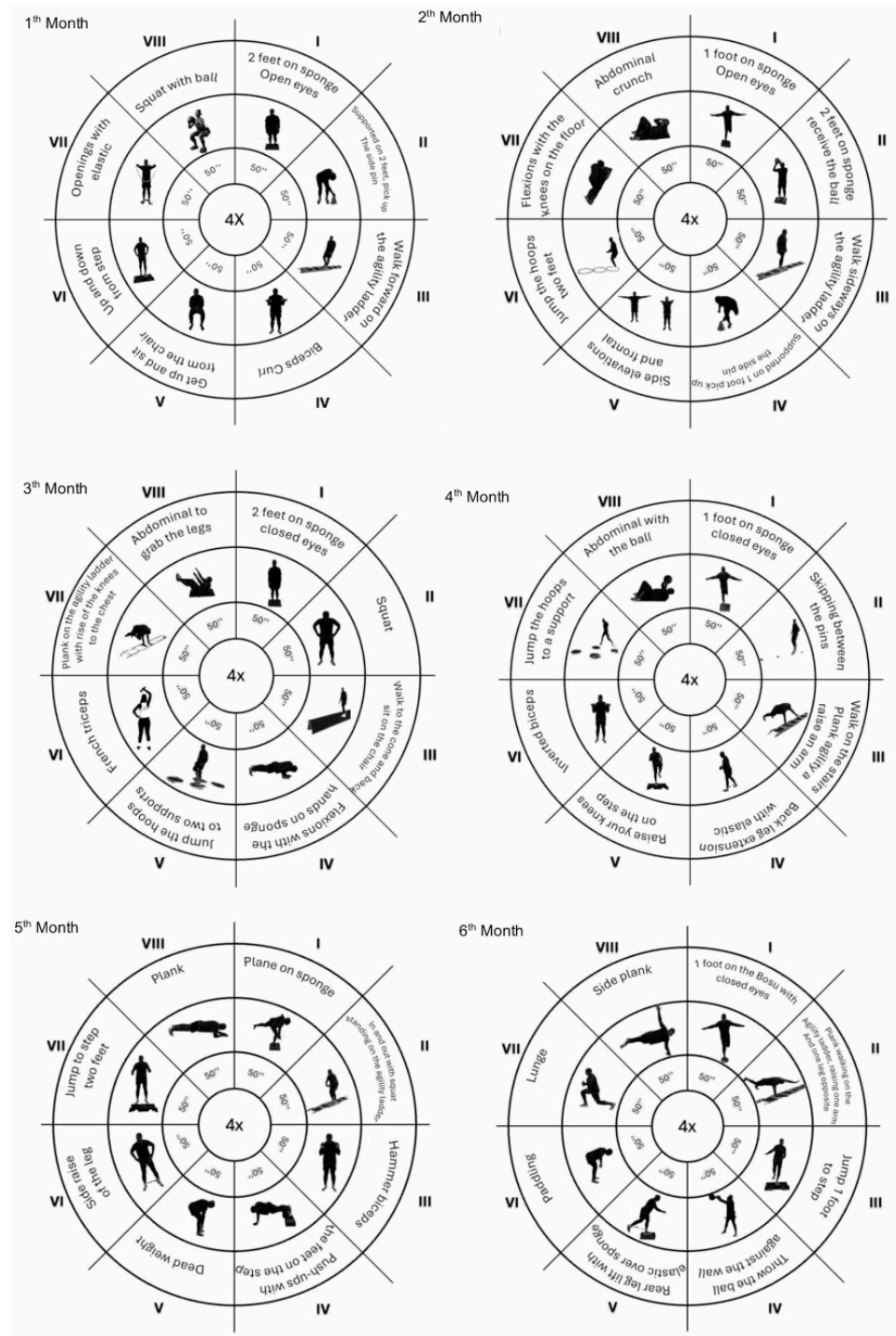


Fig. 2 Intervention used for sensorimotor training [32]



Table 1 Baseline characteristics of the participants

Group/Variables	CG	IG	<i>p</i>
Age(years)	80.00 ± 3.54	74.60 ± 3.78	0.048
Weight(kg)	72.80 ± 19.90	74.90 ± 14.80	0.856
Height(m)	1.53 ± 0.05	1.54 ± 0.06	0.719
BMI(kg/m ²)	31.20 ± 8.20	31.60 ± 6.16	0.937

The Student's *t* values indicate no significant differences between groups, except for age, which was significantly different (*p* = 0.048).

To assess physical fitness, the following measurements were carried out: agility and speed of execution; strength; and flexibility. Both the weight and BMI of both groups decreased, with the IG having a greater reduction.

With regard to agility and speed, as shown in Table 2, the CG, despite having an initial value of 9.26s, which is greater than that of the IG, managed to improve its test execution time after the intervention to 7.59s. The IG started at 8.46s and reached 7.49s in the second evaluation.

In terms of strength capacity, the strength of the lower limbs was evaluated through the sit-and-stand test (SL), and the strength of the upper limbs was evaluated through the forearm flexion test (FA). In the SL test, the CG had a lower mean value in the first evaluation (11.60 repetitions), and in the second evaluation, it increased the mean value to 13.80 repetitions. The IG started with a slightly greater value of 12.20 repetitions and then increased one more repetition to 13.20 repetitions in the second evaluation.

Table 2 shows that CG in the FA test resulted from the first evaluation of 16.80 repetitions, but in the second evaluation, the result increased by two repetitions to 18.20 repetitions. The IG obtained a superior result in the first assessment of 18.80 repetitions but reduced its

value to 18.20 repetitions, finishing the second with the same number of reps as the CG. Although we do not have significant *p* values, we have some moderate ES, such as weight (*p* = 0.351), BMI (*p* = 0.406), SL (*p* = 0.330), FA (*p* = 0.166), AD (*p* = 0.290), and large ones, such as TUG (*p* = 0.649) and SA (*p* = 0.719). Because our objective was to understand the impact of exercise on these patients, as shown in Table 2, the IG improved, as did the CG. In other words, the group that received the in-tervention exhibited substantial differences even though there were no significant differences between the groups, which supports the ES that we previously reported.

In terms of flexibility, we analyzed the flexibility of the lower limbs through the sit and reach test (SA) and the flexibility of the upper limbs through the test reach behind the right back (AD) and reach behind the left back (AE). As we can see in Table 2, in the SA test, CG obtained a value of −6.80 cm in the first evaluation, which was worse than that of IG (−4.40 cm), but its result improved by five cm, reaching −1.60 cm. On the other hand, the IG ranged from −4.40 cm in the first assessment to −0.20 cm. Both groups improved their scores on average in this test. In the AD test, CG presented an initial value of −23.30 cm, which was worse than that of IG (−17.60 cm) but presented improvements of three cm for the second evaluation (−20.20 cm), whereas IG improved its result by seven cm, ranging from −17.60 cm on average to −10.20 cm. In this case, the IG obtained better results. In the AE test, CG has an initial value of −28.40 cm, which is greater than that of IG (−19.60 cm), and its value increases from 7.00 cm to −35.00 cm. The IG, in addition to presenting a lower initial value, reduces the distance on average by 5.00 cm, ending the second evaluation with a value of −13.60 cm.

Table 2 Main outcomes between the first and second assessments in both groups (CG *n* = 5; IG *n* = 5)

Variables	Before Exercise Baseline		After Exercise 24 weeks		<i>p</i>	η ²	CI 95%
	CG	IG	CG	IG			
	M ± SD	M ± SD	M ± SD	M ± SD			
Weight(kg)	72.80 ± 19.90	74.90 ± 14.80	71.50 ± 19.10	72.30 ± 15.4	<i>p</i> = 0.351	0.109 [#]	(54.1;91.6)
BMI(kg/m ²)	31.20 ± 8.20	31.60 ± 6.16	30.60 ± 7.79	30.50 ± 6.63	<i>p</i> = 0.406	0.088 [#]	(23.4;38.5)
TUG(s)	9.26 ± 2.38	8.46 ± 1.36	7.80 ± 1.63	7.49 ± 0.80	<i>p</i> = 0.649	0.027 [#]	(7.1;9.5)
SL(rep)	11.60 ± 2.70	12.20 ± 1.92	13.8 ± 4.09	13.20 ± 1.30	<i>p</i> = 0.330	0.118 [#]	(10.1;15.3)
FA(rep)	16.80 ± 3.03	18.80 ± 5.22	18.20 ± 3.56	18.20 ± 4.38	<i>p</i> = 0.166	0.225 [#]	(13.4;22.6)
SA(cm)	−6.80 ± 14.40	−4.40 ± 9.18	−1.60 ± 9.48	−0.20 ± 8.98	<i>p</i> = 0.719	0.017 ⁺	(−15.1;8.6)
AD(cm)	−23.30 ± 18.00	−17.60 ± 15.30	−20.20 ± 17.90	−10.20 ± 11.10	<i>p</i> = 0.290	0.138 [#]	(−37.8;−5.7)
AE(cm)	−28.40 ± 13.30	−19.60 ± 14.30	−35.00 ± 18.80	−13.60 ± 11.70	<i>p</i> = 0.083	0.329 [*]	(−46;−2.3)

Data presented as mean ± SD standard deviation

CG Control Group, IG Intervention Group, BMI body mass index, TUG timed up and go test, SL sit and stand test, FA forearm flexion test, SA sit and reach test, AD reach behind the back test—right, AE reach behind the back test—left

ANOVA was used to assess the global group effect at all time points. The post hoc test revealed results within each group; a *p* value < 0.05 indicated statistical significance

⁺Small effect size (0.01–0.06); [#] Medium effect size (0.06–0.14); ^{*} Large effect size (> 0.14)



Table 3 Comparative analysis of variation after the exercise program (CG $n=5$; IG $n=5$)

Variables	CG		IG	
	24-weeks	<i>p</i> value	24-weeks	<i>p</i> value
TUG(s)	1.46	0.221	0.97	0.020
SL(rep)	-2.20	0.051	-1.00	0.298
FA(rep)	-1.40	0.052	0.40	0.646
SA(cm)	5.20	0.079	4.20	0.049
AD(cm)	3.10	0.212	7.4	0.080
AE(cm)	-6.60	0.343	6.00	0.023

CG Control Group, IG Intervention Group, AV1 1st assessment, AV2 2nd assessment, TUG timed up-and-go test, SL sit-and-stand test, FA forearm flexion test, SA sit-and-reach test, AD reach behind the back test-right, AE reach behind the back test-left

p value: $p < 0.05$ shows significant differences

To observe the distinct evolution of individuals who underwent intervention and those who did not, we performed a statistical analysis of the variation. We confirmed that there were significant differences in the results of the TUG ($p=0.020$), SA ($p=0.049$), and AE ($p=0.023$) tests, as shown in Table 3.

Discussion

This research aimed to analyze the effects of Sensorimotor Training (SMT) on physical fitness throughout the aging process in diabetic women. The main findings indicate that the intervention group (IG) experienced significant improvements in agility, speed (assessed by the TUG test), lower limb strength, and flexibility compared to the control group (CG), while upper limb strength showed inconsistent changes. These results suggest that SMT enhances neuromuscular control, postural stability, and functional independence, which are critical factors for fall prevention in this population. Our findings align with previous research indicating that sensorimotor exercises improve neuromuscular control and proprioception, thereby reducing fall risk in older adults [34, 35]. However, unlike some studies that reported consistent improvements in upper limb strength, our results showed a decrease in upper limb strength repetitions in the IG, which may be attributed to the SMT program's primary focus on lower extremity function and postural control. This specificity highlights the importance of tailoring interventions to target both upper and lower body components when comprehensive strength improvements are desired.

Previous studies have reported that proprioception loss is a major cause of balance deficits and falls in the elderly. Our data support this, demonstrating improved proprioceptive control following SMT. However, despite improvements in flexibility, both groups remained within lower percentiles, suggesting that additional mobility-focused exercises may be necessary to enhance this domain further. These nuanced findings contribute to the

understanding of how different physical qualities respond to SMT in diabetic elderly populations. A major concern for professionals working with elderly individuals is the high number of falls. These findings are corroborated by Chandler [36], who reported that fatigue resistance can affect the ability to respond effectively to a disturbance in equilibrium, which is associated with mobility. Studies have shown that precarious mobility and a decrease in physical fitness are predictors of morbidity and mortality. Changes in mobility predict loss of independence and death in people over 65 years of age; individuals with mobility impairments have a higher risk of death and dependence than those who maintain their mobility [37]. Similarly, low levels of cardiorespiratory fitness have been associated with the risk of morbidity and mortality from chronic degenerative diseases, including arterial disease, coronary artery disease, systemic arterial hypertension, DM, and some types of cancer [38].

An experimental study with diabetic rats investigated the effects of quercetin supplementation and moderate aerobic training on myostatin and follistatin levels in heart tissue. The animals were divided into control, diabetic, diabetic with supplementation, diabetic with exercise, and diabetic with combined supplementation and exercise groups. The results showed that both quercetin supplementation and exercise alone significantly reduced myostatin levels, a protein associated with muscle growth inhibition, with the most pronounced effect observed when both interventions were combined. Additionally, follistatin levels, an antagonist of myostatin, significantly increased in all treated diabetic groups compared to the healthy control group. These findings suggest that aerobic training and quercetin supplementation may beneficially modulate proteins related to muscle and cardiac health in diabetes, potentially contributing to therapeutic strategies aimed at improving cardiovascular and muscular function in this context [39].

Aging is associated with a decline in muscle strength, particularly in the lower limbs, which contributes to mobility impairments and reduced independence. This study revealed that both IG and CG showed improvements in lower limb strength following the intervention. However, upper limb strength did not improve consistently, possibly due to the specificity of SMT, which primarily targets postural control and lower extremity function. Similar studies by Heubel et al. [40] found that multicomponent training, including strength and balance exercises, significantly enhanced functional fitness and glycemic control in older adults with DM. Aging results in a decline in physical qualities, including strength [1, 10, 11, 41]. When the values obtained for lower limb strength were analyzed, we found that both methods improved the results. In the upper limb strength test, the IG decreased the number of repetitions performed in the



first assessment, whereas the CG increased it. According to the reference values of Baptista and Sardinha [42] in the strength test of the lower limb strength test, the CG and IG are in the 50th percentile. The upper limb strength test results of the CG and IG were between the 75th and 90th percentiles. The values obtained in the strength test prove that both participants presented excellent capacity concerning general standards for their age. Additionally, as one of the factors that contribute to improvements in lower limb proprioception is the learning effect, a steady increase in the difficulty of sensorimotor exercises leads to increased proprioception [18].

Flexibility, particularly in the lower limbs, is crucial for maintaining functional movement patterns and preventing injuries. The results indicated greater improvements in lower limb flexibility compared to upper limb flexibility, aligning with findings from Baptista and Sardinha [42] who reported that progressive sensorimotor exercises improve range of motion and joint stability. However, despite improvements, both IG and CG remained within lower percentiles for flexibility, suggesting that additional stretching or mobility-focused exercises may be needed alongside SMT for more comprehensive benefits.

One of the key findings of this study was the improvement in proprioceptive control, which is particularly beneficial for elderly individuals with diabetes-related neuropathy. Proprioception loss is a major contributor to balance deficits and fall risk in older adults [43]. SMT, which includes unstable surface training, single-leg stance exercises, and coordinated movement drills, has been shown to improve postural stability and equilibrium control, leading to greater confidence in movement and reduced fear of falling. Heubel et al. [40] verified the effects of 16 weeks of multicomponent training, composed of strength, flexibility, and balance exercises, on the functional fitness and glycemic parameters of 13 elderly people with DM. These researchers reported significant improvements in the mean flexibility indices in the sit and reach test (11.40 ± 8.70 cm; 14.50 ± 9.80 cm) and in the strength and endurance of the upper limbs, as evaluated by the elbow flexion test at 30" (first evaluation 16.60 ± 3.40 reps; second evaluation 19.40 ± 4.20 reps). Compared with our study, the lower flexibility values obtained are much greater, whereas the upper limb strength values are similar. Thus, we can say that once again, the intervention improved not only the capacity for agility and speed but also the flexibility of the upper and lower limbs. Having only reduced the strength of the upper limbs.

One of the strengths of this study is its focus on a specific clinical population—elderly women with type 2 diabetes—who are at increased risk of falls and mobility impairments. By demonstrating the benefits of SMT on key functional parameters such as agility, strength, and

proprioception, our findings have practical implications for clinicians and exercise professionals designing fall prevention programs. The progressive and individualized nature of the training, grounded in the FITT principle, makes it adaptable to different levels of fitness and clinical status.

Furthermore, the observed improvements in mobility and muscle function have potential indirect benefits for glycemic control and cardiovascular health, supporting SMT as a complementary intervention for diabetes management [40]. However, the small sample size and age differences between groups limit generalizability. Future studies with larger, age-balanced cohorts are needed to confirm these findings and optimize training protocols across diverse elderly populations [44].

A limitation of this research is the small number of participants, largely due to the strict inclusion criterion of having diabetes mellitus. This reduces statistical power and increases the risk of Type II errors, potentially obscuring subtle but clinically relevant effects. Future research should involve larger samples and explore physiological markers such as glucose metabolism to deepen understanding of SMT's multifaceted benefits.

Conclusion

This study highlights the positive effects of SMT on physical fitness in older women with diabetes. The observed gains in agility, strength, flexibility, and proprioception emphasize its potential for fall prevention and maintaining functional independence. Improvements in proprioception and neuroplasticity enhance balance and coordination, thereby reducing fall risk. Adaptations in skeletal muscle led to increased strength and agility, which contributed to enhanced mobility and independence. Although no metabolic biomarkers were measured in this study, improved mobility and muscle function may indirectly support better metabolic regulation and insulin sensitivity, as suggested by previous research [45]. Flexibility gains help counteract joint stiffness, promoting easier movement, while potential cardiovascular and hormonal benefits, reported in related literature, may also contribute to overall health. By addressing multiple physiological factors, SMT may emerge as an effective strategy for counteracting diabetes-related physical decline and enhancing quality of life for aging women with diabetes. The study has several limitations, despite random assignment, a baseline imbalance was observed, with age differing marginally between groups ($p = 0.048$). This represents a potential limitation, as age is a established confounding variable strongly associated with functional capacity. While we attempted to control for this statistically by including age as a covariate in our secondary analysis, residual confounding may persist. However, considering the limitations of sample size



and intervention duration, future research should seek to investigate long-term effects and refine training protocols to maximize benefits for older adults with diabetes.

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s12877-025-06591-4>.

Supplementary Material 1.

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Institutional Review Board Statement

The Ethics Committee of the University of Évora approved this project (approval number: 21040).

Authors' contributions

Conceptualization, C.A.C., C.M., O.F., M.C.E., J.A.P., and P.N.; methodology, C.A.C. and C.M.; data collection, C.A.C. and C.M.; formal analysis, C.A.C., O.F., J.A.P. and M.C.E.; data curation, C.M.; writing—original draft preparation, C.A.C., C.M., and M.C.E.; writing—review and editing, O.F., M.C.E., J.A.P., and P.N.; supervision, O.F., M.C.E., J.A.P., and P.N.; funding, P.N. All authors have read and agreed to the published version of the manuscript.

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Data availability

The data presented in this study are available on request from the corresponding author.

Declarations

Ethics approval and consent to participate

This study followed the Helsinki Declaration and was approved by the Research Ethics Committee of the Évora University. Informed consent was obtained from all subjects involved in the study.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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Article

Evaluating the Effects of Sensorimotor Training on the Physical Capacities of Older People

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Abstract: Background: Physical activity (PA) plays a crucial role in improving the quality of life (QoL) in older people, particularly by enhancing their balance and movement coordination. Objective: This study aimed to assess the effects of sensorimotor training intervention in older adults. Methods: A total of 90 participants, divided into a Control Group ($n = 44$) and Experimental Group ($n = 46$) were involved in a 24-week sensorimotor training program. The physical capacities of the participants were assessed both before and after the intervention program. Strength and flexibility were measured using the “Rikli and Jones” protocol (1999), while agility and speed were assessed through “Timed-up-and-go” tests. Taking into account the participants’ gender, a descriptive analysis of the sample was conducted to describe the data using the mean and standard deviation. Student’s T test was performed to compare the differences between the groups according to the first and second data collection moments (before and after the intervention). Jamovi software (v. 2.5.2.0) was used to develop the statistical analysis, using a p -value of less than 0.05 to assess the statistical significance. Results: The Experimental Group showed significant improvements across all the analyzed variables following the intervention ($p < 0.005$), indicating substantial gains in physical capacities. In contrast, the Control Group in the “sitting and reaching” test did not show a significant difference between the groups highlighting the lack of improvement without intervention. According to the effect size of the sample, it was observed that the parameters “reach behind your back (right)” and “reach behind your back (left)” showed the highest effect size comparing the Control Group and Experimental Group (ES: 0.60, 0.71). Conclusions: The findings highlight the practical clinical impact of implementing tailored physical activity programs for older adults. Such interventions are critical for enhancing QoL, reducing the risk of falls, injuries, and chronic illnesses, and promoting overall health, independence, and well-being. Integrating sensorimotor training into the routine care for older people can support healthy aging and functional independence.



Keywords: aging; agility; flexibility; strength; physical activity; functional capacity

1. Introduction

Physical activity (PA) is crucial for improving the QoL of older adults, enhancing balance, coordination (Choi et al., 2021; Dunskey, 2019; Prasad et al., 2021), physical and mental health, autonomy, and pain management (Vagetti et al., 2014). Regular PA benefits cardiovascular health, reduces anxiety and depression (Goodarzi et al., 2024), strengthens muscles, improves mobility, and fosters independence (Pfeifer et al., 2022). It also enhances emotional resilience and social interaction, reducing loneliness and increasing life satisfaction (Lindsay Smith et al., 2017).

Conversely, inactivity contributes to weakness, negative health outcomes (Ghram et al., 2021) and higher risks of mortality and cardiovascular diseases (Fletcher et al., 2018; Rizwan Sajid et al., 2021). Modern lifestyles encourage sedentarism (Woessner et al., 2021), with men generally exhibiting better physical function and QoL than women (Prasad et al., 2021). To counteract this, PA promotion programs should be frequent to improve mental health (Cabo et al., 2024) and reduce cardiovascular risks (Ciumărnean et al., 2021).

PA programs for older adults should emphasize balance, coordination, and strength to prevent falls and enhance movement control (Nikitas et al., 2022). Engaging in at least 20 min of daily PA (Fabris & Sinagra, 2022), or 150 min per week of moderate-intensity exercise provides cardiovascular benefits, reduces chronic disease risks, and supports cognitive health (McGarrigle et al., 2020). Such programs also improve mental health (Musdalifah Ahmad, 2023), well-being (Carvalho et al., 2023), and the QoL of older people (Fiorilli et al., 2022).

Physical capacities refer to the fundamental attributes that determine an individual's ability to perform physical tasks efficiently and safely. These capacities include strength, endurance, flexibility, balance, coordination, and agility, all of which are essential for maintaining mobility, preventing falls, and ensuring the overall functional independence in older adults (Mueller et al., 2021). Strength, particularly in the lower and upper limbs, supports daily activities such as standing up, walking, and carrying objects (Parraca et al., 2022). Endurance allows sustained physical effort, reducing fatigue and improving cardiovascular health (McGarrigle et al., 2020). Flexibility contributes to joint mobility and reduces stiffness, facilitating smoother movements (Shirazi et al., 2023). Balance and coordination enhance postural stability and minimize the risk of falls (Nikitas et al., 2022), while agility ensures quick and efficient movement responses to environmental challenges (Pfeifer et al., 2022).

Assessing and improving these physical capacities is crucial for promoting independence, preventing injuries, and enhancing QoL in aging populations. By evaluating these attributes through standardized tests—such as the Timed Up and Go (TUG) test for mobility, sit and reach test for flexibility, and chair stand test for strength—health professionals can design targeted interventions, like sensorimotor training, to address age-related declines and optimize physical function (Carvalho et al., 2023; Wróblewska et al., 2023).

Assessing the functional capacity helps tailor healthcare strategies and prevent falls (Wróblewska et al., 2023). It should consider mental, physical, and functional dimensions (Wróblewska et al., 2023) using tests like the “Timed Up and Go” (TUG) for mobility (Donisi et al., 2020) and short-term mortality risk (Chua et al., 2020). In this line, muscular endurance and upper and lower limb strength are essential to developing daily routines and activities (Parraca et al., 2022), and this information can be monitored using an isokinetic dynamometer (Li et al., 2006), through the evaluation of torque (Perrin et al., 1987) and

power (Janssen & Le-Ngoc, 2009) to determine the lower limb strength. Strength tests, such as the “Sit-to-stand” (Takai et al., 2009) or “chair stand test” (Cho et al., 2012), assess the fall risk, while flexibility can be measured via the “sit and reach” test for the lower limbs (Shirazi et al., 2023; Teraoka et al., 2022) and the “behind the back reach” test for the upper limbs (Correa et al., 2022; de Oliveira et al., 2024). Evaluating and analyzing strength and flexibility help to improve the motor abilities and functional capacity of older people, and in general, their QoL (Melchiorri et al., 2022).

Sensorimotor training integrates sensory input with motor responses to enhance balance, coordination, and functional movement, making it a key strategy in maintaining independence and reducing the fall risk in older adults (Asan et al., 2022; M. Martinez et al., 2009). Aging leads to sensory and motor deterioration, affecting proprioception, muscle strength, and balance control, increasing the fall risk and mobility impairments (Nikitas et al., 2022). This training helps counteract these declines by improving proprioception, neuromuscular coordination, and postural control, while also enhancing the reaction times and adaptability to environmental challenges (Ghram et al., 2021).

Sensorimotor training is widely used in rehabilitation, fall prevention, and physical activity programs for older individuals. It includes exercises that challenge balance, coordination, and sensory integration, such as balance training (e.g., tandem walking, single-leg stance), proprioceptive exercises (e.g., weight-shifting tasks), strength and stability exercises, and dual-task training that combines cognitive and motor tasks (Fabris & Sinagra, 2022; Mueller et al., 2021). These exercises often involve unstable surfaces like balance boards and foam pads or additional sensory challenges like visual occlusion.

Studies show that sensorimotor training improves functional mobility, reduces the fall risk, and enhances the overall physical performance (Carvalho et al., 2023). By incorporating sensorimotor training into structured programs, older individuals can improve their movement efficiency, maintain their independence, and sustain a higher QoL (Cabo et al., 2024).

In short, PA is one of the fundamental pillars for improving the functional capacity and QoL of older people (Cabo et al., 2024). Several health benefits are associated with physical exercise, making it essential to improve our approach to evaluate and control physical activities. This is necessary to ensure that practitioners can continue their activities, minimizing the risk of injuries, dropouts, or lack of motivation (Warburton & Bredin, 2017). Hence, this study aimed to address a gap in the research by assessing various physical abilities in a group of older individuals before and after a sensorimotor training intervention. The study hypothesis was defined as follows: Is sensorimotor training effective in improving the physical abilities of older people? To test and answer the hypothesis, the effects of the intervention on the participants’ physical capacities and performance were evaluated.

2. Materials and Methods

2.1. Design

A parallel-group randomized controlled trial was conducted, including a 6-month intervention phase and a 1-year follow-up period. For both groups (Control and Experimental), two evaluation moments were carried out, a first moment at the baseline (before starting the intervention for two months, three times a week, for 6 h a day) and after the intervention period, for two months (three times a week, for 6 h a day) (Montero & León, 2007). The Control Group (CG) did not perform any type of activity or physical program throughout the intervention period.

2.2. Participants

The study analyzed 90 participants aged between 55 and 80 years old, divided into two groups: the CG (73.70 ± 6.88 years) and the Experimental Group (EG) (72.40 ± 6.88 years). Table 1 shows the characteristics of the CG and EG to contextualize and create a framework for the study sample.

Table 1. Characteristics of the CG and EG to contextualize the sample.

	N	Age (year)		Weight (kg)		Height (m)		BMI	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Control Group	44	73.70	6.08	70.10	12.70	1.58	0.08	28.10	4.69
Experimental Group	46	72.40	6.88	68.40	14.20	1.58	0.09	27.40	5.03

Kg: kilograms; m: meters, BMI: body mass index; SD: standard deviation.

The participants had to meet the following inclusion criteria: (1) age between 55 and 80 years old; (2) without prostheses (except dental prostheses); and (3) have not been involved in surgical intervention 6 months before the study. The exclusion criteria were as follows: (1) musculoskeletal diagnosis; (2) problems in locomotion; (3) psychiatric diseases and neurological disorders; and (4) clinical cardiovascular diagnosis. To establish the inclusion and exclusion criteria, we conducted a thorough anamnesis that included questions regarding the participants' clinical status.

2.3. Ethics

This project was approved by the University of Évora's Ethics Committee (approval number: 21040; registration number: NCT05398354; <https://www.clinicaltrials.gov/ct2/show/NCT05398354?term=NCT05398354&draw=2&rank=1>), accessed on 20 January 2025. The study was registered with the Clinical Trials.gov PRS Protocol Registration and Results System. Each participant provided informed consent before participating, according to the Helsinki Declaration for Human Studies (2013).

2.4. Intervention

The sensorimotor training program was conducted for 6 months, with a frequency of twice a week. The duration of the sessions was 45 min in total. The training volume consisted of 8 exercises, where each participant performed the maximum number of repetitions within 50 s, completing 4 sets. As the program progressed, the load progressively increased. To achieve this, the session was divided into three levels of intensity: easy (no external load for the first eight weeks), intermediate (increased external burden for the previous level from the 17th to the 24th week), and advanced (application of external load: elastic bands, shin guards, and free weights, from the 9th to the 16th week). Each month, a different type of session was developed. However, despite prescribing a structured training program with progressions for all participants, we consistently considered each individual's unique progression. Recognizing that the participants had different levels of initial physical fitness, we tailored the plan to suit each person's capabilities, ensuring that the exercises were accordingly adjusted to match their individual needs and optimize their development throughout the intervention. Each session was divided into three phases: the initial phase (10 min), consisting of a 5 min walk followed by a joint warm-up; and the fundamental phase (25 min), where the patients worked on a corresponding circuit of exercises. This circuit consisted of 4 cycles, with eight exercises each (50 s on, 15 s off); and a return to calm (10 min), where muscle stretching was performed (Choi et al., 2021) (Figure 1).

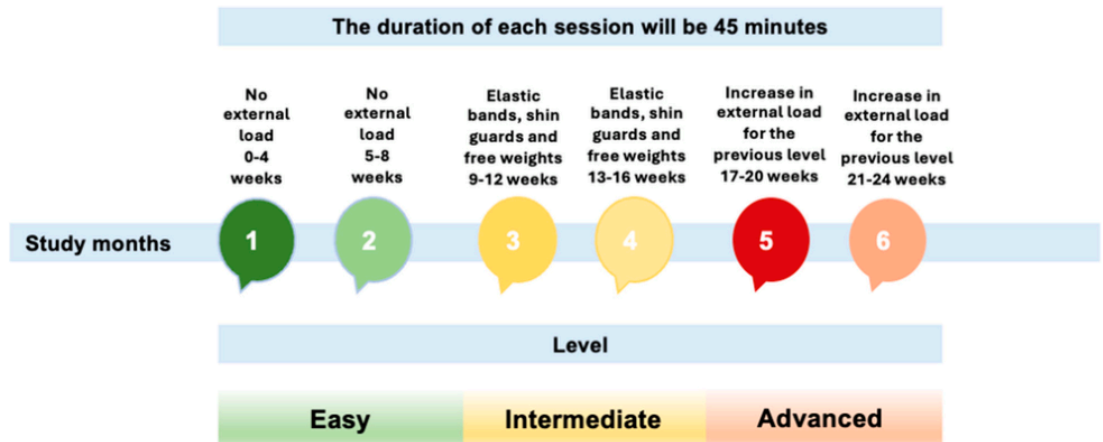


Figure 1. Study timeline graph.

Figure 2 shows the main exercises carried out during the intervention, with a short explanation of them. These exercises are part of a sensorimotor training program already applied to the population (Cabo et al., 2022), from which we obtained the results now published in this article.

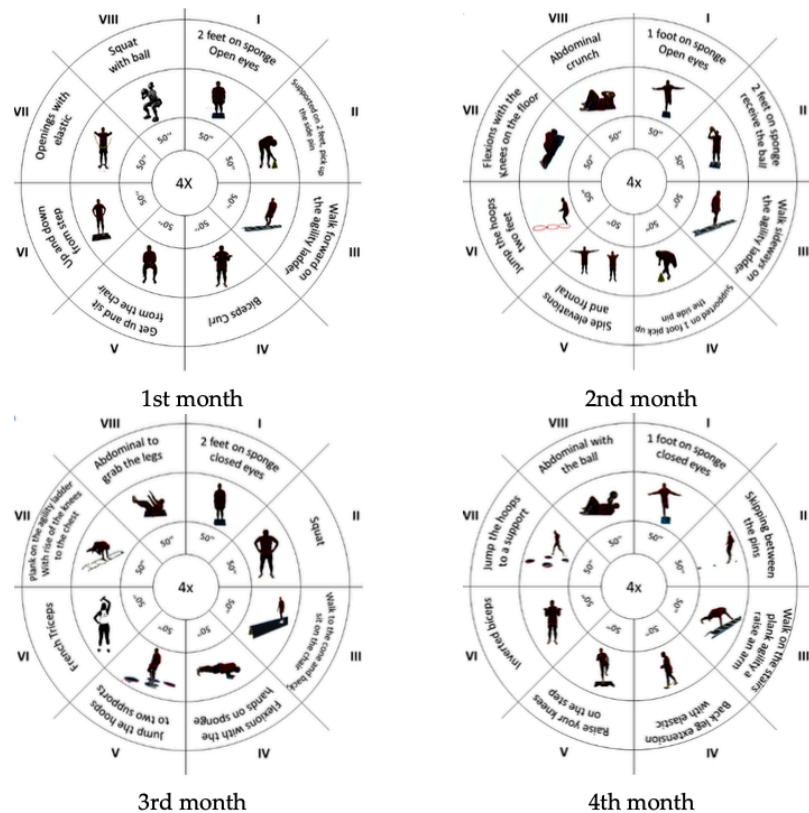


Figure 2. Cont.

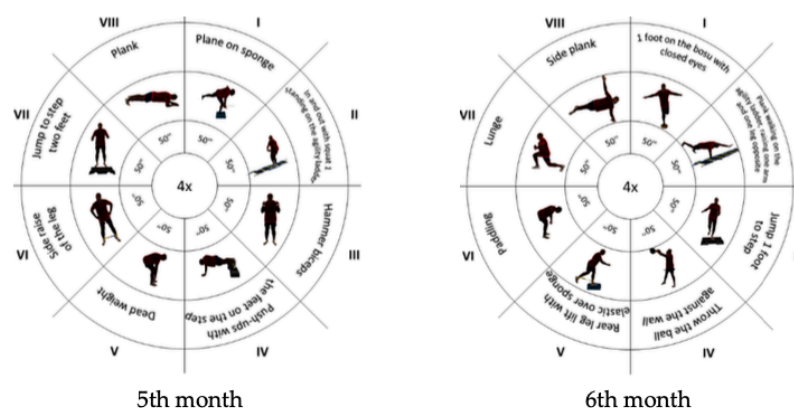


Figure 2. Intervention used for sensorimotor training.

2.5. Measuring Instruments

A variety of instruments were used for the assessments under study. All measures were taken at the baseline and at the end of the intervention. Before the first measurement, all the participants were involved in a familiarization phase to adapt themselves to the different instruments and assessments associated with this project. The instruments included the following: a stadiometer (Seca 22, Hamburg, Germany); a scale; the Timed Up and Go test (TUG); a lower limb muscular endurance test; an upper limb strength test; the sit and reach test; and the behind the back reach test.

Evaluations

To assess the physical fitness of the participants, they wore tracksuit bottoms and were asked to remove accessories and any objects in their pockets. The following procedures were carried out:

1. **Bodyweight and height.** The participants were instructed to take off their heavy outerwear (coats, sweaters, etc.), shoes, and socks before the measurements. In addition, they were instructed to take off belts and other accessories (such as necklaces and bands) and to empty their pockets. A stadiometer (Seca 22, Hamburg, Germany) was used to measure their height. The measuring scale on this device was positioned perpendicular to the ground on a vertical surface. The participants were asked to stand with their arms relaxed along their bodies and their shoulders balanced. The height was measured in centimeters and rounded to the closest millimeter. A scale was used to measure their body weight. $\text{Weight (Kg)}/\text{height}^2$ was the formula used to compute the BMI when the body weight was recorded in kilograms.
2. **Agility and execution speed** were assessed through the TUG test, which involved getting out of a chair, walking three meters in a straight line, going back, and then sitting down again, which was used to measure speed (Prasad et al., 2021).
3. **Muscular endurance** was evaluated using functional tasks such as rising from a chair or performing repeated bending and straightening movements for 30 s. These exercises targeted the lower limb strength and endurance, focusing on key muscle groups like the vastus medialis obliquus (VMO) and vastus lateralis (VL). The performance was quantified by reference to the number of repetitions completed within the 30 s, providing a measure of endurance and strength in the lower extremities, as outlined in Dunskey (2019).
4. **The upper limb strength** was assessed by counting the number of repetitions that a participant could perform in 30 s, using a specified weight during arm flexion–

- extension exercises. This measure provided a functional evaluation of the participants' upper limb strength and endurance, emphasizing the capacity to sustain repetitive motion and muscular power. Additional details of the specific weight used and the positioning during the exercise would further clarify this methodology (Dunsky, 2019).
5. The lower limb flexibility was assessed using the "sit and reach" test, in which the participants gently bent over while sitting with one leg out in front of them, and then moved their hands down their leg till they touched (or passed) their toes (Mueller et al., 2021).
 6. The upper limb flexibility was assessed using the "behind the back reach" test, which consisted of measuring with a ruler the distance between (or the overlap of) the middle fingers behind the back (Dunsky, 2019).

2.6. Statistical Analysis

To identify the normality of the sample, Kolmogorov–Smirnov's test was considered, identifying a p -value higher than 0.05; therefore, normality was assumed (Field, 2013). In this line, Levene's test was applied to assess the homogeneity of the sample. Parametric models were used to test the study's hypotheses (O'Donoghue, 2012). Taking into account the CG and EG, a descriptive analysis of the sample was conducted to characterize the data using the mean and standard deviation ($M \pm SD$).

Afterward, a Student's T test was applied to compare the differences between the groups considering the first and second data collection (before and after the intervention). The effect size (ES) was calculated through Cohens d , and was considered trivial (0–0.2), small (0.2–0.6), moderate (0.6–1.2), large (1.2–2), very large (2–4), and extremely large (>4) (Hopkins et al., 2009). These metrics provide a clearer understanding of the magnitude of the observed changes between the pre- and post-intervention assessments. The Intraclass Correlation Coefficient (ICC) between the values obtained of each parameter's reliability was determined as follows: <0.5 (poor), 0.5–0.75 (moderate), 0.75–0.90 (good), and ≥ 0.90 (excellent) (Koo & Li, 2016). In this line, the parameters of the present study showed values between 0.82 and 0.94, representing a good and excellent validity.

The statistical analyses were performed using Jamovi (Desktop version 2.5.2.0). Statistical significance was determined at $p < 0.05$.

3. Results

3.1. Descriptive and Inferential Analysis Considering the EG

Table 2 shows the main results according to the pre- and post-intervention values. All the analyzed variables showed improvement from pre- to post-intervention, particularly the "reach behind your back (right)" and "reach behind your back (left)", variables which presented high values of ES.

Table 2. Descriptive and inferential analysis of the pre- and post-intervention considering the EG.

Variables	Mean	SD	Student's <i>t</i> Test	Mean Differences	<i>p</i> -Values
Timed up and go (pre) (s)	7.26	± 1.23	3.90	0.416	<0.001
Timed up and go (post) (s)	6.85	± 0.81			
Stand and sit with leaning (pre) (rep)	13.00	± 2.30	−3.64	−1.043	<0.0001
Stand and sit with leaning (post) (rep)	14.00	± 1.97			
Stand and sit without leaning (pre) (rep)	15.30	± 2.95	−5.04	−1.370	<0.001
Stand and sit without leaning (post) (rep)	16.60	± 2.57			

Table 2. Cont.

Variables	Mean	SD	Student's <i>t</i> Test	Mean Differences	<i>p</i> -Values
Forearm flexion (pre) (rep)	17.30	±5.83	−3.33	−2.522	0.002
Forearm flexion (post) (rep)	19.80	±4.04			
Sitting and reaching (pre) (rep)	−2.54	±8.70	−4.43	−3.565	<0.001
Sitting and reaching (post) (rep)	1.02	±8.24			
Reach behind your back (right) (pre) (m)	−13.80	±11.70	−7.29	−6.261	<0.001
Reach behind your back (right) (post) (m)	−7.50	±9.12			
Reach behind your back (left) (pre) (m)	−18.50	±11.00	−8.97	−7.391	<0.001
Reach behind your back (left) (post) (m)	−11.20	±9.43			

s: second; rep: repetition; m: meter; SD: standard deviation; $p < 0.005$.

3.2. Descriptive and Inferential Analysis Considering the CG

Considering the values of the CG, Table 3 shows no differences in any of the variables studied. It is identified that the variable with the lower *p*-values was “sitting and reaching” ($p = 0.155$). These values show that the CG did not improve their capacities compared to the intervention group.

Table 3. Descriptive and inferential analysis of the pre- and post-values considering the CG.

Variables	Mean	SD	Student's <i>t</i> Test	Mean Differences	<i>p</i> -Values
Timed up and go (pre) (s)	8.15	±2.89	0.763	0.076	0.450
Timed up and go (post) (s)	8.08	±2.94			
Stand and sit with leaning (pre) (rep)	13.50	±3.42	−0.947	−0.318	0.349
Stand and sit with leaning (post) (rep)	13.80	±2.96			
Stand and sit without leaning (pre) (rep)	15.50	±4.31	−0.120	−0.045	0.905
Stand and sit without leaning (post) (rep)	15.60	±3.63			
Forearm flexion (pre) (rep)	18.30	±4.69	1.007	0.386	0.319
Forearm flexion (post) (rep)	17.90	±4.11			
Sitting and reaching (pre) (rep)	−0.61	±9.97	1.446	1.204	0.155
Sitting and reaching (post) (rep)	−1.82	±9.37			
Reach behind your back (right) (pre) (m)	−9.32	±12.50	1.100	2.636	0.277
Reach behind your back (right) (post) (m)	−12.00	±20.40			
Reach behind your back (left) (pre) (m)	−15.80	±12.90	−1.310	−1.056	0.197
Reach behind your back (left) (post) (m)	−14.80	±11.90			

s: second; rep: repetition; m: meter; SD: standard deviation; $p < 0.005$.

3.3. Analysis of the Effect Size

According to the statistical analysis comparing the EG and CG, no significant differences were observed when comparing the group means.

The ES of the differences, along with their corresponding confidence intervals, are presented in Table 4. By analyzing the ES, we can gauge the practical significance of the intervention's impact on various physical abilities, beyond mere statistical significance.



Table 4. Analysis of the effect size considering the pre- and post-intervention.

Variables	Pre-Intervention			Post-Intervention			ES	σ	95% CI	
	M	SD	n	M	SD	n			LL	UL
Times up and go	7.26	1.23	46	6.85	0.81	46	−0.39	0.210524737	−0.81	0.02
Stand and sit with leaning	13.00	2.3	46	14.00	1.97	46	0.47	0.211337371	0.05	0.88
Stand and sit without leaning	15.30	2.95	46	16.60	2.57	46	0.47	0.211372433	0.06	0.88
Forearm flexion	17.30	5.83	46	19.80	4.04	46	0.50	0.211727587	0.08	0.91
Sitting and reaching	−2.54	8.7	46	1.02	8.24	46	0.42	0.210802398	0.01	0.83
Reach behind your back (right)	−13.80	11.7	46	−7.50	9.12	46	0.60	0.213163448	0.18	1.02
Reach behind your back (left)	−18.50	11	46	−11.20	9.43	46	0.71	0.215029136	0.29	1.13

M: mean; SD: standard deviation; ES: effect size; CI: confidence interval; LL: lower limit; UL: upper limit; $p < 0.005$.

Figure 3 increases the comprehensive interpretation of the Table 4 data considering the proposal to interpret the ES values (Hopkins et al., 2009). This figure highlights that the TUG test had a negative and moderate ES. On the other hand, “reach behind your back (right)” and “reach behind your back (left)” were the variables that presented the largest positive ES. When we examine the distinctions between the groups, we observe once more that training influences the TUG test and the forearm flexion (Table 5).

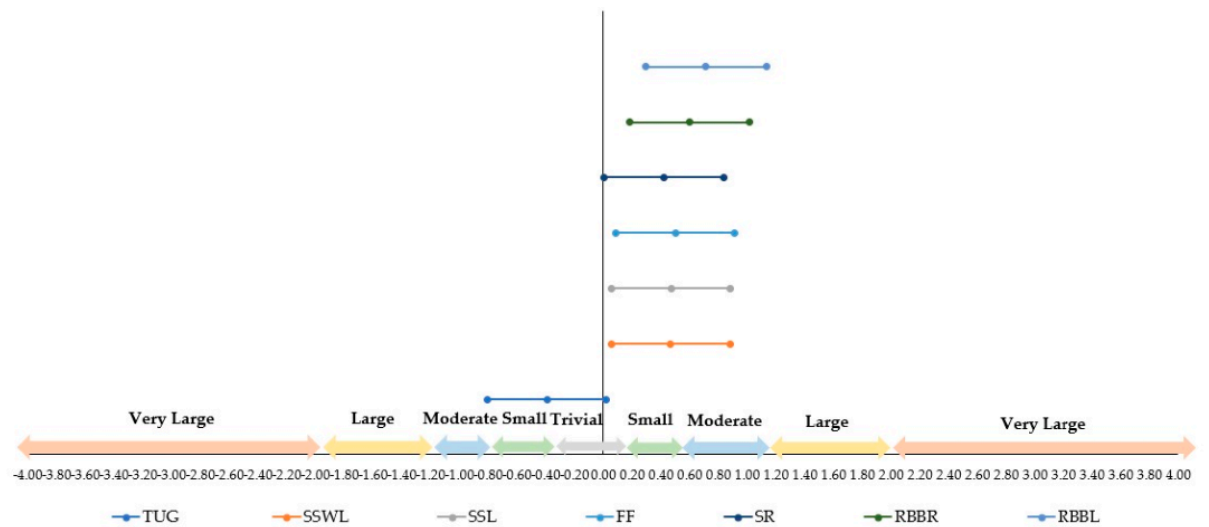


Figure 3. Interpretation of the effect size considering the analyzed variables. Note. Timed up and go (TUG); stand and sit with leaning (SSWL); stand and sit without leaning (SSL); forearm flexion (FF); sitting and reaching (SR); reach behind your back (right) (RBBR); reach behind your back (left) (RBBL). ES is considered trivial (0–0.2), small (0.2–0.6), medium (0.6–1.2), large (1.2–2), very large (2–4), and extremely large (>4) (Cohen’s d).

Table 5. Analysis of post-intervention values according to the intervention effect.

Variables	Pre-Intervention		Post-Intervention		Pre-Intervention	Post-Intervention
	Mean	SD	Mean	SD	<i>p</i> -Value	<i>p</i> -Value
Timed up and go (pre) (s)	7.26	±1.23	8.15	±2.89	0.059	0.008
Timed up and go (post) (s)	6.85	±0.81	8.08	±2.94		
Stand and sit with leaning (pre) (rep)	13.00	±2.30	13.50	±3.42	0.395	0.702
Stand and sit with leaning (post) (rep)	14.00	±1.97	13.80	±2.96		
Stand and sit without leaning (pre) (rep)	15.30	±2.95	15.50	±4.31	0.737	0.111
Stand and sit without leaning (post) (rep)	16.60	±2.57	15.60	±3.63		
Forearm flexion (pre) (rep)	17.30	±5.83	18.30	±4.69	0.389	0.026
Forearm flexion (post) (rep)	19.80	±4.04	17.90	±4.11		
Sitting and reaching (pre) (rep)	−2.54	±8.70	−0.61	±9.97	0.330	0.130
Sitting and reaching (post) (rep)	1.02	±8.24	−1.82	±9.37		
Reach behind your back (right) (pre) (m)	−13.80	±11.70	−9.32	±12.50	0.086	0.182
Reach behind your back (right) (post) (m)	−7.50	±9.12	−12.00	±20.40		
Reach behind your back (left) (pre) (m)	−18.50	±11.00	−15.80	±12.90	0.285	0.113
Reach behind your back (left) (post) (m)	−11.20	±9.43	−14.80	±11.90		

SD: standard deviation; $p < 0.005$.

3.4. Analysis of the MANOVA

According to the MANOVA test analysis, significant differences were observed in the TUG test, stand and sit without leaning, forearm flexion, and reach behind your back (left), with corresponding significance values of $p < 0.001$, $p = 0.005$, $p = 0.003$, and $p < 0.001$, respectively (Table 6).

Table 6. Analysis of post-intervention values according to the MANOVA.

Variables	Sum of Squares	Mean Square	F-Values	<i>p</i> -Values
Timed up and go (post) (s)	6.85	±0.81	79.0907	<0.001
Stand and sit with leaning (post) (rep)	14.00	±1.97	0.3351	0.564
Stand and sit without leaning (post) (rep)	16.60	±2.57	8.1732	0.005
Forearm flexion (post) (rep)	19.80	±4.04	9.4793	0.003
Sitting and reaching (post) (rep)	1.02	±8.24	7.1769	0.009
Reach behind your back (right) (post) (m)	−7.50	±9.12	3.7447	0.056
Reach behind your back (left) (post) (m)	−11.20	±9.43	12.7130	<0.001

F-value interpretation intervals: $F < 1 \rightarrow$ no significant difference between groups; $1 \leq F < 5 \rightarrow$ small variation between groups (small effect); $5 \leq F < 10 \rightarrow$ moderate difference between groups (medium effect); $F \geq 10 \rightarrow$ considerable difference between groups (large effect); $F \gg 10 \rightarrow$ very large variation between groups, indicating a very strong effect; $p < 0.005$.

When analyzing the F-values, we observed notable differences across the tests:

- TUG test: $F = 79.0907$, indicating a substantial variance between group means and a strong effect.
- Stand and sit without leaning and forearm flexion: $F = 8.1732$ and $F = 9.4793$, respectively, highlighting a more pronounced variance in this measure.



- Reach behind your back (left): $F = 12.7230$, showing a considerable difference between the groups.

These results reinforce the impact of the intervention on the key functional parameters. The notably high F-value in the TUG test suggests that the intervention had a strong effect on mobility performance, a critical factor in reducing the fall risk among the elderly. Additionally, the significant findings in the upper and lower limb mobility tests further support the relevance of sensorimotor training in improving the overall functional capacity.

4. Discussion

This study aimed to examine the effects of a sensorimotor training program on the physical capacities of older participants. The subjects shared similar characteristics in regard to age, weight, height, and BMI, which revealed that both the male and female groups were classified as overweight based on the values obtained.

Sensorimotor training uniquely integrates sensory and motor functions, emphasizing proprioceptive and neuromuscular coordination. This dual focus enables older adults to enhance their physical capacities such as strength, flexibility, and balance while addressing the multifaceted nature of mobility challenges (Freire & Seixas, 2024). Tasks involving balance and proprioception, such as standing on unstable surfaces or performing single-leg movements, train the body to respond dynamically to external stimuli. These exercises enhance both postural stability and neuromuscular control, equipping the participants with better reflexive and adaptive capabilities to prevent falls (Pšeničnik Sluga & Kozinc, 2024).

The discussion of tests assessing functional mobility and physical capacity in older adults can offer valuable insights into their effectiveness, sensitivity, and real-world application. The tests used—TUG, SSWL, SSL, FF, SR, RBBR, RBBL—each measure specific components of physical function, with relevance to the older population.

The timed standing and walking test, commonly represented by the TUG test, is widely utilized to assess balance, mobility, and the risk of falls in older adults. It involves standing up from a chair, walking a short distance (typically 3 m), turning around, and returning to sit down. This test is simple to administer and reflects real-life tasks, such as getting up from a chair and walking, which are fundamental for independence in daily activities. Research suggests that prolonged completion times are associated with an increased risk of falls and mobility impairments in older adults (Podsiadlo & Richardson, 1991). Furthermore, the TUG test is recommended by geriatric guidelines as a screening tool for fall risk (Barry et al., 2014). Based on the results of this study, the participants' average time was 7.26 s, which decreased to 6.85 s following the intervention. These values align with the average found in other studies (Andrade et al., 2021; Bretan et al., 2013; B. P. Martinez et al., 2016).

Standing and sitting tests, particularly when performed on flat surfaces and inclined planes, assess lower body strength, balance, and coordination. These movements mimic activities of daily living, such as getting in and out of chairs or beds, and are indicative of an individual's functional independence, challenging balance, and muscle control. The 30 s chair stand test (30s-CST), which measures how many times an individual can rise to a full standing position from sitting within 30 s, is commonly used to evaluate lower limb strength. It has been shown to have moderately high reliability and validity in community-dwelling older adults (Rikli & Jones, 1999). According to the reference values provided by Baptista and Sardinha (Baptista & Sardinha, 2005), the participants in the lower limb strength test ranked between the 75th and 90th percentiles. Our results indicate that the participants demonstrated excellent strength both initially and after the intervention, with noticeable improvements in the measured values. Additionally, since one key factor in enhancing lower limb proprioception is the learning effect, progressively increasing the difficulty of sensorimotor exercises contributes to improved proprioception.

The performance in these tests correlates with an individual's ability to perform essential tasks, such as ascending stairs or rising from lower seating, which tend to decline with age due to reduced muscle mass and balance (Lord et al., 2002). The standing and sitting tests, both with and without inclination, offer a useful measure of functional ability and strength in different real-world conditions.

Forearm flexion, typically measured through the handgrip strength test, is a strong predictor of overall muscular strength and health status in older adults. It has been widely accepted as a marker for physical limitations and is associated with mortality, frailty, and disability in older populations. The handgrip test is practical, simple to perform, and provides an objective measure of upper body strength. It is particularly valuable in settings where comprehensive fitness tests are not feasible and serve as a standalone indicator of health and functional ability. Assuming the reference values of Baptista and Sardinha (Baptista & Sardinha, 2005), the participants in our study, and considering the lower limb strength test ranked between the 75th and 90th percentiles, their performance improved from the first assessment to the second.

Tests assessing flexibility and range of motion, such as sitting and reaching or reaching behind the back, are crucial for evaluating the upper body and spinal flexibility in older adults. These movements reflect the ability to perform daily tasks like dressing, grooming, or reaching for objects on shelves. As flexibility declines with age, so does the ability to perform these tasks comfortably and independently (La Greca et al., 2022). These tests help clinicians to assess the degree of joint and muscle stiffness and guide interventions aimed at improving flexibility and preventing further declines in functional capacity. The participants' results were analyzed and compared with Ruivo (Ruivo, 2015), revealing that they fell between the 50th and 75th percentiles. In the upper limb flexibility test, however, the participants ranked between the 10th and 35th percentiles. Thus, contrasting their strength results, their flexibility scores were lower compared to the age-specific reference values. Nevertheless, the participants showed improvement in both tests following the intervention (Jones & Rikli, 2022). Together, these tests provide a comprehensive assessment of the critical physical abilities of older adults' independence. The tests range from those that measure strength (e.g., handgrip, chair stands) and balance (e.g., TUG) to those that evaluate flexibility and mobility (e.g., reaching, sitting). The application of these tests in clinical and research settings supports the identification of declines in physical function, planning interventions, and tracking the progress of older adults. Each test offers valuable insights into the specific aspects of functional mobility, helping to tailor interventions that address the physical limitations associated with aging.

The analysis of the Control Group data in Table 3 reveals no statistically significant improvements across any of the measured variables, indicating that the physical capacities remained stable without intervention. The variable "sitting and reaching," with a p -value of 0.155, showed the smallest difference, though it was still not statistically significant, suggesting minimal variation even in flexibility. These results underscore the effectiveness of targeted physical interventions, as the Control Group did not experience the gains observed in the intervention group. The findings highlight the critical role that structured exercise programs, such as sensorimotor training, play in enhancing balance, strength, and flexibility, which are essential for maintaining independence and reducing the fall risk in older adults. This study reaffirms that routine physical activity, especially interventions focused on balance and functional mobility, is crucial for preserving and improving the physical function as individuals age.

The results from the MANOVA analysis reinforce the effectiveness of sensorimotor training in improving functional mobility and motor control in the elderly. The significant differences observed in the TUG test ($F = 79.0907$, $p < 0.001$), stand and sit without leaning



($F = 8.1732$, $p = 0.005$), forearm flexion ($F = 9.4793$, $p = 0.003$), and reach behind your back (left) ($F = 12.7130$, $p < 0.001$) highlight the intervention's impact on both dynamic balance and upper limb mobility. The high F-value for the TUG test suggests a particularly strong effect on functional mobility and fall risk reduction, which is crucial for elderly populations (Sherrington et al., 2017). These findings align with previous studies that indicate that sensorimotor training enhances postural control, strength, and flexibility, leading to improved functional independence and a reduced fall incidence (Granacher et al., 2011; Lesinski et al., 2015).

Furthermore, previous research has demonstrated that sensorimotor training improves proprioception and neuromuscular adaptation, which are essential for postural stability and fall prevention (Pizzigalli et al., 2011). The improvements in upper limb flexibility and strength, observed in the forearm flexion and reach behind your back tests, further support the idea that multimodal training interventions can enhance mobility beyond lower limb function (Muehlbauer et al., 2015).

These results reinforce the importance of structured sensorimotor programs in geriatric rehabilitation, particularly in individuals at the risk of mobility decline. Future studies should investigate the long-term retention effects and evaluate how different intensities and durations of training influence these functional outcomes.

The integration of balance-focused tasks in sensorimotor training has a direct impact on fall prevention. Improved proprioception and postural stability help older adults maintain control during perturbations. Training programs often simulate real-life scenarios, such as reaching for an object or recovering from a stumble, enabling the participants to develop reactive strategies that reduce fall risk (Pšeničnik Sluga & Kozinc, 2024).

Neuromuscular control is significantly enhanced through sensorimotor training, which emphasizes the synchronization of sensory input and motor output. Proprioceptive exercises, such as standing on unstable surfaces or performing single-leg tasks, strengthen neural pathways and improve the brain's ability to process and respond to movement-related stimuli. This leads to faster and more accurate movement adjustments, improving overall coordination and reducing the likelihood of injuries (Aman et al., 2015).

Sensorimotor training integrates sensory input with motor actions to enhance physical performance and functional abilities. When we compare different groups that have undergone this training, distinct improvements are often observed in their performance on the TUG test and in forearm flexion. Overall, sensorimotor training offers comprehensive benefits by integrating sensory inputs and motor outputs. It significantly enhances functional mobility and strength, contributing to improved specific physical tasks. By focusing on the integration and improvement of sensory and motor pathways, individuals can achieve greater independence and quality of life (Gomiero et al., 2018; Kuş et al., 2023).

In this context, the application of the sensorimotor training program proved fundamental in enhancing the physical abilities assessed. The intervention demonstrated a significant positive impact on the participants' QoL and their risk of falls. By addressing the key areas such as strength, balance, and mobility, the training not only improved their functional independence but also contributed to the prevention of fall-related injuries—a critical aspect of maintaining health and well-being in older adults.

One limitation of this study was the need to conduct the intervention during the COVID-19 pandemic, which required additional precautions to ensure safety. These included increasing the space between the participants, providing extra hygiene materials, and implementing physical distancing protocols. These measures may have influenced the nature of the training sessions by potentially reducing social interactions and the group dynamics, which are known to enhance the motivation and engagement in exercise programs. Additionally, the fear of contagion could have impacted the adherence to the training

sessions, as some of the participants may have been hesitant to travel to the location or participate fully due to their concerns about exposure. This could have also introduced a selection bias, as more vulnerable individuals may have been excluded from the study, thereby limiting the generalizability of the findings to the broader older population. Future studies should consider these pandemic-related factors when interpreting the outcomes and designing interventions in similar contexts. Traveling to the location where the program was conducted also posed a challenge. In addition, the CG did not carry out any type of physical activity during the intervention. However, the lack of an active control condition (e.g., light stretching or participation in social activities) could lead to confounding factors such as placebo effects or differences in motivation between the groups.

In the future, it would be valuable to extend the study to include a wider range of age groups, including those who are still actively employed. This broader assessment would provide a more comprehensive understanding of the sensorimotor behavior across the lifespan, not just during aging. Early intervention could be implemented to improve the analyzed skills in this study, promoting healthier outcomes over time. In order to address the situation of lower flexibility test results in future programs, we recommend incorporating a dedicated flexibility training component with longer static stretches and dynamic stretching routines targeting the main joints and muscle groups. The use of individualized stretching protocols based on baseline flexibility assessments would better meet the specific needs of the participants.

5. Conclusions

The rising number of older adults underscores the need for tailored PA programs to support healthy aging. This study highlights the benefits of sensorimotor training, particularly in improving balance, strength, and overall physical function—key for reducing the fall risk and maintaining independence. While flexibility showed less improvement, balance and strength exercises effectively addressed broader physical needs. The intervention group demonstrated significant physical gains, unlike the Control Group, reinforcing the value of structured PA. Regular assessments of functional mobility are essential for adapting PA programs to ensure both effectiveness and practical applicability. Supporting an active lifestyle through such programs can help older individuals maintain autonomy, reduce the injury risk, and enhance the overall well-being.

The findings of this study provide valuable insights into the benefits of sensorimotor training for older adults, particularly in improving balance, coordination, and overall physical capacities. These results can be applied in real-world settings by integrating sensorimotor training into rehabilitation programs, fall-prevention strategies, and community-based exercise initiatives aimed at promoting functional independence in aging populations. Healthcare providers, physical therapists, and fitness professionals can incorporate sensorimotor training exercises, such as balance and proprioceptive training, into structured interventions to reduce fall risks and enhance mobility.

Despite its strengths, this study has some limitations. The sample size may limit the generalizability of the findings, and the intervention period may not fully capture the long-term effects. Additionally, individual variations in adherence and baseline physical condition could influence the outcomes. Future research should explore the long-term impact of sensorimotor training, investigate its effects on cognitive function, and examine its integration with other exercise modalities to maximize the benefits for older adults.

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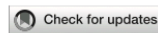


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Effectiveness of different physical activity programs in improving older adults' physical capacities: a randomized controlled trial

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Introduction: As people age, maintaining physical fitness becomes essential for preserving independence, preventing falls, and improving overall quality of life. Physical activity (PA) mitigates the physical decline associated with aging, enhancing balance, strength, flexibility, and coordination. Effective exercise programs for older people should address age-related physical challenges while remaining safe and accessible.

Objective: This study aims to identify the most effective PA program to enhance the physical capacities of older people. By comparing training modalities such as Pilates, Aqua Aerobic, and Sensorimotor training, the study evaluates their impact on key physical abilities to determine the optimal program for promoting functional independence and reducing injury risk in older people.

Methods: This study examined 153 participants, divided into a Control Group (N = 44), Sensorimotor Group (N = 46), Aqua Aerobic Group (N = 41), and Pilates Group (N = 22). Over a 24-week intervention, physical capacities were assessed using the Rikli and Jones battery for strength and flexibility and the timed-up-and-go test for agility and speed. Data were collected pre- and post-intervention. To analyze the changes, we used Student's T-test and Cohen's d for effect size (ES), with statistical significance set at $p < 0.05$. Additionally, ANOVA was applied to examine the main effects of time, group, and their interaction, with Partial Eta Squared used to determine the effect size (ES) in these comparisons.

Results: The Sensorimotor Group showed significant gains in all tests ($p < 0.05$), while the Aqua Aerobic Group showed improvements in the Stand



and Sit with and without Leaning ($p < 0.001$), Forearm Flexion ($p = 0.005$), and Reach Behind your Back ($p = 0.002$). In contrast, the Control and Pilates Groups did not exhibit significant improvements in any of the assessed variables. The analysis of the moment*group interaction effect revealed significant differences among the groups, except for the Timed Up and Go (TUG) test.

Conclusion: In conclusion, sensorimotor and aquatic training significantly improved physical function, especially balance, strength, and mobility, in older people.

KEYWORDS

aqua aerobic, older people, pilates, physical capacities, sensorimotor training

1 Introduction

By 2050, the number of people aged 80 and older is expected to reach 434 million—a threefold increase. Globally, the population over 60 is growing at a rate of 3% per year, outpacing the growth of younger age groups. Projections indicate that by 2050, 22% of the global population will be older people (World Health Organization, 2020). This demographic shift represents a significant social revolution of the 21st century, with profound social, political, and economic implications.

As people age, molecular and cellular deterioration affects all bodily systems, leading to a decline in physical and psychological health. However, physical activity (PA) has been shown to slow this decline by enhancing or maintaining intrinsic and functional capacities such as strength, balance, and flexibility. This makes PA a key factor in mitigating the effects of aging on biopsychosocial functions, thereby improving the quality of life for the older people (Wickramarachchi et al., 2023). Additionally, the role of PA in enhancing health outcomes and reducing healthcare costs aligns with the objectives of current and future policy decisions (Duijvestijn et al., 2023).

A particular kind of training called sensorimotor training integrates the motor and sensory systems to enhance movement control and coordination. According to certain research, sensorimotor training may help healthy people with their postural sway, balance, and coordination. Research on its efficacy for senior citizens is, nevertheless, scarce. It is yet unknown if sensorimotor training results in a direct improvement in muscle strength, even though it can improve motor abilities. Therefore, more investigation is required to ascertain the precise effect of sensorimotor training on strength (Di Corrado et al., 2023; Varjan et al., 2024).

Joseph Pilates developed the Pilates method in the 1920s, and it is recognized as one of the most effective strategies for achieving the goals of Healthy Ageing due to its holistic approach. The method combines exercises that integrate the mind and body, requiring strength, flexibility, and trunk stability while also emphasizing breathing, posture, and muscle control (Kloubec, 2011). This versatility contributes to the method's effectiveness, leading to psychomotor benefits and enhanced functional capacity, promoting greater independence and quality of life. In recent years, the body of research on Pilates has grown, with studies indicating its benefits for various populations, including older adults. Evidence suggests that Pilates is effective in improving balance, flexibility, muscle strength, and posture, which are essential for preventing falls and maintaining

autonomy in daily activities (Pereira et al., 2022). Furthermore, recent systematic reviews have highlighted its positive impact on chronic conditions, such as low back pain, by improving core stability and reducing pain intensity (Patti et al., 2024). Despite these promising findings, further research is needed to explore its long-term effects on physical capacities in the older population, particularly in comparison with other exercise modalities.

Aquatic exercise has also gained popularity among older adults, as it minimizes or overcomes some of the limitations of land-based programs due to the unique properties of water, such as buoyancy and viscosity. These properties reduce joint stress while providing resistance, making water-based exercise a safe and effective alternative for individuals with mobility limitations or joint-related conditions. Additionally, evidence suggests that aquatic exercise programs are equally or even more effective than land-based ones in enhancing balance, strength, and overall wellbeing in older individuals (Farinha et al., 2021).

Given these considerations, key questions arise: Are sensorimotor training, Pilates, and aqua aerobics effective methods for promoting healthy aging? If so, how do they contribute to this goal? This study aimed to evaluate the effectiveness of sensorimotor training, Pilates, and aqua aerobics in enhancing physical capacities in individuals over 55 years of age. By comparing these exercise programs to a control group, we seek to determine which approach yields the most significant benefits for healthy aging. We hypothesize that each program will contribute to improved physical capacities, with distinct advantages depending on the training method.

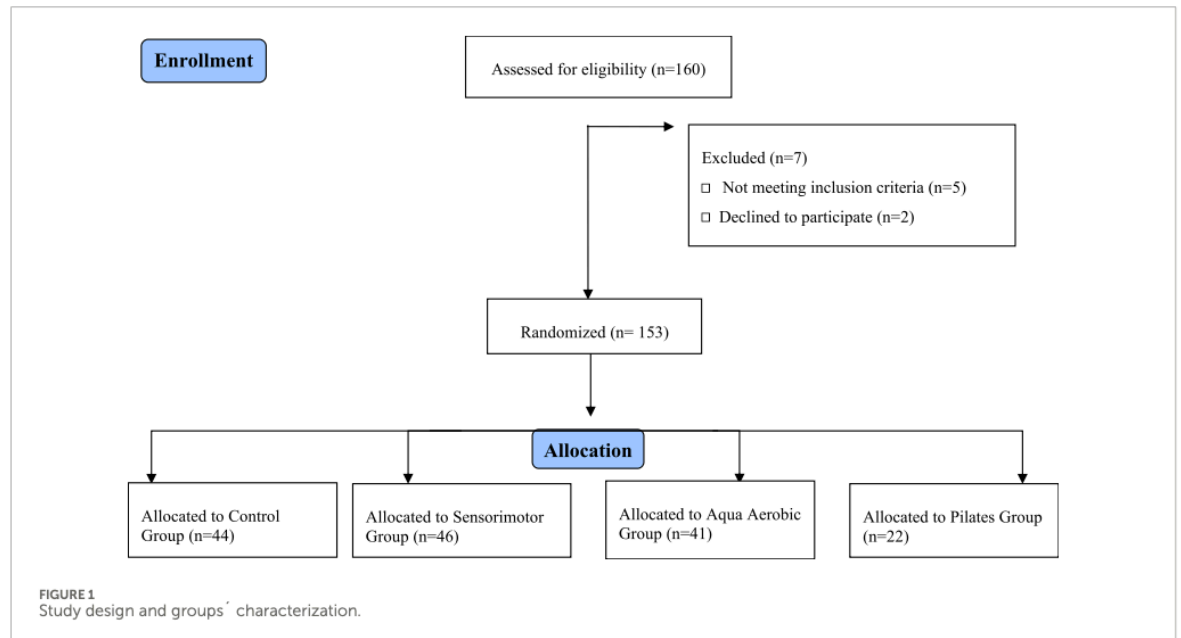
2 Materials and methods

2.1 Design

The present paper is randomized controlled trial, examining the evolution of characters over a long time, and evaluating the physical capacity of older people after different PA programs (Montero and León, 2007).

2.2 Participants

Sample size calculations were performed using the G*Power 3.1.9.4 software (Kiel University, Kiel, Germany), selecting the statistical test to compare the differences between groups. Thus,



accepting an alpha risk of 0.05 and assuming a moderate ES of 0.4, a total of 112 participants were sufficient to reach a minimum potency of 95%. From a total of 160 regular participants in the program, this study included 153 subjects aged between 55 and 80 years. The study population comprised individuals residing in Portugal, specifically in the municipality of Almada. All participants were community-dwelling older adults who met the study's inclusion criteria. Participants were randomly assigned to the experimental or control group using computer-generated randomization with stratification based on age and baseline functional capacity. To minimize expectancy bias, participants were informed about the general objectives of the study but blinded to the specific purpose of the group comparisons. Additionally, researchers responsible for data analysis were blinded to group allocation. A parallel-group randomized controlled trial was conducted, with a 6-month intervention phase. **Figure 1** describes the study design and particularities associated with each group.

The participants were randomly assigned to the four groups shown in **Table 1** (Control Group $N = 44$; Sensorimotor Group $N = 46$; Aqua Aerobic Group $N = 41$; and Pilates Group $N = 22$). No dropouts occurred, and subjects were evaluated previously and shortly after the end of the intervention program. **Table 1** displays the characteristics of the sample to provide context and frame the sample used in the study.

Participants should meet the following inclusion criteria: (1) aged between 55 and 80 years old; (2) without prosthesis (except dental prosthesis); and (3) who had no surgical interventions 6 months before data collection. Exclusion criteria: (1) musculoskeletal diagnosis; (2) problems in locomotion; (3) psychiatric diseases and neurological disorders; and (4) clinical cardiovascular diagnosis. These inclusion and exclusion criteria were established to prevent any damage associated with the participants because the intervention focused on a sensorimotor training program under different situations.

2.3 Ethics

The Ethics Committee of the University of Évora approved this project (approval number: 21040). The study was registered with the Clinical [Trials.gov](https://www.clinicaltrials.gov) PRS Protocol Registration and Results System (Registration Number: NCT05398354; <https://www.clinicaltrials.gov/ct2/show/NCT05398354?term=NCT05398354&draw=2&rank=1>).

Each participant provided informed consent before participating, according to the Helsinki Declaration for Human Studies.

2.4 Intervention programs

The sensorimotor program (**Figure 2**) was conducted for 6 months, with a frequency of twice a week. As the program progressed, there was a progressive increase in the load. To this end, the session was divided into three levels of intensity: easy (no external load during the first 8 weeks), intermediate (application of external load: eic bands, shin guards and free weights, from the 9th to the 16th week) and advanced (increase in external load for the previous level, from the 17th to the 24th week). Each month, a different type of session was developed. Each session lasted 45 min, divided into three phases: the initial phase (10 min), consisting of a 5-min walk followed by a joint warm-up; and the fundamental phase (25 min), where the patients worked on a corresponding circuit of exercises. This circuit consisted of four cycles, with eight exercises each (50 s on, 15 s off); and a return to calm (10 min), where muscle stretching was performed.

The aqua aerobic program was conducted for 6 months, with a frequency twice a week. An aqua aerobics plan focused on improving mobility, strength, balance, and cardiovascular health while minimizing injury risks. The sessions began with a 10-min warm-up, involving gentle walking or marching in shallow

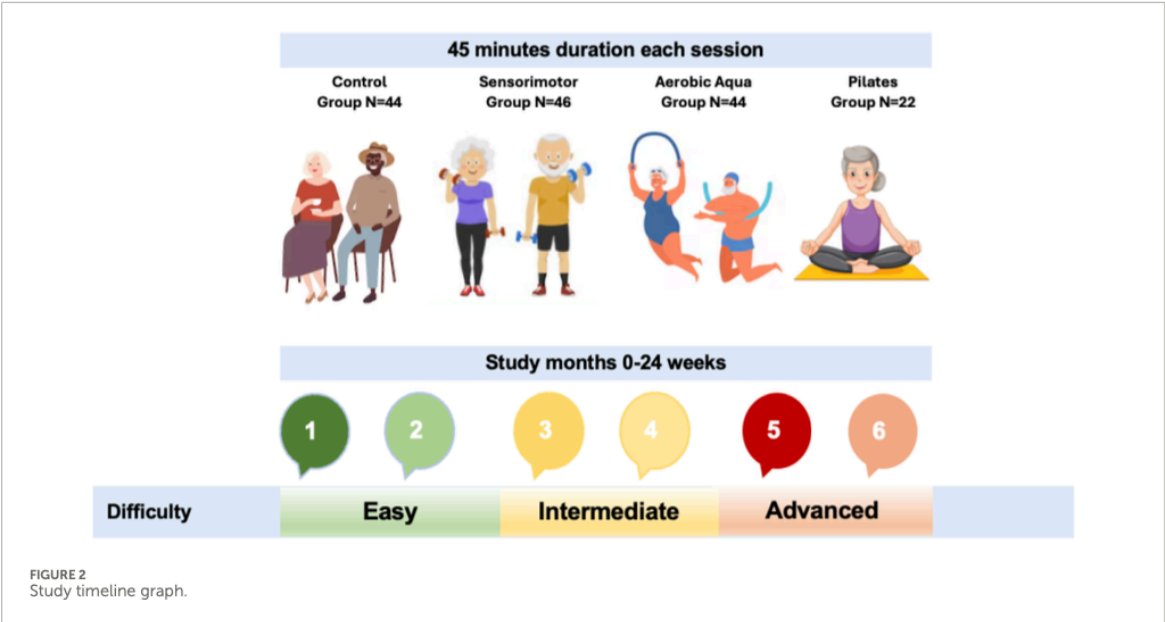


TABLE 1 Characteristics of the sample selected to perform the study.

	Gender	N	Age (year)		Weight (kg)		Height (m)		BMI (kg/m ²)	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD
Control Group	Female	37	72.6	5.47	68.2	11.6	1.56	0.05	28.1	4.82
	Male	7	79.6	6.08	80.1	14.3	1.68	0.05	28.2	4.24
Sensorimotor Group	Female	36	71.8	7.02	66.8	14.2	1.55	0.06	27.7	5.41
	Male	10	74.7	6.07	74.3	13.5	1.68	0.07	26.1	3.18
Aqua Aerobic Group	Female	28	73.7	6.73	69.7	14.1	1.55	0.05	29.0	5.82
	Male	13	74.9	6.55	81.3	13.1	1.67	0.07	28.9	3.51
Pilates Group	Female	18	70.6	4.53	65.6	9.52	1.59	0.05	26.0	3.64
	Male	4	72.5	5.45	74.1	9.55	1.64	0.03	27.5	2.46

Note. Kg: Kilograms; m: Meters, BMI: body mass index; SD: standard deviation.

water, along with arm circles and shoulder rolls to prepare the body. The main workout lasted 20 min, starting with 5 min of water walking or jogging, both forward and backward, to boost balance and coordination. This was followed by leg lifts, alternating between side and front lifts, aimed to increase strength and flexibility. Arm curls using water resistance were then performed to build upper body strength. Seated bicycle movements, while supporting the pool wall, target core and leg strength. The sessions terminated with a 10-min cool down of slow walking and gentle stretching to relax muscles and improve flexibility.

The Pilates program was conducted for 6 months, with a frequency of twice a week. Prioritizing safety, flexibility, strength, and balance. The sessions began with a gentle warm-up,

incorporating deep breathing and light stretches to prepare the body. Participants then moved into core strengthening exercises, such as pelvic tilts and seated leg lifts, to enhance stability. Following this, they engaged in gentle spine articulation, like the cat-cow stretch, to promote spinal flexibility. Side-lying leg lifts and clamshells were included to strengthen the hips and glutes. Balance exercises, such as standing on one leg while holding onto a chair for support, were conducted to improve stability. The sessions ended with a cool down, featuring seated forward bends and deep breathing to relax the muscles and promote a sense of wellbeing.

The Control Group did not participate in any activity during the intervention period but underwent assessments both before and after the intervention for comparison with the other groups.

This allowed for an evaluation of the effects of the Sensorimotor Group, aerobic aqua group, and Pilates Group by providing baseline and post-intervention data without any external influence from physical activity.

A variety of tools were used to evaluate the studied variables. All measures were performed at baseline, at the end of the intervention program. Previous to the first measurement, all subjects participated in a familiarization phase to adapt themselves to the different instruments and assessments included in this study.

Main measures:

To assess the physical fitness of the participants, a tracksuit bottom was used and subjects were asked to remove accessories and any objects in their pockets. The following evaluations were carried out:

- (I) Agility and execution speed were assessed through the Timed Up and Go (TUG) test, which consists of getting up from a chair, walking in a straight line 3 m away, and walking back and sitting down again (Barry et al., 2014; Bretan et al., 2013).
- (II) Muscular endurance was evaluated by rising from the chair or bending and straightening for 30 s, during which the strength of the lower limbs involving the vastus medialis obliquus (VMO) and the vastus lateralis (VL) was also calculated (Lemmink et al., 2003).
- (III) Upper limb strength was determined by the number of times that a determined weight can be lifted by performing a flexion-extension of the arms for 30s (Ginn et al., 2006).
- (IV) Lower limb flexibility was assessed using the “sit and reach” test, in which the participants, from a seated position with one leg extended, slowly bent over, sliding their hands down the extended leg until they touched (or passed) their toes (Mayorga-Vega et al., 2014).
- (V) Upper limbs flexibility was assessed using the “behind the back reach”, which consisted of measuring with a ruler the distance between (or the overlap of) the middle fingers behind the back (Ginn et al., 2006).

2.5 Statistical analysis

To assess the normality of the sample, the Kolmogorov-Smirnov test was conducted, revealing a p-value greater than 0.05. Therefore, the normality of the sample was assumed (Field, 2013). Parametric models were used to test the study's hypotheses (O'Donoghue, 2012). The sample data was analysed to describe and understand it better. Average and standard deviation were used to look at how the data differed based on the gender of the participants. Afterward, a Student's t-test was conducted to compare the differences between groups before and after the intervention, based on the first and second data collection. The ES of the differences was calculated using Cohen's d proposal: trivial (0–0.2), small (0.2–0.6), moderate (0.6–1.2), large (1.2–2), very large (2–4), and extremely large (>4) (Cohen, 2013; Hopkins et al., 2009).

We employed a two-way repeated measures ANOVA to analyse the data. To comprehensively understand the effects of the intervention across different groups and time points, we conducted a two-way repeated measures ANOVA. This statistical method allowed us to evaluate the main effects of time (pre-vs. post-intervention), group (Control, Sensorimotor, Aqua Aerobic, Pilates),

and the interaction effect between time and group. By using the two-way repeated measures ANOVA, we could determine whether the changes over time differed significantly between the groups, offering a more nuanced understanding of the intervention's impact. This approach provided a robust analysis of the data, accounting for both within-subject and between-group variations. To analyse the ES (η^2), we used Partial Eta Squared.

The software Jamovi (v2.3.18) was used to conduct statistical analyses. Statistical significance was determined at $p < 0.05$.

3 Results

Table 2 shows the differences between the pre- and post-intervention values according to the developed programs. These results reported that the users included in the intervention programs developed significant differences in the analyzed variables. In this line, the participants who participated in the Aqua Aerobic Group showed differences between the pre- and post-intervention values in certain variables (Stand and Sit with Leaning, Stand and sit without Leaning, Forearm flexion, and Reach Behind your Back (left)). In this population, the ES was negative, small, and moderate.

The analysis of the moment*group interaction effect revealed significant differences between the groups, except in the Timed Up and Go (TUG) test, where no significant differences were found. Regarding ES, the Reach Behind Your Back test showed the highest values, with a moderate ES for the right side and a large ES for the left side. These findings highlight the substantial impact of the intervention on upper body flexibility, particularly in shoulder mobility.

Figure 3 shows the results related to the ES of the analysis (Hopkins et al., 2009), which improves the comprehension regarding the results obtained. The ES analysis revealed notable differences between the groups across various physical function tests. The sensorimotor training group showed the most substantial positive effects, particularly in flexibility and postural control measures. This was especially evident in the “Reach Behind Your Back” test (right: ES = −1.074; left: ES = −1.323) and the “Sitting and Reaching” test (ES = −0.653), indicating significant improvements in mobility and trunk flexibility. The aqua aerobic group also demonstrated moderate to strong effects, though generally lower than the sensorimotor group, especially in reach and upper-limb flexibility tasks. The Pilates group displayed only mild and localized effects, with slight improvements in upper-body strength (e.g., “Forearm Flexion,” ES = 0.207). As expected, the control group showed minimal or inconsistent effect sizes, with no meaningful improvements. These findings highlight the effectiveness of sensorimotor training in enhancing functional mobility and postural stability in older adults.

4 Discussion

This study aimed to examine the impact of various activity programs (such as Control Group, Sensorimotor Group, Aqua Aerobic, and Pilates) on the physical wellbeing of older adults. The study is characterized by a robust design, including a 6-month intervention period, which facilitated a meaningful assessment of physical fitness

TABLE 2 Inferential analysis of pre-and post-intervention values according to the different intervention programs.

Variables (pre-and post-values)	Control Group		Sensorimotor Group		Aqua aerobic group		Pilates group		Intervention effect Moment*Group	
	p value	ES	p value	ES	p value	ES	p value	ES	p value	ES (η^2)
Timed Up and Go (s)	0.450	0.115	< 0.001	0.575	0.085	0.276	0.456	0.162	0.395	0.020
Stand and Sit with Leaning (rep)	0.349	-0.142	< 0.001	-0.537	< 0.001	-0.688	0.413	-0.178	0.039	0.055
Stand and Sit without Leaning (rep)	0.905	-0.018	< 0.001	-0.743	< 0.001	-0.637	0.472	-0.156	< 0.001	0.115
Forearm Flexion (rep)	0.319	0.151	0.002	-0.490	0.005	-0.467	0.342	0.207	0.003	0.090
Sitting and Reaching (rep)	0.155	0.218	< 0.001	-0.653	0.203	0.202	0.677	0.089	0.003	0.090
Reach Behind your Back (right) (m)	0.277	0.165	< 0.001	-1.074	0.126	-0.244	0.307	-0.223	< 0.001	0.108
Reach Behind your Back (left) (m)	0.197	-0.197	< 0.001	-1.323	0.002	-0.505	0.409	-0.179	< 0.001	0.227

Note. S: seconds; rep: Repetitions; m: Meter; ES: effect size; $p < 0.05$. Cohen's d for ES: trivial (0–0.2), small (0.2–0.6), moderate (0.6–1.2), large (1.2–2), very large (2–4), and extremely large (>4); Partial Eta Squared for ES (η^2): Small ES (0.01–0.06); # Medium ES (0.06–0.14); *Large ES (>0.14). Bold values with statistical significance.

changes over time. The incorporation of sensorimotor, aerobic aqua, and Pilates groups allowed for a comprehensive evaluation of the effects of different exercise modalities. The main findings indicated that participants in the intervention programs demonstrated significant improvements across all analyzed variables. Additionally, those involved in aqua aerobics exhibited notable differences in specific variables (Stand and sit with leaning, Stand and sit without leaning, Forearm flexion, and Reach Behind your Back (left) before and after the intervention. The ES for this population ranged from small to moderate, with negative values. These results underscore the importance of targeting mobility, strength, and balance in the aging process. To improve the physical capacities of older adults, it is recommended to carry out a sensorimotor program that focuses on the main activities and movements required in daily routines. Such programs can improve balance, coordination, and effectiveness, ultimately enhancing quality of life. Furthermore, the well-defined physical fitness assessment methods ensured a homogeneous sample, thereby enhancing the external validity of the findings for the older adult population.

The results of the TUG test (Shumway-Cook and Woollacott, 2007) among different groups—sedentary individuals, those participating in Pilates, sensorimotor training, and aqua

aerobics—can reveal significant insights into the impact of various PA programs on functional mobility. In the Control Group, significant values were not obtained. Participants in sensorimotor training typically show even greater improvements on the TUG test because this type of training targets balance and coordination, essential elements for mobility in older adults (Freire and Seixas, 2024). The integration of various sensory inputs during sensorimotor training is crucial for enhancing neuroplasticity, which allows the brain to reorganize and adapt to new stimuli. This process enables participants to react more effectively to external stimuli, potentially improving their balance and coordination. However, it is important to note that not all physical activities lead to a reduction in fall risk. According to Bianco et al. (2014) activities that specifically stimulate reaction time are most effective in reducing falls and injuries among older adults. These types of exercises promote faster and more accurate responses to environmental challenges, which are key factors in fall prevention. When analysing the data we obtained in our study, we found significant values with this activity ($p < 0.001$). Aqua aerobics and Pilates participants did not exhibit significant values.

The Control and Pilates groups performed more poorly on the Stand and Sit with Leaning test, often taking longer to complete the



task compared to other groups. This delay indicates compromised strength, balance, and functional mobility, which are common among those who do not engage in regular PA (Maki and McIlroy, 1997). Lack of movement leads to muscle atrophy and reduced proprioception, significantly increasing the risk of falls and functional decline in this population (Cameron et al., 2016). In contrast, sensorimotor and aquatic aerobic groups showed even greater improvements.

The Forearm Flexion test (Rikli and Jones, 1999), when analyzing the results from the Control and Pilates groups, showed no significant findings. This population often experiences muscle atrophy and decreased overall physical performance, leading to challenges in daily tasks that require upper body strength (Cameron et al., 2016). Additionally, insufficient PA can contribute to a decreased quality of life and increased dependency on caregivers. In contrast, sensorimotor and aquatic aerobic groups showed significant results. Enhanced neuroplasticity and strength gained through sensorimotor training enable participants to perform the Forearm Flexion test more effectively, indicating improved upper body function and reduced fall risk. Aqua aerobics incorporates resistance exercises that targets the upper body, leading to improvements in muscle tone and strength.

Sensorimotor training contributes to improvements in the Sitting and Reaching test, although the primary focus of such training is balance and coordination. The dynamic movements and stability exercises involved in sensorimotor training indirectly enhance flexibility by improving muscle control and joint stability. Studies suggest that participants in sensorimotor training show increased overall mobility and flexibility, which can enhance their performance in flexibility tests like Sitting and Reaching (Pšeničnik Sluga and Kozinc, 2024). Compared to our study, only the Sensorimotor Group had significant results in this test.

Sensorimotor training positively impacted shoulder mobility, leading to moderate improvements in the “Reach Behind Your Back” test (Ahmad et al., 2019), although its primary focus was on balance and coordination. Participants in sensorimotor training programs often show a greater functional range of motion (ROM) than sedentary individuals, allowing them to perform better in shoulder flexibility tests (Freire and Seixas, 2024). In the Reach behind your backtest, both left and right, the Sensorimotor Group had significant results. In addition, on the Reach Behind your Back Left we also observed significant results from the Aqua Aerobic Group. Aqua aerobics offers significant benefits for shoulder flexibility due to the unique properties of water. The buoyancy of water reduces joint strain, allowing participants to perform a wider ROM with less discomfort. Aqua aerobics routines often incorporate shoulder and upper body movements, which improve joint mobility and flexibility over time (Song and Oh, 2022). As a result, older people who engage in aqua aerobics tend to perform well in the “Reach Behind Your Back” test, often surpassing sedentary individuals and showing comparable improvements to those in Pilates programs (Tsourlou et al., 2006).

The results suggest that the Sensorimotor and Aqua Aerobics groups demonstrated significant improvements in specific variables, highlighting the targeted benefits of these interventions. However, the negative effect sizes observed in certain measures, such as the Timed Up and Go (TUG) test, warrant further investigation. It remains uncertain whether these negative values stem from measurement errors, participant variability, or an actual decline in performance, requiring additional analysis to clarify these findings.

This study has several limitations. The small sample size in certain groups (e.g., Pilates, $N = 22$) may reduce statistical power, and the predominance of female participants limits generalizability.

to males. The sensorimotor training protocol lacks detailed descriptions of targeted muscle groups, repetition schemes, and risk management strategies. Additionally, the absence of long-term follow-up prevents assessment of sustained intervention effects. Potential confounders, such as diet, medication, and baseline fitness levels, were not controlled. The study's age range (55–80 years) may also limit applicability to other populations. Lastly, the practical significance of small or negative effect sizes, particularly in tests like the Timed Up and Go (TUG), warrants further investigation.

Future studies should focus on increasing the sample size to enhance statistical power and improve the generalizability of the findings. A wider range of outcome measures, including cognitive function and quality of life assessments, should be incorporated to provide a more comprehensive understanding of the intervention effects. Long-term follow-up evaluations should be conducted to assess the sustainability of the benefits over time. It is also recommended to collect more detailed demographic data to facilitate the exploration of potential subgroup effects based on factors such as comorbidities and age ranges. Additionally, the clinical relevance of effect sizes should be further investigated alongside statistical significance to better interpret the practical implications of the findings.

As a future research direction, it is suggested to apply this program to a larger sample to allow for the extrapolation of results to the broader adult population. Furthermore, developing a program based on sensorimotor perception for individuals with specific comorbidities is proposed, aiming to determine whether the intervention leads to significant improvements in motor skills affected by these conditions.

5 Conclusion

This study highlights the effectiveness of exercise interventions for older adults, with sensorimotor and aquatic training demonstrating distinct benefits. The sensorimotor group showed significant improvements in balance, coordination, and strength, while the aquatic aerobics group enhanced lower body strength, mobility, and flexibility. In contrast, the Control and Pilates groups showed no significant gains, reinforcing the advantages of sensorimotor and aquatic training.

Despite the promising results, limitations such as small sample size, gender imbalance, and lack of long-term follow-up affect generalizability. Future studies should address these factors to confirm long-term benefits. Overall, sensorimotor training appears to be the most effective for enhancing overall physical function in older adults.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by the Committee of the University of Évora approved this project (approval number: 21040). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

CAC: Conceptualization, Methodology, Software, Formal analysis, Writing – original draft. VH-B: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft. OF: Validation, Writing – review and editing, Supervision. CM: Methodology, Data curation, Writing – review and editing. JMG: Validation, Data curation, Writing – review and editing, Visualization. MCE: Validation, Investigation, Writing – review and editing, Visualization. JAP: Data curation, Writing – review and editing, Visualization, Supervision.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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OPEN The role of physical exercise in enhancing Health, quality of life and joy among older adults

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Physical exercise (PE) plays a vital role in promoting health, quality of life (QoL), and well-being in older adults. It helps prevent chronic diseases, improves strength, balance, and cognitive function, and reduces fall risk. Enjoyment and psychological engagement are also essential for long-term adherence. This randomized controlled trial (RCT) study aimed to examine the effects of a 24-week structured sensorimotor training program on physical activity (PA) levels, body composition, quality of life, and enjoyment in older adults. A total of 124 participants (65–80 years old) were allocated to an experimental group (EG, $n = 46$) or control group (CG, $n = 78$). The EG engaged in a 24-week supervised sensorimotor training program, while the CG maintained their usual lifestyle. PA levels were assessed using the International Physical Activity Questionnaire – Short Form (IPAQ-SF); enjoyment of PA was evaluated using the Physical Activity Enjoyment Scale (PACES); and QoL was measured with the SF-36 questionnaire. Body composition, PA, and QoL were evaluated at baseline and post-intervention. Both groups showed small reductions in body composition measures. The only statistically significant difference was observed in walking activity (minutes per week), with $p = 0.022$ and partial eta squared (η^2) = 0.148, favoring the EG. No significant differences were found for overall PA levels, PACES scores, or SF-36 dimensions. Effect sizes for other outcomes ranged from $\eta^2 = 0.001$ to 0.148, with p values ranging from 0.022 to 0.78. While the sensorimotor training program was associated with improved walking activity, no significant differences were found for other measured outcomes. The results suggest that moderate PA programs may yield selective benefits in older adults. Further research with longer follow-up and enhanced focus on motivational and psychosocial components is recommended.

Keywords Aged, Physical activity, Sensorimotor training, Quality of life, Exercise, Randomized controlled trial, Physical fitness, Enjoyment

Abbreviations

BMI	Body Mass Index
CG	Control Group
EG	Exercise Group
ES	Effect Size
HRQoL	Health-Related Quality of Life
IPAQ	Physical Activity Questionnaire Short Form
MVPA	Moderate-to-Vigorous-Intensity to Physical Activity
PA	Physical Activity
PACES	Physical Activity Enjoyment Scale
RCT	Randomized Controlled Trial
QoL	Quality of Life
SF	36-Item Short-Form Survey
WHO	World Health Organization

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The phenomenon of population aging has emerged globally due to increased life expectancy and declining fertility rates. Aging is a gradual, permanent, natural, and progressive process that leads to physical and mental changes, which can affect key areas of daily functioning. These include reduced mobility, diminished autonomy in performing daily activities, challenges in maintaining social relationships, and decreased ability to adapt to environmental and technological changes. However, aging also presents opportunities to promote active and meaningful lives. A comprehensive approach to healthy aging must consider not only physical health but also emotional well-being, cognitive vitality, and social participation. Maintaining interpersonal relationships, engaging in community activities, and preserving autonomy are crucial factors in supporting the health and dignity of older adults^{1,2}.

The concept of “quality of life” (QoL) can be viewed from multiple perspectives, with one approach emphasizing its multi-contextual nature—defined and assessed through both objective conditions and subjective evaluations. QoL encompasses physical, emotional, and social domains and significantly influences a person's overall health. For older adults, key physical aspects, such as energy levels, ability to perform daily tasks, and absence of pain, are vital. The extent to which these factors are affected varies based on lifestyle, environment, and the degree of capacity decline they experience¹.

The positive impact of regular physical activity (PA) on health and QoL in older adults is well-documented. PA plays a key role in healthy aging and helps prevent chronic diseases while reducing frailty and fall risk and preserving physical function (e.g., walking speed, handgrip strength). It also supports healthier body composition, reflected in weight, waist circumference, and body mass index (BMI) measurements. Beyond physical benefits, regular PA also contributes to improved emotional well-being, increased self-esteem, and stronger social ties. However, accurate PA monitoring is needed to better understand its link to health outcomes^{3,4}.

Promoting PA is essential for public health. The World Health Organization (WHO) recommends at least 150 min of moderate-to-vigorous-intensity PA (MVPA) per week. Assessing PA helps estimate the risk of disability and healthcare needs in older adults by preventing disability caused by chronic diseases or functional decline. PA is recorded using either self-reported methods or objective monitors. Self-reported tools, such as questionnaires, offer broad data collection and greater feasibility, while objective devices like pedometers and accelerometers provide more accurate activity tracking^{5,6}.

While both objective and subjective tools exist for population studies, much of the research relies on subjective self-report methods (e.g., questionnaires, logs, recalls). Recalling PA can be cognitively challenging for older adults, leading to issues with memory, response accuracy, and question interpretation, which reduce the validity of self-reported daily activities. Despite this, self-report methods are cost-effective and practical for large-scale studies. Additionally, surveys provide detailed information on the type (e.g., recreational, household, work-related) and duration (e.g., minutes per day or week) of PA⁷.

In this study, we employed three validated instruments—IPAQ-SF to assess physical activity levels, SF-36 to evaluate health-related quality of life, and PACES to capture enjoyment of physical activity. These tools were chosen for their established reliability and validity in older adult populations and their collective ability to explore the behavioral and psychosocial dimensions of PA participation. Importantly, enjoyment has been shown to mediate and predict sustained engagement in PA, while both enjoyment and PA level are associated with higher perceived QoL in aging populations. This theoretical interrelation forms the rationale for combining these instruments in our study framework.

The International Physical Activity Questionnaire Short Form (IPAQ-SF) is well-suited for large-scale population studies on PA in adults. It measures PA across three domains: walking, moderate-intensity PA, and vigorous-intensity PA. Although the IPAQ-SF's validity has been confirmed even in older adults, it tends to overestimate time spent in all PA intensities. Additionally, the IPAQ-SF and objective measurements aligned in identifying individuals meeting WHO-recommended PA levels in only 40% to 46% of cases health^{8,9}. Despite this limitation, the IPAQ-SF demonstrates acceptable convergent validity with objective tools such as accelerometers, particularly at the group level, and shows sensitivity to population variations, making it a valuable tool in epidemiological research. It has proven useful in studying the relationship between PA and older adults QoL, metabolic syndrome, sarcopenia, and mental¹⁰.

In recent years, interest in assessing QoL has grown significantly, leading to the development of various scales and questionnaires. According to bibliographic research, the SF-36 Health Questionnaire is the most widely used tool for evaluating health-related QoL (HRQoL). This questionnaire has been adapted for diverse research, clinical, and social intervention settings. It has been applied to both the general population and individuals with health conditions. It is regarded as a reference standard for the development or validation of other HRQoL measurement tools^{1,11}.

Enjoyment, defined as a multidimensional affective response encompassing joy, satisfaction, and psychological well-being, is a significant predictor of participation in PA. In this context, enjoyment reflects a positive attitude towards engaging in PA. Research has linked enjoyment to various psychological and behavioral traits among exercise participants, including intrinsic motivation, commitment, persistence, well-being, and adherence¹². Self-Determination Theory (SDT), developed by Ryan and Deci¹³, offers a theoretical framework for understanding intrinsic motivation. According to SDT, motivation is enhanced when three basic psychological needs are fulfilled: autonomy (feeling in control of one's actions), competence (feeling effective), and relatedness (feeling connected to others). The extent to which PA fulfills these needs plays a vital role in generating enjoyment and sustaining motivation. Meeting these needs fosters what is referred to as “optimal motivational functioning”¹⁴.

Autonomous or self-determined motivational forms are associated with more adaptive behavioral patterns characterized by higher effort and persistence. Exercise motivated by intrinsic rewards represents the highest level of self-determination, as individuals engage in PA because they genuinely enjoy it. Consequently, higher self-determined motivation is linked to positive emotions contributing to overall well-being^{15,16}.



The Physical Activity Enjoyment Scale (PACES), originally an 18-item measure, was designed to assess satisfaction with PA. Mullen et al.¹⁷ recently confirmed an 8-item version using older adults in a year-long fitness program. However, the measurement characteristics of PACES across different fitness categories remain unclear, which is unfortunate given its potential to predict adherence to group exercise regimens and evaluate satisfaction in such programs.

Despite extensive evidence supporting PA in aging populations, relatively few interventions have explicitly examined how structured sensorimotor training impacts enjoyment, PA levels, and QoL in combination. Sensorimotor exercises target coordination, balance, and neuromuscular control—elements critical to maintaining autonomy in older age.

This study aimed to examine the effects of a sensorimotor physical training program on health outcomes and quality of life in older adults, as well as the mediating role of exercise enjoyment and activity levels.

We hypothesized that (1) participants in the experimental group would exhibit significantly greater improvements across these outcomes than those in the control group, and (2) higher enjoyment and PA levels would be associated with better QoL post-intervention.

This study used a two-group pre-post RCT design; thus, while correlational links between enjoyment, PA, and QoL were explored, causal mediation effects were not formally tested.

Methods

Experimental design

This study is a parallel-group, randomized controlled trial designed to assess changes in functional capacity among older adults following a 6-month physical activity (PA) intervention. The trial evaluates the longitudinal effects of a sensorimotor exercise program on physical and psychological health parameters¹⁸.

The study was developed under the premises of the Declaration of Helsinki¹⁹, being approved by the Bioethics Committee of the University of Évora (Registration number 21040) and developed under the ethical standard for sports science research²⁰. The study was registered with the ClinicalTrials.gov PRS Protocol Registration and Results System (Registration Number: NCT05398354; <https://www.clinicaltrials.gov/ct2/show/NCT05398354?term=NCT05398354&draw=2&rank=1>).

Participants

Sample size calculations were performed using the G*Power 3.1.9.4 software (Kiel University, Kiel, Germany), selecting the statistical test to compare the differences between groups. Thus, accepting an alpha risk of 0.05 and assuming a moderate ES of 0.4, a total of 112 participants were sufficient to reach a minimum potency of 95%. From a total of 160 regular participants in the program, this study included 124 subjects aged between 55 and 80 years. The study population comprised individuals residing in Portugal, specifically in the municipality of Almada. All participants were community-dwelling older adults who met the study's inclusion criteria. Participants were randomly assigned to the experimental or control group using computer-generated randomization with stratification based on age and baseline functional capacity. To minimize expectancy bias, participants were informed about the general objectives of the study but blinded to the specific purpose of the group comparisons. Additionally, researchers responsible for data analysis were blinded to group allocation. A parallel-group randomized controlled trial was conducted, with a 6-month intervention phase. Figure 1 describes the study design and particularities associated with each group.

A total of 124 community-dwelling adults aged 55 to 80 years participated. Participants were randomly allocated (simple randomization using computer-generated sequences) into an experimental group (EG) or a control group (CG). Assessments were conducted at baseline and post-intervention (6 months later). Inclusion criteria included: (1) age 55–80 years; (2) no major surgical procedures in the past 6 months; (3) ability to engage in physical exercise; (4) sufficient literacy to comprehend study materials and complete self-report questionnaires independently; and (5) functional independence in daily living activities, as self-reported. Exclusion criteria included: (1) diagnosed musculoskeletal, cardiovascular, psychiatric, or neurological conditions; (2) impaired mobility; (3) uncorrected sensory deficits (vision or hearing) that would interfere with participation; and (4) cognitive impairments that could hinder understanding of instructions or completion of assessments (e.g., a known diagnosis of dementia or observed difficulties during screening).

This information ensures that participants were capable of safely engaging in the intervention and accurately reporting their experiences. Baseline and post-intervention measurements included physical activity levels, quality of life, body composition, and enjoyment of physical activity, enabling the evaluation of changes in participant outcomes over time.

Baseline differences between the experimental and control groups were assessed using independent samples t-tests for continuous variables to confirm initial group comparability. No statistically significant differences were found at baseline.

Intervention

Intervention content

The sensorimotor training intervention was carried out over a period of 24 weeks, consisting of two 45-minute sessions per week, totaling 48 sessions. Each session followed a standardized format and was conducted in small groups of 6 to 10 participants, supervised by trained exercise professionals specializing in fitness for older adults. Each session included three phases: warm-up (10 min): Gentle aerobic exercises such as walking in place, arm circles, and shoulder rolls, followed by dynamic stretching and mobility movements targeting the major joints (e.g., hips, knees, shoulders); main exercise circuit (25 min): Participants completed a circuit of 8 exercises, each performed for 50 s, with 10 s allocated for transitioning between exercises. The full circuit was repeated four times, totaling approximately 30 min of active work within the main phase; cool-down (10 min): This



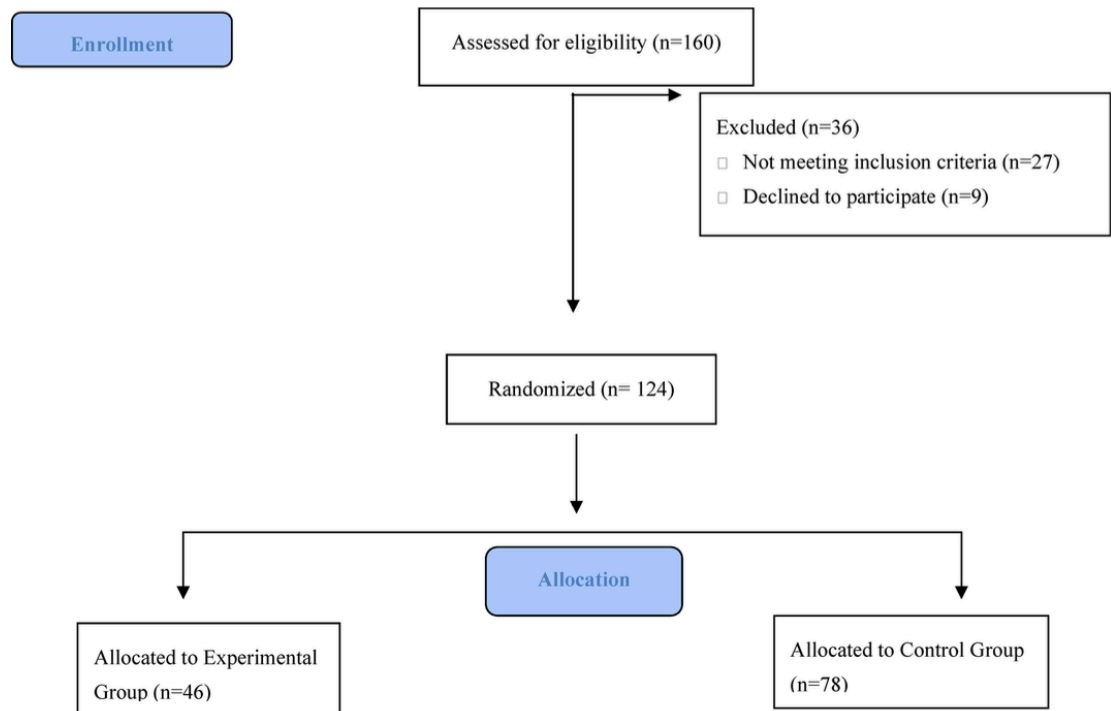


Fig. 1. Study design and groups characterization.

phase focused on stretching the major muscle groups, breathing control, and relaxation techniques to facilitate recovery and promote flexibility.

The intervention was progressively structured into three 8-week phases, each with increasing complexity and intensity: phase 1 (Weeks 1–8 – Easy): Exercises were performed using body weight only, focusing on postural control and basic balance. Activities included tandem stance, sit-to-stand transitions, arm swings with trunk rotation, and single-leg standing with visual fixation; phase 2 (Weeks 9–16 – Intermediate): Moderate external resistance was introduced using elastic resistance bands, light dumbbells (0.5–2 kg), and balance cushions. The exercises incorporated dual-task challenges such as coordination tasks (e.g., walking while clapping or counting backwards) and dynamic movements like lateral stepping and object transfers; phase 3 (Weeks 17–24 – Advanced): Exercises were further intensified by increasing external loads and including unstable surfaces such as foam pads or BOSU balls. Complex motor tasks involving multi-directional movement, obstacle navigation, and cognitive-motor dual-tasks (e.g., naming categories while performing step-ups) were added to enhance proprioception, agility, and cognitive engagement.

Exercise progression was individualized based on participant performance, balance control, and perceived exertion. Instructors followed pre-established criteria to ensure consistent delivery while allowing adaptations when needed to maintain safety and motivation. Participants could choose simpler variations of exercises when appropriate. To ensure standardization, a detailed training manual was provided to all facilitators, and weekly team meetings were held to review session fidelity and adjust activities as needed. Safety was prioritized by using non-slip flooring, accessible handrails, and real-time monitoring during sessions. A variety of accessible equipment—such as elastic bands, light hand weights, cones, balance discs, chairs, foam rollers, and unstable platforms—was incorporated to provide diverse sensorimotor stimuli.

Prior to the intervention, all participants attended a familiarization session to become acquainted with the exercises, equipment, and training structure, aiming to increase comfort and reduce potential instrumentation bias. The intervention was implemented by two certified exercise technicians who received specific training to ensure high fidelity to the protocol, under the supervision of a project coordinator. Notably, the same technicians conducted the outcome assessments but were blinded to group allocation to reduce potential bias²¹. Participants in the control group received standard care and were only involved in baseline and post-intervention assessments; they did not participate in any structured exercise program during the study period.

Measures:

A variety of tools were used for the assessments under study. All measures were taken at baseline, at the end of the intervention. Before the first measurement, all participants were involved in a familiarization phase to adapt themselves to the different instruments and assessments included in this project. To assess the physical



fitness of the participants they wore tracksuit bottom and were asked to remove accessories and any objects in their pockets. The following measures were carried out:

- Anthropometrics and body composition. Bodyweight and height were assessed. Before the measurements, participants were asked to remove their shoes, socks, and heavy clothing (coats, sweaters, coats, etc.). They were also asked to empty their pockets and remove belts and other accessories (bands, pendants, etc.). Height was measured using a stadiometer (Seca 22, Hamburg, Germany). This instrument was placed on a vertical surface with the measuring scale perpendicular to the ground. Participants were positioned in a standing position, with their shoulders balanced, and their arms relaxed along their body. Height was taken in cm and rounded to the nearest mm. Body weight was measured using a scale. Body weight was determined in kg, and the BMI using the formula: $\text{weight (kg)}/\text{height}^2 (\text{m}^2)$.
- Health-related quality of life assessed with the SF-36 Portuguese version^{22–24}, a 36-question tool, which results in 8 dimensions of health status (physical function, physical role, bodily pain, general health, vitality, social function, emotional role, and mental health) and 2 summary components (physical and mental). Dimensions and components are scored from 0 to 100, where 0 is the worst state, and 100 is the best.
- Physical Activity Level assessed with IPAQ-SF⁸. This instrument consists of four questions informing on the frequency (days/week) and duration (minutes/day) of daily walks and activities requiring moderate to vigorous physical exertion, as well as the time (minutes/day) spent on sitting activities on weekdays and weekends. PA was classified into three categories according to the IPAQ consensus group: sedentary (< 600 Met-minutes/week), active (≥ 600 Met-minutes/week), and very active (≥ 3000 Met-minutes/week). This instrument was completed by the participants in its Portuguese version²⁵.
- Exercise enjoyment was assessed with the 8-item Portuguese version of the Physical Activity Enjoyment Scale (PACES), a validated and widely used instrument for measuring subjective enjoyment of physical activity in adults and older populations. It consists of 8 items rated on a 7-point bipolar scale (where 1 = “I like it” and 7 = “I hate it”, with 4 = “neutral”), capturing participants’ affective response to the exercise experience. Total scores range from 8 to 56 points, with higher scores indicating greater enjoyment. The Portuguese adaptation of PACES has demonstrated acceptable internal consistency and construct validity in older Portuguese adults. The scale was administered to all participants in the experimental group at baseline and post-intervention to evaluate changes in exercise enjoyment¹⁶.

Statistical analysis

Normality of data distribution was verified using the Kolmogorov–Smirnov test²⁶. Parametric tests were applied²⁷. Descriptive statistics (mean $\pm$ SD) were calculated. Between-group differences were analyzed using independent samples t-test, with group (EG vs. CG) as the between-subject factor and time (pre vs. post) as the within-subject factor. Treatment effect was estimated as $\Delta = [(\text{Post} - \text{Pre})/\text{Pre}] \times 100$. Effect sizes (ES) were calculated using both partial eta squared (η^2) with thresholds for η^2 of 0.01 (small), 0.06 (moderate), and 0.14 (large)²⁸. Where appropriate, 95% confidence intervals (CIs) were also reported to provide precision of the estimates. Analyses were performed using Jamovi 2.5.2.0. Significance level set at $p < 0.05$.

Results

Participant details

Table 1 shows the characteristics of the sample to contextualize and framework the sample used in the study.

Table 1. Characteristics of participants at the baseline.

According to the results, the 124 participants were of similar ages. In terms of weight and height, they were similar, both being overweight²⁹.

Body composition, physical activity, and health-related quality of life

Regarding body composition, the BMI results of both groups decreased from baseline to the following 24 weeks, with the EG having a greater reduction (Table 2). There were no significant differences in this variable ($p = 0.141$). It also has a small ES ($\eta^2 = 0.018$).

	EG N=46	CG N=78	p
Age (years) ^a	72.40 $\pm$ 6.90	73.20 $\pm$ 5.80	0.505
Weight (kg) ^a	68.40 $\pm$ 14.20	71.30 $\pm$ 13.40	0.257
Height (m) ^a	1.57 $\pm$ 0.08	1.58 $\pm$ 0.07	0.595
Body mass index (kg/m ²) ^a	27.40 $\pm$ 5.00	28.30 $\pm$ 4.70	0.311
Gender: ^b			0.711
- Female	78.30%	76.90%	
- Male	21.70%	23.10%	

Table 1. Characteristics of participants at the baseline. ^aValues expressed as Mean $\pm$ Standard Deviation; p-value of analysis of variance (independent samples t-test). ^bValues expressed as percentage (%); p-value of analysis of Chi-square.



	Baseline		24 weeks		Treatment (%)	Effect size	P
	Exercise	Control	Exercise	Control			
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean (95%CI)	P ^η	
Body composition							
Body mass index (kg/m ²)	27.4 ± 5.0	28.3 ± 4.6	26.8 ± 5.1	28.0 ± 4.5	−1.1 (−2.6 to 0.4)	0.018	0.141
Physical Activity Enjoyment Scale (PACES)							
Very unpleasurable/Very pleasurable (1–7)	6.74 ± 0.57	6.82 ± 0.52	6.83 ± 0.48	6.66 ± 0.86	3.4 (−2.0 to 8.9)	0.013	0.217
No fun/A lot of fun (1–7)	6.78 ± 0.46	6.74 ± 0.59	6.83 ± 0.43	6.66 ± 0.71	1.3 (−3.6 to 6.2)	0.002	0.605
Very unpleasant/Very pleasant (1–7)	6.80 ± 0.45	6.83 ± 0.54	6.76 ± 0.56	6.82 ± 0.45	−0.8 (−5.2 to 3.5)	0.001	0.707
Not invigorating/Very invigorating (1–7)	6.76 ± 0.52	6.88 ± 0.45	6.72 ± 0.65	6.68 ± 0.65	2.4 (−2.6 to 7.3)	0.007	0.350
Not gratifying/Very gratifying (1–7)	6.78 ± 0.46	6.85 ± 0.48	6.78 ± 0.47	6.78 ± 0.52	0.7 (−3.6 to 5.0)	0.001	0.749
Not exhilarating/Very exhilarating (1–7)	6.78 ± 0.47	6.77 ± 0.64	6.85 ± 0.42	6.74 ± 0.57	0.3 (−5.5 to 6.1)	0.000	0.915
Not stimulating/Very stimulating (1–7)	6.76 ± 0.52	6.87 ± 0.46	6.76 ± 0.56	6.77 ± 0.56	1.5 (−2.9 to 6.0)	0.004	0.496
Not refreshing/very refreshing (1–7)	6.78 ± 0.46	6.68 ± 0.90	6.63 ± 0.90	6.52 ± 0.98	−2.6 (−11.3 to 6.1)	0.003	0.555
International Physical Activity Questionnaire (IPAQ)							
Vigorous activity (minutes/week)	160.0 ± 195.7	180.4 ± 163.6	155.3 ± 101.6	174.7 ± 144.9	0.2 (−29.7 to 27.7)	0.001	0.924
Moderate activity (minutes/week)	259.2 ± 177.4	233.7 ± 192.9	343.8 ± 263.6	255.1 ± 198.8	23.5 (−75.3 to 82.8)	0.065	0.103
Walking activity (minutes/week)	145.1 ± 166.9	209.1 ± 184.0	248.8 ± 305.6	216.1 ± 238.9	68.1 (−26.7 to 109.7)	0.148	0.022
Total physical activity (minutes/week)	564.3 ± 299.5	623.2 ± 369.8	747.9 ± 403.2	645.9 ± 396.1	28.9 (−80.9 to 89.4)	0.076	0.078
Total sedentary activity (minutes/week)	680.9 ± 507.4	879.6 ± 369.7	692.6 ± 503.6	760.3 ± 461.5	15.3 (−23.7 to 60.4)	0.010	0.388
SF-36 dimensions (scale 0–100)							
Physical function	77.1 ± 22.4	76.9 ± 21.7	79.8 ± 21.1	78.2 ± 20.9	1.8 (−7.8 to 16.9)	0.010	0.279
Role physical problems	93.9 ± 16.5	88.5 ± 18.5	87.5 ± 21.9	85.7 ± 19.2	−3.6 (−17.9 to 12.2)	0.001	0.710
Body pain	68.9 ± 22.2	65.0 ± 24.8	67.8 ± 25.2	67.8 ± 25.2	−5.9 (−20.9 to 14.6)	0.001	0.725
General health	59.7 ± 17.7	65.7 ± 17.0	62.2 ± 17.9	67.3 ± 17.0	1.8 (−6.2 to 18.5)	0.008	0.327
Vitality	72.9 ± 12.4	68.7 ± 15.8	66.1 ± 16.0	64.9 ± 13.9	−3.8 (−14.4 to 3.4)	0.012	0.223
Social function	94.8 ± 14.6	90.5 ± 17.2	93.2 ± 14.1	91.9 ± 16.2	−3.2 (−19.6 to 8.7)	0.005	0.453
Role emotional problems	97.8 ± 10.3	89.9 ± 18.5	91.8 ± 15.6	84.2 ± 20.1	12.5 (−17.5 to 27.5)	0.005	0.436
Mental health	66.1 ± 12.8	69.8 ± 15.7	67.8 ± 14.5	69.3 ± 13.8	3.3 (−8.3 to 11.6)	0.001	0.751

Table 2. Body composition, physical activity, and health-related quality of life measured at baseline and changes after the 24 weeks of physical training (EG $n = 46$; CG $n = 78$). P values of analysis of variance to compare differences between groups at 24 weeks. SF-36 = Short Form 36 Health Survey. Partial Eta Squared ($P\eta^2$) = $\eta^2 = 0.01$ indicates a small effect; $\eta^2 = 0.06$ indicates a medium effect; $\eta^2 = 0.14$ indicates a large effect.

PACES questionnaire showed small differences between the baseline and the assessment after 24 weeks in both groups. No significant differences were observed in this variable. In addition, only the variable: Not invigorating/very invigorating (1–7) had a moderate ES ($P\eta^2 = 0.007$), while the others had a small ES.

IPAQ showed differences between the pre and post-test in both groups. However, only the Walking Activity (minutes/week) variable showed significant results ($p = 0.022$). In addition, the Moderate Activity (minutes/week) and Total Physical Activity (minutes/week) variables had a moderate ES ($P\eta^2 = 0.065$; $P\eta^2 = 0.076$, respectively), and the Walking Activity (minutes/week) variable had a large ES ($P\eta^2 = 0.148$).

Although statistical significance was observed in the Walking Activity domain, it is important to highlight the potential clinical relevance of this finding. An increase in walking time per week among older adults is strongly associated with improved functional mobility and a reduction in fall risk, particularly when walking exceeds 150 min per week. This threshold is often referenced in physical activity guidelines for older populations and has been linked to better balance, cardiorespiratory fitness, and muscle endurance. Therefore, the observed increase in walking minutes is not only statistically relevant but may also translate into meaningful improvements in independence and safety in daily living.

SF-36 dimensions questionnaire (scale 0–100) showed small differences between both moments of evaluation in both groups. There were no significant differences in this variable. In addition, all the variables had a small ES ($P\eta^2 < 0.06$).

Table 2. Body composition, physical activity, and health-related quality of life measured at baseline and changes after the 24 weeks of physical training (EG $n = 46$; CG $n = 78$).

Discussion

This randomized controlled trial evaluated the multidimensional effects of a 24-week sensorimotor training program on physical activity levels, body composition, and self-perceived quality of life in older adults.

Participants in the study shared similar characteristics regarding age, weight, and height. The BMI, calculated using the participants' weight and height, indicated that both male and female groups fell into the overweight



category. Despite this, considering the body composition analysis after intervention, the BMI results of both groups decreased from the beginning until the following 24 weeks, with the EG showing a greater reduction.

Several studies indicate that women tend to participate in PE programs more frequently than men in older age groups^{30,31}. According to our research, which involved 124 older adults, more than 70% of those engaging in the program were female. This trend aligns with broader findings in geriatric studies, where women consistently show greater engagement in organized exercise activities. This may be attributed to factors such as greater health consciousness, stronger social support networks, or a higher motivation to maintain functional independence compared to men^{32,33}. These gender differences in participation rates are important to consider when designing exercise programs for older adults, as they suggest that tailored motivational strategies may be necessary to encourage both men and women to stay active and achieve similar health benefits³⁴.

In our study, the PACES questionnaire revealed minimal differences in overall enjoyment of PA between the CG and the EG over the 24-week sensorimotor training program. No statistically significant changes in general enjoyment were observed, suggesting that the intervention, while potentially beneficial in physical terms, did not significantly influence participants' affective experience of exercise. However, the item "Not invigorating/Very invigorating" did show a moderate effect size, indicating that some participants perceived the activity as more energizing, though this perception was not consistent across all aspects of enjoyment¹⁷.

For instance, a study by Rejeski et al³⁵ demonstrated that structured exercise programs led to significant improvements in the enjoyment of PA for some older adults, particularly when the program included social components and varied activities. Similarly, studies by Teixeira et al³⁶ and Hammer et al³⁷ found that while PA enjoyment can improve with consistent participation in exercise programs, the increase in enjoyment is often moderate and highly individualized.

From a motivational standpoint, these findings can be better understood through SDT, developed by Ryan and Deci¹³. SDT posits that intrinsic motivation—and by extension, enjoyment—is most likely to arise when three basic psychological needs are fulfilled: autonomy (feeling volitional and self-directed), competence (feeling effective), and relatedness (feeling socially connected). In our study, it is possible that the training structure did not fully support these needs. For example, limited choice in activities may have restricted autonomy, unclear or unacknowledged improvements could have diminished perceived competence, and lack of social interaction might have impeded relatedness. When these needs are unmet, intrinsic motivation—and therefore enjoyment—is less likely to emerge, even if physical outcomes improve.

Thus, while sensorimotor training may enhance physical capabilities such as balance and strength, this does not automatically lead to greater enjoyment of the activity. The modest changes in PACES scores observed in our study underscore the importance of developing interventions that not only target physical improvements but also actively promote the psychological and motivational conditions necessary for sustained PA engagement in older adults³⁸.

In our study, the IPAQ revealed differences in PA levels between the initial assessment and the assessment after 24 weeks for both the CG and the EG. Notably, the Walking Activity variable (minutes/week) showed statistically significant results, with a large ES, indicating that walking increased substantially in the experimental group following the sensorimotor training intervention. Additionally, the variables Moderate Activity (minutes/week) and Total Physical Activity (minutes/week) exhibited moderate ES, suggesting some improvements in overall PA, albeit to a lesser extent than walking. These findings align with other studies examining the impact of PA interventions on older adults, particularly concerning walking and moderate activity. Research by Tomioka et al.³⁹ found that walking is often the most accessible and sustainable form of PA for older adults individuals, and interventions focusing on balance and strength, such as sensorimotor training, can enhance walking ability by improving postural control and lower limb strength. Similarly, studies by Pahor et al⁴⁰ and Hung et al⁴¹ have highlighted that increasing walking activity is one of the most effective strategies for improving overall PA levels in older populations, particularly when combined with functional training exercises that target mobility and endurance.

The large ES for the Walking Activity variable in our study suggests that participants in the experimental group may have found walking easier or more enjoyable following the intervention. This supports findings from the literature, such as the study by Huang et al⁴², which observed that older adults who engaged in targeted exercise programs, including balance and coordination activities, demonstrated significant improvements in their capacity and willingness to walk longer distances. Walking is a low-impact, accessible activity that can significantly contribute to the total volume of PA, which may explain the notable increase in this variable in our study. In contrast, while Moderate PA and Total PA also showed improvements with moderate ES, these changes were less pronounced. This may reflect the natural preference among older adults for walking over more strenuous or structured forms of PA. Studies by Galle et al⁴³ have similarly found that moderate-intensity activities, although beneficial, often require additional motivation or specific program elements, such as social support or tailored guidance, to achieve larger improvements. The significant increase in walking activity, supported by a large ES, highlights the potential of sensorimotor training to promote increased PA, particularly walking, in older adults. However, moderate-intensity and overall, PA levels may require further targeted strategies to achieve similar significant improvements. These findings underscore the importance of designing interventions that focus on functional capacity and practical, enjoyable activities like walking that older adults can easily incorporate into their daily lives.

In our study, the SF-36 dimensions questionnaire, which evaluates various aspects of health-related quality of life on a scale from 0 to 100, showed small differences between the baseline assessment and the 24-week follow-up in both the CG and the EG. There were no significant differences between the groups in any SF-36 variables, and all variables had a small ES, indicating that the sensorimotor training intervention had a limited impact on self-reported quality of life in this population over the 24 weeks. These results are consistent with findings from other studies investigating PA interventions' on the QoL in older adults. For example, Brown et



al⁴⁴, found that while exercise interventions can improve physical health markers, changes in self-reported QoL as measured by the HRQoL are often modest or not statistically significant in short-term studies. One possible explanation for the limited effects observed is a ceiling effect, as baseline SF-36 scores were already moderate to high. This can restrict the measurable room for improvement, especially in relatively healthy and functionally independent older adults. A systematic review by Rejeski and Mihalko⁴⁵ similarly concluded that physical gains from exercise do not always correspond to perceived improvements in QoL—particularly when the intervention period is short or when participants already report satisfactory levels of well-being at baseline. Another study by Stewart et al⁴⁶, found that while PA can enhance physical functioning and reduce disability, significant changes in subjective QoL—especially in dimensions related to emotional well-being and mental health—often emerge only over longer durations.

This delayed impact may partly explain the small differences observed in our study, as 24 weeks may not have been sufficient for meaningful perceived changes in QoL to manifest. Furthermore, research by Zhang et al⁴⁷, indicates that psychological mediators such as self-efficacy, perceived autonomy, and social support strongly influence how older adults interpret improvements in their QoL. Since our study did not directly address or enhance these psychological dimensions, this may have further limited the perceived impact of the intervention on QoL outcomes.

The small ES and lack of significant differences in SF-36 dimensions in our study align with existing literature, which suggests that while PA improves physical health, its effect on self-reported QoL—especially in short-term programs—is often limited unless paired with strategies that also target emotional and psychosocial factors. Several limitations should be acknowledged in this study. First, the sample population was predominantly female (over 70%), which, while consistent with trends in geriatric exercise research, may limit the generalizability of the findings to older male adults. Future research should strive for a more balanced gender representation by employing targeted recruitment strategies aimed at engaging older men—such as involving male-focused community groups or emphasizing exercise components that may be more appealing to this demographic. Additionally, while improvements in physical activity levels and body composition were observed, the enjoyment of physical activity, as measured by PACES, showed only modest changes. This suggests that the program may not have fully addressed motivational factors critical for sustained engagement. Future interventions should consider incorporating a wider variety of exercise formats, opportunities for social interaction, and greater personalization to align with individual preferences and enhance enjoyment. Furthermore, designing interventions aligned with Self-Determination Theory (SDT) may enhance psychosocial engagement. Incorporating structured strategies that support autonomy (e.g., participant-led goal setting), competence (e.g., progressive skill challenges with feedback), and relatedness (e.g., peer-based group activities) can foster greater intrinsic motivation, potentially improving adherence and long-term outcomes.

Secondly, the QoL, as measured by the SF-36, showed only small changes, with no significant differences between the experimental and control groups. This may be due to a ceiling effect or the relatively short duration of the intervention. Short-term programs like the 24-week duration used in this study may not be sufficient to elicit measurable improvements in self-reported QoL, particularly in areas related to emotional well-being and mental health. Extending the length of interventions and incorporating psychological and social support elements may yield more substantial and lasting improvements.

Thirdly, the study lacked a post-intervention follow-up, which limits the ability to assess the sustainability of observed benefits over time. Without follow-up data, it is unclear whether improvements in physical activity levels, body composition, or functional ability were maintained beyond the active intervention period. Follow-Up Assessments in Future Studies: Long-term data would strengthen conclusions about behavior change and sustained QoL impact. Longitudinal follow-ups are recommended to better understand long-term adherence and the lasting impact of sensorimotor training on health and QoL.

Fourthly, the study lacked a post-intervention follow-up, limiting the ability to assess the sustainability of observed benefits over time. Without longitudinal data, it remains unclear whether gains in physical activity levels, body composition, or functional capacity were maintained after the end of the intervention. Future studies should incorporate follow-up assessments to evaluate long-term adherence and the durability of effects associated with sensorimotor training.

Fifthly, the study may be affected by self-selection bias, as individuals who chose to participate were likely more health-conscious or motivated than the general older adult population. This could lead to an overestimation of intervention effects. Strategies to recruit a more representative and diverse sample—particularly individuals who are less active or less engaged in health behaviors—should be prioritized in future research. Additionally, although participants shared similar baseline characteristics (age, weight, height), this homogeneity may limit generalizability. Broader inclusion criteria and recruitment across diverse settings (urban vs. rural, varied socioeconomic backgrounds) are recommended to better reflect the heterogeneity of the older population.

Sixthly, and importantly, adherence and dropout data were not collected or reported, limiting insight into the feasibility and acceptability of the intervention. Understanding session attendance, reasons for dropout, and barriers to participation is essential for evaluating real-world applicability. Future trials should monitor adherence systematically and report these data transparently.

Seventhly, no mention was made of assessor blinding in the study protocol, which could introduce bias in outcome evaluations, particularly when subjective measures are used. Although the trainers were experienced and implemented the intervention under supervision, failure to ensure or report assessor blinding represents a methodological limitation. Future studies should employ independent, blinded assessors to reduce the risk of detection bias in randomized designs.

Finally, several outcomes—such as physical activity levels, enjoyment, and quality of life—relied exclusively on self-reported instruments, which may be influenced by recall bias, social desirability, or cognitive limitations. The absence of screening for literacy or cognitive status means that some participants may have had difficulty



understanding or accurately completing the questionnaires. Incorporating objective assessments and pre-screening for cognitive competence would help improve the reliability of self-reported data in older adult populations. In sum, while the study provides valuable insights into the effects of sensorimotor training in older adults, these limitations highlight important areas for improvement in future research to ensure methodological rigor, broader applicability, and more robust conclusions.

Conclusions

The findings of this study reveal several notable observations regarding the impact of a 24-week sensorimotor training program on body composition, PA levels, and quality of life among older adults. While participants across the EG and CG were similar in terms of age, weight, and height, both groups exhibited a decrease in BMI over the study period, with the EG showing a greater reduction, albeit not statistically significant.

The PA levels, assessed through the IPAQ, demonstrated notable improvements, particularly in walking activity, which showed significant results and a large ES. Moderate activity and total physical activity also showed moderate ES, indicating the program's potential to promote more active lifestyles in older adults.

Regarding enjoyment of physical activity, as measured by PACES, only small changes were observed, with no significant differences. However, the "Not invigorating/Very invigorating" variable showed a moderate ES, suggesting some participants experienced increased perceived enjoyment during exercise.

Finally, the quality of life, as evaluated by the SF-36, showed slight improvements in both groups, though these changes were not statistically significant, and ES remained small.

In summary, the study results indicate that both groups experienced improvements in body composition, PA, and QoL after the 24-week training period. However, the EG demonstrated improvements than the CG, although statistical significance was not reached for all outcomes, the observed trends—particularly in walking activity and BMI—suggest clinically meaningful benefits of sensorimotor training in this population.

Practical applications:

- Implement evidence-based sensorimotor training programs to improve mobility, balance, and functional independence in older adults. These programs can reduce fall risk, enhance muscular coordination, and contribute to greater autonomy in daily living tasks, thereby supporting healthy aging and reducing healthcare burdens.
- Promote walking as a primary, accessible form of physical activity, especially for older populations. Walking is safe, low-cost, and adaptable to individual fitness levels. It has been shown to improve cardiovascular health, cognitive function, mood, and quality of life, making it an ideal foundation for PA interventions in aging populations.
- Tailor physical activity interventions to accommodate individual preferences, physical capabilities, and motivational profiles. By fostering a sense of autonomy, competence, and relatedness—key principles from SDT—programs can enhance enjoyment and long-term adherence to PA routines.
- Use physical activity assessments (e.g., SF-36, PACES, IPAQ-SF) to evaluate participants' baseline fitness levels, health perceptions, and enjoyment of exercise. These tools help guide personalized adjustments to maximize effectiveness and satisfaction.
- Understand the multifaceted impact of PA on aging, not only in terms of physical health (e.g., strength, endurance, body composition) but also in improving mental health, emotional well-being, and over-all quality of life. Interventions should aim for holistic outcomes by integrating physical, psychological, and social dimensions.
- Design community-based, socially engaging programs that foster interaction, routine, and purpose among older adults. Such environments have been shown to improve exercise adherence and increase the likelihood of sustained benefits.

Data availability

The data that support the findings of this study are available from the first author (carolina.cabo@uevora.pt) upon reasonable request.

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Author contributions

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Declarations

Competing interests

The authors declare no competing interests.

Ethics approval and consent to participate

The study was approved by the Ethics Committee of the University of Évora (approval number: 21040).

Consent for publication

Informed consent was obtained from all subjects involved in the study.

Additional information

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Effects of sensorimotor training on postural sway during quiet standing in healthy older adults: a randomized controlled trial

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Abstract

Background Maintaining balance and body orientation in humans depends on the efficient functioning of the postural control system. This study aimed to examine the effects of a sensorimotor training program on postural control in older adults and to explore differences in postural performance between trained and untrained individuals.

Methods Eighty-six participants aged 55–80 years were randomly assigned to a control group (CG, $n=43$; mean age: 73.50 ± 6.08) or an exercise group (EG, $n=43$; mean age: 72.40 ± 7.03). The intervention consisted of a 6-month sensorimotor training program comprising 45 min sessions twice weekly, using circuits of progressively challenging exercises.

Results ANCOVA-adjusted comparisons revealed no statistically significant between-group differences. However, within-group analyses showed that the control group experienced increases in postural variability (rangeRatio_CE, sway_deg_CE), whereas the exercise group demonstrated minimal or negative changes, indicating relative stabilization of postural behavior. The experimental group also showed improved mediolateral stability (reduced mdML_OE) and maintained or subtly increased anteroposterior sway (maxAP_OE, maxR_OE, rangeAP_OE), reflecting enhanced postural adaptability and confidence, particularly under eyes-closed conditions.

Conclusions Six months of sensorimotor training may help preserve postural control, enhance sensorimotor adaptability, and prevent deterioration observed in untrained peers. These findings support the clinical utility of targeted sensorimotor interventions as preventive strategies to maintain balance and reduce fall risk in aging populations.

Keywords Aging · Postural control · Center of pressure · Quiet standing · Risk of falls · Sensorimotor training

Abbreviations

AP Anteroposterior
BMI Body mass index

OE Open eyes
CE Closed eyes
CG Control group

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<i>Conf_area</i>	Confidence ellipse area
<i>COP</i>	Center of pressure
<i>EG</i>	Exercise group
<i>ES</i>	Effect size
<i>PA</i>	Physical activity
<i>WHO</i>	World Health Organization
<i>Max</i>	Maximal
<i>MaxD</i>	Maximal distance
<i>MaxR</i>	Maximum radial sway
<i>MD</i>	Mean distance
<i>MeanSpd</i>	Mean speed
<i>Mean_V</i>	Mean velocity
<i>ML</i>	Mediolateral
<i>PCA</i>	Principal component analysis
<i>PlanarD</i>	Planar deviation
<i>Range</i>	Range of distance
<i>RangeRatio</i>	Directional coupling
<i>RMS</i>	Root mean square
<i>SwayCoeff</i>	Coefficient of sway direction
<i>SwayLen</i>	Sway area per second
<i>Sway_Deg</i>	Sway direction

Introduction

Aging naturally leads to reduced physical abilities, such as muscle strength and mobility, increasing the risk of falls in older adults [1, 2]. Additional factors like medication use, frailty, and functional limitations further elevate this risk [3, 4]. Falls often result in serious injuries, hospitalization, and diminished quality of life [5, 6].

The World Health Organization (WHO) highlights the importance of physical activity (PA)—especially strength and balance exercises—for improving function and preventing falls [7]. Regular PA supports neuromuscular function by integrating sensory, motor, and nervous systems, which are essential for balance and postural control [8–10]. These systems work together to maintain stability and reduce fall risk [11].

The sensory system detects body position relative to the environment, while the motor system activates muscles for movement. The nervous system integrates sensory input and coordinates muscle responses to maintain posture [10, 12]. However, aging impairs sensorimotor function, disrupting motor control and increasing fall risk [13]. Older adults often compensate with modified movement strategies to maintain balance [14, 15].

Assessing postural control is crucial in geriatric care, as falls are the leading cause of accidental death among older adults. Standardized assessments combine identification of risk factors with functional motor evaluations [16]. Tools like the Timed Up and Go (TUG), Berg Balance Scale (BBS), and Short Physical Performance Battery

(SPPB) are commonly used to predict fall risk. More sensitive methods, such as static posturography using force platforms, offer detailed analysis of postural sway and balance deficits [17].

Postural sway during quiet standing is assessed through center of pressure (CoP) displacement, which represents the point where ground reaction forces act. CoP trajectories reliably estimate center of mass (CoM) behavior, often modeled as an inverted pendulum around the ankles. More advanced models, such as double-pendulum systems, include hip and trunk movements to better reflect balance strategies used by older or neurologically impaired individuals. Analysis of CoP provides insights into neural and musculoskeletal control mechanisms and helps identify balance disorders [18, 19]. Previous studies have shown that greater CoP displacement amplitude and velocity are associated with reduced postural stability and increased fall risk, particularly when movements approach the limits of the base of support [20, 21].

Various CoP variables are used to assess fall risk, especially in individuals with neurological or age-related balance impairments. During quiet standing, CoP motion reflects efforts to keep the body's center of mass within the base of support. Movements near the limits of stability are associated with higher fall risk [22]. Even basic balance tests on stable surfaces can yield meaningful data. Therefore, static posturography using force platforms is a practical and widely accepted method to evaluate balance in older adults, especially those unable to perform complex tasks [17, 23].

Visual input plays a crucial role in maintaining postural stability by providing continuous information about body orientation relative to the environment. With advancing age, visual acuity and contrast sensitivity tend to decline, leading to increased postural sway and greater reliance on somatosensory and vestibular feedback. For this reason, assessing balance under both eyes-open and eyes-closed conditions allows the quantification of visual contribution to postural control and helps identify compensatory sensory strategies [24–26].

Sensorimotor training is a structured program that improves the integration of visual, vestibular, and proprioceptive inputs with motor responses. It includes static and dynamic posture tasks, gait exercises, and dual-task challenges, which progressively engage the neuromuscular system [27–29]. This training promotes adaptive balance strategies and has been shown to reduce fall risk [30–32].

Although studies have shown that sensorimotor training improves balance and reduces fall risk, few have used detailed CoP metrics in large samples of older adults. Additionally, previous interventions have often been shorter or less structured, leaving a gap in understanding the long-term benefits of progressive, circuit-based training [33–35].



This study examined the effects of a 6-month randomized sensorimotor training program in 86 older adults, assigned to either an exercise group (EG) or a control group (CG). The aim was to evaluate changes in postural control by comparing pre- and post-intervention outcomes between groups. Specifically, we analyzed spatiotemporal, positional, and dynamic center of pressure (CoP) parameters to identify subtle improvements in balance that standard clinical tests may not detect.

We hypothesized that guided and supervised sensorimotor training would improve postural stability—particularly in mediolateral and anteroposterior directions—by enhancing sway control. These improvements could help prevent falls and support more effective fall-prevention strategies in older adults.

Materials and methods

The reporting of this randomized clinical trial adhered to the CONSORT 2010 guidelines [Citation] [36]. This study included a total of 86 participants, aged between 55 and 80 years, who were enrolled in a parallel-group randomized clinical trial with a 6-month intervention period.

Study design and ethical approval

The study was approved by the Ethics Committee of the University of Évora (approval number: 21040). This investigation is part of a study protocol, registered at ClinicalTrials.gov (Identifier: NCT05398354) under the title “Active Retirement: Effects of the Application of a Training Program.” The authors confirm that all ongoing and related trials for this intervention are registered.

Participants

Participants were recruited through community centers and local senior programs over a 6-month recruitment period. Recruitment was conducted via informational sessions and direct contact facilitated by program coordinators.

The aim of this study was to examine the effect of a 6-month sensorimotor training program on postural control in older adults, by comparing pre- to post-intervention changes between participants in the experimental group (EG) and the control group (CG).

Of the 108 participants initially recruited, 86 met the inclusion criteria and were included in the analysis. No adverse events occurred, and no participants withdrew during the study. Participants, aged 55–80 years, were enrolled in a parallel-group randomized clinical trial. They were

randomly assigned to the EG or CG and underwent assessments before and after the intervention.

Randomization was performed using a computer-generated random sequence created with IBM SPSS Statistics (version XX, IBM Corp., Armonk, NY, USA) with a 1:1 allocation ratio. Group allocation was conducted by an independent researcher not involved in recruitment or outcome assessment.

Both groups received identical assessments, but only the EG participated in the training program. Outcome evaluations were conducted by blinded assessors to reduce bias. Due to the nature of the intervention, blinding participants and instructors was not possible.

Sample size calculations were performed using G*Power 3.1.9.4 (Kiel University, Germany). Assuming an alpha level of 0.05, a beta of 0.2, and a moderate effect size (0.5), 86 participants (43 in each group) were required to achieve a statistical power of at least 90%.

Baseline group comparisons revealed no statistically significant differences between the experimental and control groups regarding demographic or anthropometric characteristics ($p > 0.05$), confirming their equivalence prior to the intervention.

Inclusion and exclusion criteria

Inclusion criteria required participants to be between 55 and 80 years old, have no surgical procedures in the past 6 months, and not use prosthetic devices except dental prostheses.

Exclusion criteria included musculoskeletal disorders, locomotor impairments (e.g., wheelchair use or inability to walk independently for at least 15 min), psychiatric or neurological conditions, and diagnosed cardiovascular disease.

Experimental procedures

The sensorimotor training program lasted 6 months, with two sessions per week. Intensity increased progressively: the first 8 weeks involved no external load, followed by the introduction of elastic bands, shin guards, and free weights from weeks 9 to 16. Load was further increased during weeks 17–24. Each month introduced a different session format. Each 45 min session consisted of three phases: a 10 min warm-up, including a 5 min walk around the training room on a smooth, obstacle-free path, followed by joint mobility exercises; a 25 min main phase involving a circuit of eight exercises performed in four cycles (50 s of activity with 15 s of rest); and a 10 min stretching phase (Fig. 1) [37].

The main phase focused on improving components of postural control such as static and dynamic balance, proprioception, and coordination. Exercises were performed

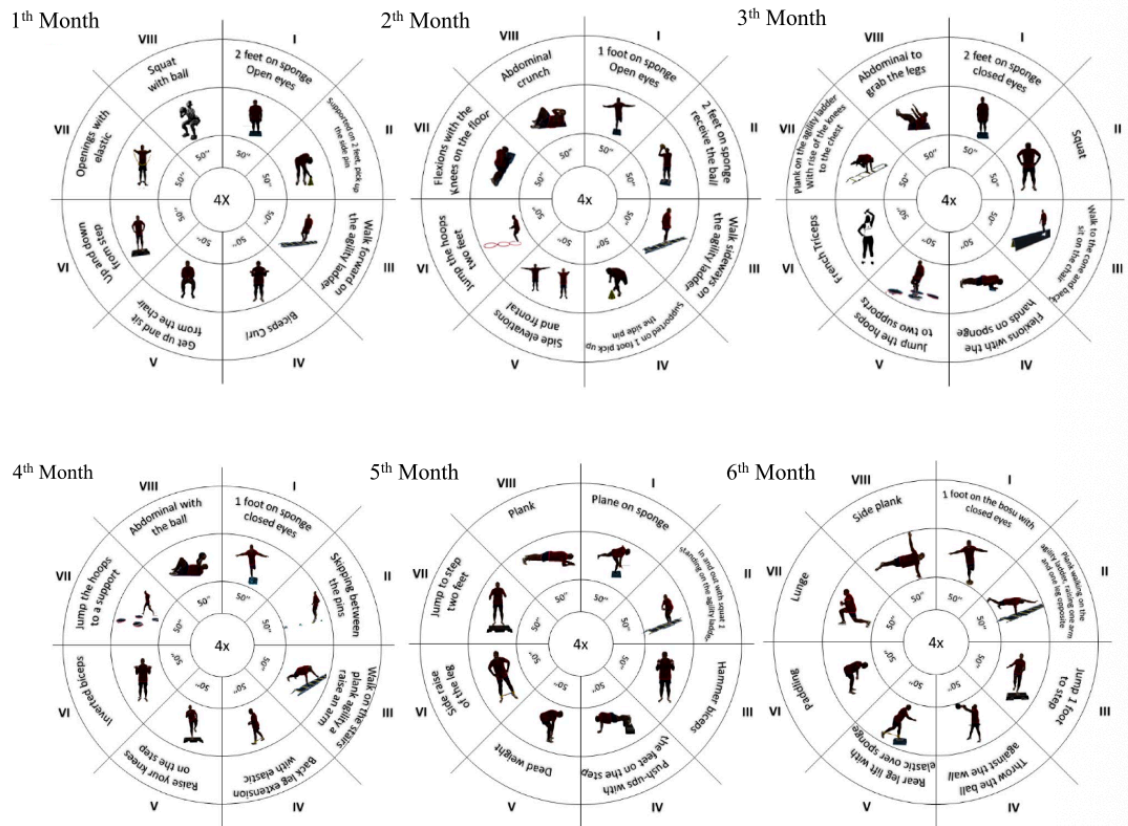


Fig. 1 Main sessions organized by study month [37]

in various positions, including standing, semi-tandem, tandem, and single-leg stance, on both stable and unstable surfaces. To increase sensory stimulation and postural challenge, equipment such as foam pads, balance discs, and elastic bands was incorporated. The difficulty of the tasks progressed gradually over time to promote neuromuscular adaptation. Progressions included narrowing the base of support, closing the eyes to remove visual input, introducing dual-task conditions, and increasing movement complexity through tasks such as reaching, turning, and stepping.

All sessions were supervised by trained instructors, who ensured the correct execution of the exercises and provided real-time feedback. Due to the nature of the intervention, blinding of participants and instructors was not feasible. However, instructors were not involved in outcome assessment or data analysis. Outcome assessments were performed by assessors blinded to group allocation.

Participants were instructed to perform the exercises at a self-selected pace, with particular emphasis on safety, postural control, and precision.

This structured and progressive training protocol was designed to stimulate the sensory and motor systems involved in postural regulation, contributing to improved balance and fall prevention in older adults.

Data acquisition and processing

Data were collected using a unidirectional, portable, wireless force platform (45 × 45 cm) with four load cells, connected to a signal acquisition unit (PLUX®, Lisboa, Portugal). The raw data were processed using a fourth-order, zero-lag, low-pass Butterworth filter with a 10 Hz cutoff frequency, following established guidelines [38]. Due to variability in foot positioning, center of pressure (CoP) trajectories were centered relative to their arithmetic mean, as commonly done in



previous studies [21, 39]. CoP coordinates were calculated according to the manufacturer's specifications. Spatiotemporal, positional, and dynamic variables were analyzed using Matlab R2024a (MathWorks Inc., USA).

During data collection, participants stood upright on the platform with arms at their sides and feet centrally positioned. They maintained a bipedal stance while looking straight ahead. CoP displacement was recorded under two visual conditions—eyes open (EO) and eyes closed (EC)—for 120 s in both the anteroposterior (AP) and mediolateral (ML) directions.

Spatiotemporal variables (static and dynamic)

The positional and dynamic spatiotemporal variables were adapted from the work of Quijoux et al. [17], with a focus on those most sensitive to sensorimotor changes. Their work reviews and compares advanced stabilogram-based variables for assessing fall risk in older adults. It also outlines the theoretical assumptions behind each variable and provides a reproducible method for their calculation. The code used in our analysis was developed based on their methodology.

Static variables: Mean distance (MD) refers to the average distance of the center of pressure (CoP) from the center of its trajectory, typically calculated using the centered CoP signal [21]. It reflects postural stability by indicating how far the CoP moves from a central point during quiet standing. A wider base of support generally reduces MD, particularly in the mediolateral direction, suggesting greater stability. Maximal distance (maxD) is the furthest point the CoP reaches from the center of its path, also based on the centered signal [39]. Like MD, it measures the extent of postural sway, highlighting the maximum displacement during standing. Root mean square (RMS) represents the variability of CoP movement and corresponds to the standard deviation of the CoP path in each direction. For the planar trajectory, RMS is the square root of the average squared distance from the trajectory's centroid [21]. Range describes the total span of CoP displacement and offers detailed insight into sway under different visual conditions [17]. The ratio of amplitudes compares CoP motion in the mediolateral (ML) and anteroposterior (AP) directions, helping to identify balance control strategies in older adults [40]. Planar deviation (planarD) is the square root of the combined variance in the ML and AP directions [41], capturing the overall horizontal spread of sway. The coefficient of sway direction (swayCoeff) is calculated as the covariance between ML and AP CoP signals, divided by the product of their standard deviations. This measure reflects directional coupling and is associated with fall risk [17]. Confidence ellipse area (conf_area), also

known as sway area, represents the 95% confidence ellipse around the mean CoP position [42]. Larger areas typically indicate reduced postural control and a higher risk of falling. Principal sway direction quantifies the dominant direction of CoP oscillation using principal component analysis (PCA). It is expressed as the angle (0° – 90°) from the AP axis to the main eigenvector of the CoP trajectory [43].

Dynamic variables: For the dynamic variables, mean speed (meanSpd) of the center of pressure (CoP) is a widely used and reliable indicator of postural control, especially in the anteroposterior (AP) direction. It reflects age-related balance changes and is associated with fall risk [3, 21]. **Sway area per second (SwayLen) represents the average area swept by the CoP each second. It is calculated by summing the areas of triangles formed between consecutive CoP points and the mean CoP position [21].** This variable has shown significant differences between fallers and non-fallers [17].

Statistical analysis

Descriptive statistics for the intervention and control groups were generated using Jamovi (version 2.6.26). Data normality was assessed with the Shapiro–Wilk test; p -values above 0.05 indicated a normal distribution, while p -values ≤ 0.05 indicated non-normality. For all inferential analyses, the level of statistical significance was set at $p < 0.05$ (two-tailed). Given the exploratory nature of the secondary within-group comparisons, no formal correction for multiple comparisons was applied; therefore, these results should be interpreted with caution. Paired-sample t -tests (Student's t) were conducted, followed by ANCOVA to examine the effects of the intervention.

No missing data were observed, as all participants completed baseline and post-intervention assessments.

In ANCOVA, post-test values of center of pressure (CoP) variables were treated as the dependent variable, pre-test values were included as covariates to control for baseline differences between groups, and effect sizes were reported using partial eta-squared: 0.01–0.059 (small), 0.06–0.14 (medium), and > 0.14 (large) [3]⁷. Pairwise differences were assessed using Cohen's d with 95% confidence intervals: 0.2–0.49 (small), 0.5–0.8 (medium), and > 0.8 (large) [44, 45].

Postural control data were analyzed using ANCOVA to compare the experimental (EG) and control (CG) groups. Group comparisons were based on post-test scores adjusted for pre-test values. In addition, pre–post changes within each group and between-group differences (post-test minus pre-test values) were calculated using a customized spreadsheet.



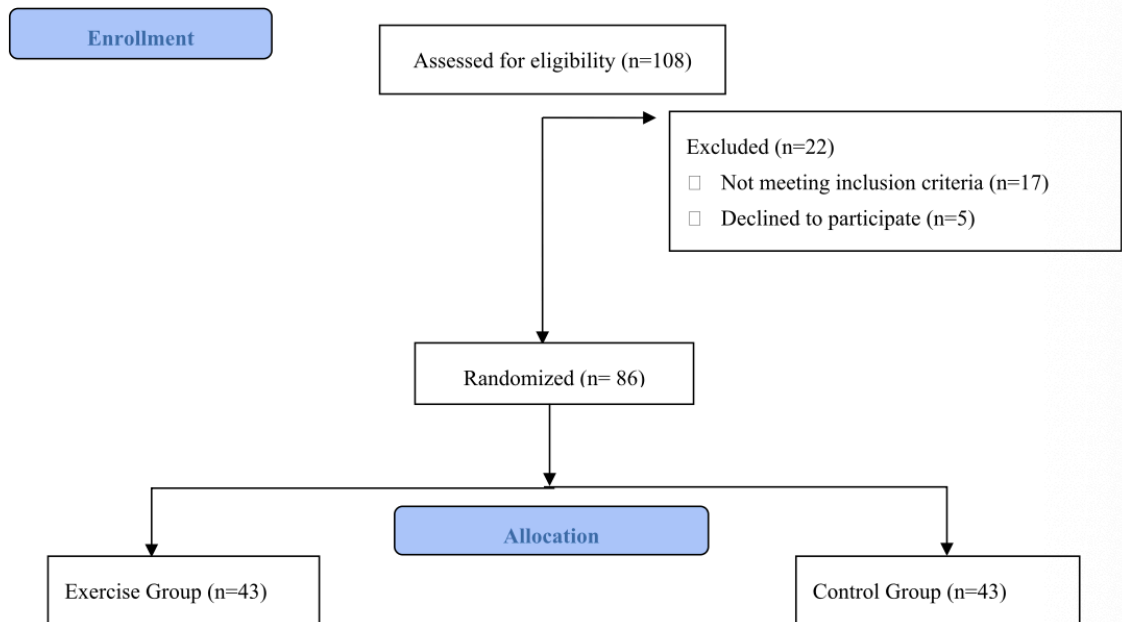


Fig. 2 Study design and groups' characterization

Table 1 Characteristics of study participants

	Exercise group	Control group
Total	43	43
Men	13	10
Women	30	33
Age	72.40 (± 7.03)	73.50 (± 6.08)
BMI	27.00 (± 5.27)	27.90 (± 4.45)

Variable distributions

To provide indicative values for the analyzed variables, means and standard deviations are reported for both groups across all CoP measures and visual conditions.

Results

The study involved a total of 86 participants out of a total of 108 participants recruited initially (Fig. 2), with 22 participants excluded according to the inclusion criteria, aged between 55 and 80 years. Data in the text are mean $\pm$ SD. Of these participants, EG=43 (mean age: 72.40 $\pm$ 7.03 years) and CG=43 (mean age: 73.50 $\pm$ 6.08 years) (Table 1). The data of the excluded participants was deleted from the database, and there was no data corruption or other data loss,

such as equipment/software malfunction. We evaluated different linear variables.

First, we conducted a general analysis of the pre- and post-test values to identify overall changes within each group and determine whether significant improvements occurred. As shown in Table 2, in the control group, significant pre-post differences ($p < 0.05$, indicated by *) were observed for the following variables: mdMLA_OE, mavR_OE, rmsRatio_OE, swayArea_OE, meanVx_OE, swayLenML_OE, swayLenTotal_OE, meanSwayML_OE, meanSwayTotal_OE, mdMLA_CE, rmsML_CE, rmsStab_CE, rmsRA_CE, rmsRatio_CE, swayArea_CE, meanVx_CE, swayLenML_CE, swayLenAP_CE, swayLenTotal_CE, meanSwayML_CE, meanSwayRA_CE, and meanSwayTotal_CE.

Similarly, in the experimental group, significant pre-post changes ($p < 0.05$, indicated by *) were found for mdMLA_OE, mavR_OE, rmsAP_OE, rmsRatio_OE, swayArea_OE, meanVx_OE, swayLenML_OE, swayLenTotal_OE, meanSwayML_OE, meanSwayTotal_OE, mdMLA_CE, rmsML_CE, rmsRA_CE, rmsML_CE, meanVx_CE, swayLenML_CE, swayLenAP_CE, swayLenTotal_CE, meanSwayML_CE, meanSwayRA_CE, and meanSwayTotal_CE (Table 2).

These findings indicate that both groups exhibited significant within-group changes across multiple postural control parameters. Therefore, ANCOVA was performed to assess



Table 2 Results of ANCOVA comparing postural control parameters for between-group comparisons (adjusted post-test means with 95% CIs), supported by ANCOVA outputs (p -values, F -values, and partial η^2 for each variable)

Variables	Control group			Experimental group			ANCOVA		
	Pre-test	Post-test	Mean differences [95% CI]	Cohen's d [95% CI]	Pre-test	Post-test	Mean differences [95% CI]	Cohen's d [95% CI]	F p Partial η^2
mdML_OE	0.45 ± 0.13	0.50 ± 0.17	0.05 [0.09; 0] *	0.31 [0.62; 0]	0.40 ± 0.13	0.42 ± 0.12	0.02 [0.06; -0.03]	0.13 [0.43; -0.18]	3.2 0.076 0.04
mdAP_OE	0.36 ± 0.13	0.36 ± 0.15	0 [0.04; -0.05]	-0.03 [0.27; -0.33]	0.28 ± 0.12	0.27 ± 0.1	-0.01 [0.02; -0.04]	-0.14 [0.17; -0.44]	3.3 0.075 0.04
maxR_OE	2.93 ± 1.77	2.49 ± 0.93	-0.44 [0.11; -0.99]	-0.25 [0.06; -0.55]	2.42 ± 1.42	2.14 ± 1.12	-0.28 [0.18; -0.74]	-0.19 [0.12; -0.49]	1.4 0.236 0.02
rangeAP_OE	3.75 ± 2.36	3.02 ± 1.36	-0.73 [0.03; -1.5]	-0.29 [0.01; -0.6]	2.86 ± 1.71	2.38 ± 1.29	-0.49 [0; -0.97] *	-0.31 [0; -0.61]	2.8 0.098 0.03
rangeRatio_OE	1.23 ± 0.42	1.5 ± 0.53	0.26 [0.46; 0.07] *	0.42 [0.73; 0.11]	1.37 ± 0.38	1.65 ± 0.67	0.28 [0.49; 0.07] *	0.4 [0.71; 0.09]	0.8 0.37 0.01
sway_deg_OE	61.38 ± 24.7	70.98 ± 21.05	9.59 [19.72; -0.53]	0.29 [0.6; -0.02]	70.25 ± 17.05	74.11 ± 17.42	3.86 [10.78; -3.05]	0.17 [0.47; -0.13]	0.4 0.51 0.01
mean_V_OE	7.01 ± 2.41	8.63 ± 3.15	1.62 [2.3; 0.95] *	0.74 [1.07; 0.4]	6.15 ± 1.97	7.31 ± 2.58	1.16 [1.62; 0.71] *	0.78 [1.12; 0.44]	1.3 0.261 0.02
swayLenML_OE	126.01 ± 45.76	168.81 ± 70.48	42.8 [56.89; 28.71] *	0.93 [1.29; 0.57]	117.15 ± 41.69	150.5 ± 57.45	33.35 [43.38; 23.33] *	1.02 [1.39; 0.65]	0.9 0.352 0.01
swayLenTotal_OE	172.47 ± 59.17	213.23 ± 77.83	40.76 [57.64; 23.88] *	0.74 [1.08; 0.4]	152.9 ± 49.01	182.35 ± 64.65	29.45 [40.66; 18.25] *	0.81 [1.15; 0.46]	1.2 0.274 0.01
meanSpdML_OE	5.25 ± 1.91	7.03 ± 2.93	1.78 [2.37; 1.2] *	0.93 [1.29; 0.57]	4.88 ± 1.74	6.27 ± 2.39	1.39 [1.81; 0.97] *	1.02 [1.39; 0.65]	0.9 0.352 0.01
meanSpdTotal_OE	7.18 ± 2.46	8.88 ± 3.24	1.7 [2.4; 0.99] *	0.74 [1.08; 0.4]	6.37 ± 2.04	7.59 ± 2.69	1.23 [1.69; 0.76] *	0.81 [1.15; 0.46]	1.2 0.274 0.01
mdML_CE	0.42 ± 0.16	0.48 ± 0.13	0.05 [0.1; 0.01] *	0.34 [0.65; 0.03]	0.42 ± 0.13	0.47 ± 0.15	0.05 [0.1; 0.01] *	0.35 [0.66; 0.04]	0 0.92 0
maxML_CE	1.89 ± 0.84	2.27 ± 0.88	0.37 [0.66; 0.08] *	0.4 [0.71; 0.08]	1.95 ± 0.63	2.24 ± 0.99	0.29 [0.56; 0.01] *	0.32 [0.62; 0.01]	0.1 0.743 0
rmsML_CE	0.54 ± 0.21	0.6 ± 0.18	0.06 [0.11; 0.01] *	0.36 [0.66; 0.05]	0.54 ± 0.16	0.59 ± 0.19	0.05 [0.09; 0.01] *	0.37 [0.68; 0.06]	0.1 0.724 0
rangeML_CE	3.45 ± 1.49	3.97 ± 1.33	0.52 [0.94; 0.11] *	0.39 [0.69; 0.07]	3.48 ± 1.01	4.03 ± 1.7	0.54 [1; 0.08] *	0.36 [0.67; 0.05]	0 0.901 0
rangeRatio_CE	1.15 ± 0.41	1.52 ± 0.6	0.36 [0.56; 0.17] *	0.58 [0.9; 0.25]	1.54 ± 0.64	1.52 ± 0.66	-0.02 [0.18; -0.22]	-0.03 [0.27; -0.33]	1.9 0.172 0.02
sway_deg_CE	55.61 ± 27.22	68.36 ± 20.92	12.75 [21; 4.5] *	0.48 [0.79; 0.16]	68.69 ± 18.01	68.4 ± 22.97	-0.29 [6.45; -7.03]	-0.01 [0.29; -0.31]	1.3 0.266 0.02
mean_V_CE	6.45 ± 2.15	8.67 ± 3.24	2.21 [2.99; 1.44] *	0.88 [1.23; 0.52]	5.67 ± 1.78	7.34 ± 3.3	1.66 [2.42; 0.9] *	0.67 [1; 0.34]	0.8 0.369 0.01
swayLenML_CE	113.35 ± 38.8	168.82 ± 75.29	55.48 [72.59; 38.36] *	1 [1.36; 0.63]	109.12 ± 33.89	145.52 ± 58.51	36.4 [49.59; 23.22] *	0.85 [1.2; 0.5]	2.9 0.094 0.03
swayLenAP_CE	87.52 ± 35.68	97.76 ± 39.58	10.24 [19.52; 0.95] *	0.34 [0.64; 0.03]	65.35 ± 25.64	78.33 ± 48.3	12.98 [24.86; 1.11] *	0.34 [0.64; 0.03]	0 0.972 0
swayLenTotal_CE	159.16 ± 51.69	214.34 ± 78.99	55.18 [74.25; 36.11] *	0.89 [1.24; 0.53]	139.64 ± 43.08	180.94 ± 80.85	41.29 [60.01; 22.57] *	0.68 [1.01; 0.34]	0.8 0.366 0.01
meanSpdML_CE	4.72 ± 1.62	7.03 ± 3.14	2.31 [3.02; 1.6] *	1 [1.36; 0.63]	4.54 ± 1.41	6.06 ± 2.44	1.52 [2.06; 0.97] *	0.85 [1.2; 0.5]	2.9 0.094 0.03
meanSpdAP_CE	3.64 ± 1.49	4.07 ± 1.65	0.43 [0.81; 0.04] *	0.34 [0.64; 0.03]	2.72 ± 1.07	3.26 ± 2.01	0.54 [1.03; 0.05] *	0.34 [0.64; 0.03]	0 0.972 0
meanSpdTotal_CE	6.63 ± 2.15	8.92 ± 3.29	2.3 [3.09; 1.5] *	0.89 [1.24; 0.53]	5.81 ± 1.79	7.53 ± 3.37	1.72 [2.5; 0.94] *	0.68 [1.01; 0.34]	0.8 0.366 0.01

* $p < 0.05$

between-group differences while statistically controlling for baseline (pre-test) values.

Table 2 presents the results of these ANCOVA models, comparing the adjusted post-test means (with 95% confidence intervals) for all postural control variables under eyes-open (OE) and eyes-closed (CE) conditions. The table also provides the corresponding F-values, *p*-values, and partial eta-squared (η^2) effect sizes for each parameter. Significant between-group effects are identified by $p < 0.05$.

When examining the ANCOVA results, we observed that no significant between-group differences emerged after controlling for baseline values. This suggests that pre-test scores substantially influenced post-test outcomes, and that the intervention effects were not strong enough to produce statistically detectable differences between the experimental and control groups.

Consequently, we proceeded to explore potential trends using the visualization provided in Fig. 3.

According to Fig. 3, rangeRatio_CE and sway_deg_CE show significant differences, whereas mean_V_OE, CE

swayLenML_OE, swayLenTotal_OE, meanSpdML_OE, meanSpdTotal_OE, swayLenML_CE, and meanSpdML_CE demonstrate trend-level effects. The remaining variables do not exhibit clear tendencies in either direction.

The significant differences observed in Fig. 3 appear primarily in the control group, which shows a notably greater variation in these parameters. Specifically, the control group demonstrates substantial increases in rangeRatio_CE (0.58 [0.90; 0.25]) and sway_deg_CE (0.48 [0.79; 0.16]), while the experimental group does not display comparable changes (rangeRatio_CE = -0.03 [-0.27; -0.33]; sway_deg_CE = -0.01 [0.29; -0.31]). Although the experimental group shows reductions rather than increases, the absence of large changes does not imply a lack of intervention effects; rather, it suggests that the intervention may have contributed to stabilizing or preventing the deterioration observed in the control group.

Discussion

This study evaluated the effects of a 6-month sensorimotor training program on postural control in older adults. In the adjusted analyses (ANCOVA with baseline values as covariates), no statistically significant between-group differences were observed for the post-test outcomes. However, within-group pre-post analyses revealed meaningful changes across multiple Center of Pressure (CoP) parameters: the control group showed significant increases in numerous measures (marked with * in the Table 2), whereas the experimental group exhibited fewer and generally smaller pre-post changes. Notably, Fig. 3 highlights within-group increases quantified by Cohen's *d* effect sizes rather than statistical significance per se; these values indicate the magnitude and direction of change in postural parameters in rangeRatio_CE and sway_deg_CE that are driven primarily by changes in the control group; several other parameters (including mean_V_OE, swayLenML_OE, swayLenTotal_OE, meanSpdML_OE, meanSpdTotal_OE, swayLenML_CE, and meanSpdML_CE) display trend-level effects suggestive of subtle adaptation in either direction.

Although the ANCOVA results indicate that baseline performance substantially influenced post-test outcomes, the pattern of within-group changes and the forest plot representation (Fig. 3) offer clinically relevant insight. The prominent increases in rangeRatio_CE (0.58 [0.90; 0.25]) and sway_deg_CE (0.48 [0.79; 0.16]) observed in the control group are consistent with greater variability and reduced postural consistency, particularly under eyes-closed conditions. By contrast, the experimental group showed minimal or negative changes in these same metrics (rangeRatio_CE = -0.03 [-0.27; -0.33]; sway_deg_CE = -0.01 [-0.29; -0.31]), suggesting relative stabilization of postural behavior following

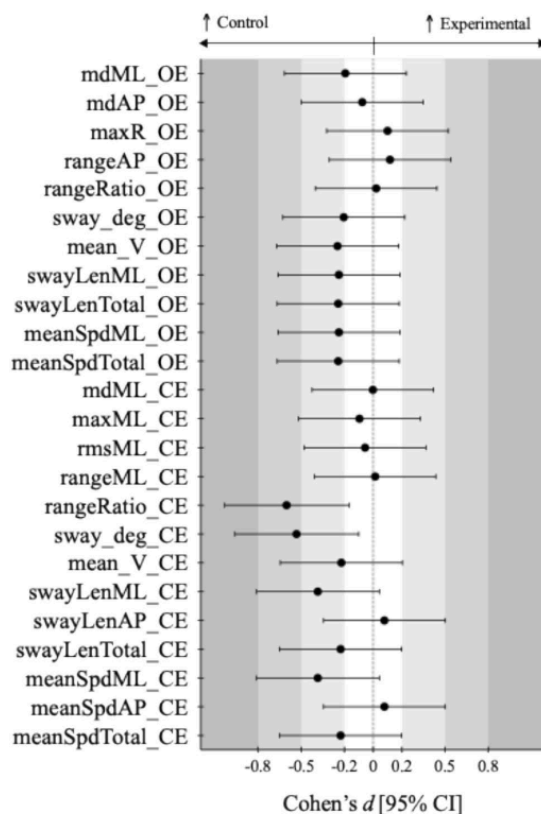


Fig. 3 Cohen's *d* [46] differences between the Control and Experimental groups for the considered variables. Error bars indicate uncertainty in the true mean changes (95% confidence intervals)



the intervention. Thus, even in the absence of statistically significant adjusted group differences, the intervention may have had a protective effect by attenuating the deterioration evidenced in the control group.

From a mechanistic viewpoint, sensorimotor training is intended to improve proprioceptive integration, vestibular contribution, and neuromuscular coordination, thereby promoting more consistent and efficient postural strategies [47]. Older adults commonly adopt stiff, cautious strategies that reduce sway amplitude but increase susceptibility to perturbation [47, 48]. In our sample, the control group increases in sway parameters—especially in the mediolateral and directional variability indices—likely reflect a loss of postural control rather than functional flexibility. Conversely, the relative maintenance of CoP metrics in the trained group, particularly under eyes-closed conditions, suggests improved reliance on nonvisual sensory inputs and potentially improved sensorimotor adaptability [25, 53].

Interpretation of sway increases deserves caution. An increase in some sway measures can reflect functional exploration of the base of support and reduced fear-related rigidity [17, 51], large, directionally inconsistent increases—such as those in *rangeRatio_CE* and *sway_deg_CE* in the control group—are more plausibly interpreted as instability. The absence of such shifts in the experimental group may indicate either successful prevention of destabilization or that training effects were insufficient to produce measurable improvements beyond natural variation and learning effects. Improvements in AP sway (*rangeAP_OE*) and maximal sway distances (*maxAP_OE*, *maxR_OE*) may reflect greater postural flexibility and confidence [17], supporting a dynamic, adaptable postural strategy.

Clinically, these results underscore two important points. First, conventional statistical adjustment for baseline differences (ANCOVA) must be reported and interpreted alongside within-group changes: the lack of significant adjusted group differences does not necessarily imply the intervention had no practical value. Second, sensorimotor programs may be particularly valuable as preventive strategies that maintain balance function and limit deterioration, especially under sensory-challenging conditions (eyes closed) that are strongly associated with fall risk. The observed pattern, control participants showing greater deterioration while trained participants remained stable supports this perspective [27, 28, 49–55].

Limitations include the modest sample size, which may limit detection of small to moderate adjusted effects, and the lack of objective monitoring of lifestyle or activity changes. CoP outcomes, while sensitive, do not directly reveal the neural or muscular mechanisms underlying the observed changes; complementary kinematic, electromyographic, or sensory-reweighting measures would strengthen mechanistic conclusions. Additionally, follow-up was limited to

immediate post-intervention assessment, leaving the durability of any protective effect unknown.

Another important limitation concerns the broad age range of our sample (55–80 years). Although the mean ages of the control and exercise groups were comparable, it is well known that physiological, sensory, and neuromuscular changes accelerate with advancing age, potentially influencing postural control and training responsiveness. Therefore, differences in the degree of age-related decline within this range may have contributed to variability in individual outcomes. Future studies should consider stratifying participants into narrower age brackets to better capture potential age-dependent effects.

Future research should include larger and more diverse samples, objective monitoring of daily activity and fall incidents, and integration of biomechanical and neurophysiological measures. Longer follow-up would clarify whether sensorimotor training produces lasting stabilization of balance or long-term functional improvements. Stratified analyses by baseline impairment level could reveal whether those with poorer initial balance benefit more.

In conclusion, while ANCOVA-adjusted comparisons did not show statistically significant between-group differences after controlling for baseline values, the overall pattern suggests that 6 months of sensorimotor training may help preserve postural control in older adults and prevent deterioration observed in untrained peers, particularly under eyes-closed conditions. These findings support the clinical utility of sensorimotor interventions as part of fall-prevention and balance-maintenance programs for aging populations [47–55].

Conclusions

In conclusion, this study suggests that a structured 6-month sensorimotor training program may help preserve postural control and adaptiveness in older adults. While adjusted between-group comparisons (ANCOVA) did not reach statistical significance, within-group analyses indicated that the training attenuated deterioration in key center of pressure (CoP) measures observed in the control group, particularly under eyes-closed conditions. These findings imply that sensorimotor training may act as a protective strategy, maintaining stability and reducing susceptibility to postural instability associated with aging.

Clinically, the observed maintenance or subtle improvement in sway parameters—especially mediolateral and directional variability—reflects enhanced neuromuscular coordination, reliance on nonvisual sensory inputs, and functional flexibility 46–54. Reductions in mediolateral instability are particularly relevant given their strong association with fall risk, while moderate increases in anteroposterior sway may



indicate greater postural confidence rather than instability. These results highlight the importance of interpreting intervention effects beyond traditional *p*-values, emphasizing within-group changes, effect sizes, and functional relevance.

Future research should aim to include larger and more diverse samples, stratify participants by age or baseline balance ability, incorporate objective monitoring of daily activity and fall history, and integrate complementary biomechanical or neurophysiological assessments. Such studies would clarify the mechanisms underlying postural improvements, the durability of training effects, and the potential for personalized sensorimotor interventions to support independence, mobility, and fall prevention across the aging spectrum.

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Data availability No datasets were generated or analyzed during the current study.

Declarations

Conflict of interest The authors declare no competing interests.

Ethical approval and consent to participate The studies involving humans were approved by the Committee of the University of Évora approved this project (approval number: 21040). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Each participant provided informed consent before participating, according to the Helsinki Declaration for Human Studies (2013).

Consent for publication All authors consent for publication.

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