UNIVERSIDADE LUSÓFONA
Centro Universitário de Lisboa
Faculdade de Educação Física e Desporto
Doutoramento em Educação Física e Desporto

EFEITOS DE UM PROGRAMA DE 12 SEMANAS DE EXERCÍCIOS PROPRIOCETIVOS E DE FORÇA SOBRE PARÂMETROS BIOMECÂNICOS DA MARCHA ASSOCIADOS ÀS QUEDAS E MEDO DE CAIR EM IDOSOS

Tese de Doutoramento apresentada a provas públicas para a obtenção do grau de doutor em Educação Física e Desporto, na especialidade de Atividade Física e Saúde, orientada pelo Professor Doutor Pedro Miguel Rosmaninho Aleixo

JULLYANNE RODRIGUES DE MOURA SILVA/ Nº 21901002

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Jullyanne Rodrigues de Moura Silva

"Versão Final"

Tese defendida por Jullyanne Rodrigues de Moura Silva em provas públicas na Universidade Lusófona, Centro Universitário de Lisboa no dia 12/01/2026, perante o júri, nomeado pelo Despacho de Nomeação n.º: 416/2025, de 28 de julho, com a seguinte composição:

Presidente: Prof. Doutor Jorge dos Santos Proença Martins, (Professor Catedrático da FEFD – Universidade Lusófona), por delegação do Senhor Reitor, Prof. Doutor José Bragança de Miranda;

Arguente: Prof. Doutor Ronaldo Eugénio Calçada Dias Gabriel (Professor Associado c/ agregação da Universidade de Trás-os-Montes e Alto Douro);

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Vogal: Prof. Doutor António João Labisa da Silva Palmeira (Professor Associado c/ agregação – Universidade Lusófona);

Vogal: Prof. Doutor Hugo Carlos Fernandes Vieira Pereira (Professor Auxiliar da FEFD – Universidade Lusófona);

Vogal: Prof. Doutor Luís Miguel Rosado da Cunha Massuça (Professor Associado da FEFD – Universidade Lusófona);

Orientador: Prof. Doutor Pedro Miguel Rosmaninho Aleixo (Professor Auxiliar da FEFD – Universidade Lusófona);

Este trabalho também foi orientado por Prof. Doutor Tiago Atalaia (Professor coordenador da Escola Superior de Saúde da Cruz Vermelha Portuguesa – Lisboa)

JULLYANNE RODRIGUES DE MOURA SILVA/ Nº 21901002

2026

O que sabemos é uma gota; o que ignoramos é um oceano.

Isaac Newton

DEDICATÓRIA

Esta tese não é apenas um documento académico, é o resultado de uma viagem coletiva, feita de apoio, resiliência e, claro, algumas doses generosas de café. Ao Professor Doutor Pedro Aleixo, meu orientador, agradeço a sua incansável orientação e a sua capacidade de transformar o caos em clareza. Ao coorientador Professor Doutor Tiago Atalaia e ao Professor Doutor João Abrantes, pela perspicácia e por me lembrarem que até os erros podem ser oportunidades. À Susana Cordeiro, um obrigada especial – pela disponibilidade constante, pelo apoio fundamental e por ter sido uma peça indispensável nesta caminhada. Aos participantes deste projeto, que foram peças fundamentais neste puzzle: sem vocês, esta investigação seria apenas teoria. À minha mãe, a minha heroína, cuja força e amor incondicional são o alicerce da minha vida. Ao meu irmão Luiz Henrique, o meu exemplo de trabalho, resiliência e superação meu primeiro amor, e à minha cunhada Laura, cuja luz inspira todos os que a rodeiam. Aos meus filhos, Lucca e Júnior, razão do meu sorriso, e das batidas do meu coração, aos meus sobrinhos, Maria e Teo, que trouxeram mais alegria pura às nossas vidas. Ao meu marido, Paulo Silva, pelo amor paciente e por ser o meu porto seguro. E a Deus, que me carregou no colo quando as minhas pernas já não aguentavam: "*Mas os que esperam no Senhor renovam as suas forças*" (Isaías 40:31). A todos, o meu eterno agradecimento – porque os melhores frutos nascem de raízes partilhadas.

E assim, depois de anos a dizer 'quando a tese acabar…, descubro que isto não é um fim é só a desculpa perfeita para começar algo novo.

RESUMO

As quedas em idosos representam um problema de saúde pública, com impacto significativo na qualidade de vida. Com base em lacunas identificadas na literatura no que concerne às quedas em idosos e à sua prevenção, foram definidos três objetivos para esta tese, os quais foram alcançados através de três artigos: (1) concretizar uma revisão sistemática que sintetize o conhecimento sobre os parâmetros biomecânicos da marcha associados ás quedas; (2) descrever as alterações biomecânicas da marcha de longa duração em mulheres idosas; e (3) avaliar os efeitos de um programa de 12 semanas de exercícios propriocetivos e de força sobre parâmetros biomecânicos da marcha associados às quedas e o medo de cair em idosos. No primeiro artigo (revisão sistemática), a velocidade da marcha, o comprimento do passo, a fase de duplo apoio, e a variabilidade da *minimum toe clearance* foram identificados como parâmetros diferenciadores entre idosos com e sem historial de quedas. No segundo artigo (estudo observacional), mulheres idosas apresentaram alterações ao longo de uma marcha de longa duração (*6-minute walk test*) em alguns parâmetros espaço-temporais e cinemáticos da marcha (velocidade da marcha; fase de apoio; fase de duplo apoio; deslocamentos angulares da anca, joelho e tornozelo). No terceiro artigo (estudo de intervenção), verificou-se a eficácia de um programa de 12 semanas de exercícios propriocetivos e de força para reduzir o medo de cair em idosos e para melhorar alguns parâmetros biomecânicos da marcha relacionados com as quedas, nomeadamente a velocidade da marcha.

Palavras-Chave: idosos, parâmetros biomecânicos, prevenção de quedas, exercícios propriocetivos, exercícios de força

ABSTRACT

Falls in older adults represent a public health problem, with a significant impact on quality of life. Based on gaps identified in the literature regarding falls and their prevention in older adults, three objectives were defined for this thesis, which were achieved through three articles: (1) to conduct a systematic review that synthesizes knowledge on biomechanical gait parameters associated with falls; (2) to assess the biomechanical changes in long-duration walking in older women; and (3) to evaluate the effects of a 12-week proprioceptive and strength exercise program on biomechanical gait parameters associated with falls and fear of falling in older adults. In the first article (systematic review), gait speed, step length, double support phase, and minimum toe clearance variability were identified as key distinguishing older adults with and without a history of falls. In the second article (observational study), older women exhibited changes in spatiotemporal and kinematic gait parameters (gait speed, stance phase, double support phase, and angular displacements of the hip, knee, and ankle) during prolonged walking (6-minute walk test). In the third article (intervention study), a 12-week proprioceptive and strength exercise program was found effective in reducing fear of falling and improving certain fall-related biomechanical gait parameters, namely gait speed.

Keywords: elderly; biomechanical parameters; fall prevention; proprioceptive exercises; strength exercises.

ACRÓNIMOS E SÍMBOLOS

Acrónimo/Símbolo	**Descrição**
6MWT	6-Minute Walk Test
ACM	American College of Sports Medicine
AP	Antero-Posterior
ATS Committee	American Thoracic Society Committee
CINAHL	Cumulative Index to Nursing and Allied Health Literature
CoM	Center of Mass
CoP	Center of Pressure
CONSORT	Consolidated Standards of Reporting Trials
CV	Coefficient of Variation
EMG	Electromyography
EPHEPP	Evidence-Based Practice in Health Promotion and Prevention
EudraCT	European Union Drug Regulating Authorities Clinical Trials
EVITA	Epidemiologia e Vigilância dos Traumatismos e Acidentes
FES-I	Falls Efficacy Scale-International
GRF	Ground Reaction Force
IMU	Inertial Measurement Unit
J.S.	Jullyanne silva
MEDLINE	Medical Literature Analysis and Retrieval System Online
ML	Medio-Lateral
MMSE	Mini-Mental State Examination
MTC	Minimum Toe Clearance
P.A.	Pedro Aleixo
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PROSPERO	International Prospective Register of Systematic Reviews
RR	Risk Ratio
SD	Standard Deviation
T.A.	Tiago Atalaia
TUG	Timed Up and Go Test
6MWT	6-Minute Walk Test

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INTRODUÇÃO

Este documento tese, foi elaborado em conformidade com as normativas do programa de Doutoramento da Universidade Lusófona e adotou o formato de compêndio de artigos. A sua organização segue uma estrutura sequencial e articulada, garantindo coerência entre os diferentes componentes da investigação.

Inicialmente, é apresentado o primeiro capítulo dedicado ao "estado da arte", o qual permitiu sintetizar o estado do conhecimento sobre o tópico e identificar as lacunas de conhecimento que poderiam constituir prioridades para futuras investigações. Decorrente do ponto dedicado ao *"estado da arte"*, segue-se a definição dos objetivos desta tese.

Os Capítulos 2, 3 e 4 correspondem, respetivamente, aos três artigos originais desenvolvidos no âmbito da investigação, cada um deles abordando uma dimensão distinta, mas complementar, da problemática em estudo. Cada um dos artigos corresponde à concretização de cada um dos objetivos definidos anteriormente.

No primeiro artigo (Capítulo 2) é apresentada uma revisão sistemática da literatura que tinha o objetivo de identificar e descrever os parâmetros biomecânicos da marcha associados às quedas em idosos. Este artigo já se encontra publicado na revista *Biomechanics*, com a seguinte referência: Silva, J., Atalaia, T., Abrantes, J., & Aleixo, P. (2024). Gait Biomechanical Parameters Related to Falls in the Elderly: A Systematic Review. *Biomechanics*, *4*(1), 165-218, https://doi.org/10.3390/biomechanics4010011. A estrutura do mesmo foi adaptada ao presente documento.

Com base nos resultados obtidos a partir da revisão sistemática da literatura referida no parágrafo anterior, identificámos alguns parâmetros biomecânicos da marcha associados às quedas em idosos. Alguns desses parâmetros foram analisados num segundo artigo (Capítulo 3), o qual teve como objetivo avaliar as características da marcha de longa duração em mulheres idosas de uma comunidade portuguesa específica. Este artigo também já se encontra publicado na revista *Current Aging Science*, com a seguinte referência: Silva, J., Atalaia, T., Martins, R., Abrantes, J., & Aleixo, P. (2025). Gait Characteristics over the Six-minute Walk Test in Older Women of a Specific Portuguese Community: A Cross-Sectional Study. *Current aging science*, *18*(1), 59–72, https://doi.org/10.2174/0118746098315374240508094923. A estrutura do mesmo foi também adaptada ao presente documento.

O terceiro artigo, apresentado no Capítulo 4, teve como objetivo analisar os efeitos de um programa de 12 semanas de exercícios propriocetivos e de força relativamente a parâmetros biomecânicos associados às quedas em idosos, identificados na revisão sistemática apresentada no Capítulo 2. Adicionalmente, foram também avaliados os efeitos desse programa relativamente à capacidade funcional e medo de cair. Este artigo já se encontra publicado na revista *Journal of Bodywork & Movement Therapies*, com a seguinte referência Silva, J., Atalaia, T., Martins, R., Silva, J. C., Abrantes, J., & Aleixo, P. (2025). Effects of a 12-WEEK proprioceptive and strength exercise program on the gait biomechanical parameters of older adults. *Journal of bodywork and movement therapies*, 45, 656–666. https://doi.org/10.1016/j.jbmt.2025.10.003. A estrutura do mesmo foi adaptada ao presente documento.

O Capítulo 5 (Discussão dos Resultados) promove uma discussão integrada dos resultados obtidos nos 3 artigos, analisando criticamente as suas implicações à luz da literatura existente. As limitações do trabalho desenvolvido, bem como propostas para futura investigação são pontos igualmente abordados neste capítulo.

Por fim, o Capítulo 6 (Conclusões) retoma a questão de partida, sintetizando as principais contribuições do trabalho e as conclusões mais relevantes decorrentes deste projeto.

No final de cada capítulo são apresentadas as respetivas referências bibliográficas citadas no mesmo.

Os anexos deste documento complementam a investigação, com materiais produzidos no âmbito da investigação, documentos de suporte externos que incorporam documentação institucional, e instrumentos validados: (1) parecer do comité de ética para a realização da presente investigação; (2) folhetos de recrutamento de participantes; (3) consentimento informado; (4) autorização de recolha de imagens dos participantes no estudo; (5) formulário de caracterização dos participantes; (6) horário das aulas de exercícios; (7) ficha de registo de assiduidade ao programa; (8) parecer de aprovação e registo da revisão sistemática (*PROSPERO*); (9) parecer de aprovação do registo do estudo (*EudraCT*); (10) a autorização de utilização da *Falls Efficacy Scale-International* (FES-I); (11) FES-I; (12) *Mini-Mental State Examination* (MMSE).

CAPÍTULO I

ESTADO DA ARTE

1. ESTADO DA ARTE

1.1. Definição de idoso e dados epidemiológicos

De acordo com o American College of Sports Medicine (2022), indivíduos com mais de 65 anos são classificados como idosos. Contudo, a definição de idoso apresenta variações consoante o contexto socioeconómico e as expectativas de longevidade de cada país, sendo influenciada por fatores biológicos, sociais e culturais (WHO, 2024). Assim, de forma a ter uma definição que abranja a maior parte das várias realidades mundiais, a *World Health Organization* considera idoso, indivíduos com idade igual ou superior a 60 anos (WHO, 2024). Por outro lado, os idosos podem ser subdivididos em duas faixas etárias de forma a compreender melhor as diferenças no processo de envelhecimento: entre 65 e 74 anos; com 75 anos ou mais (Orimo et al., 2006). Tal subdivisão reflete as distintas necessidades relativas à saúde, mobilidade e inclusão social em cada fase, sendo fundamental para orientar estratégias que promovam um envelhecimento saudável e ativo.

O envelhecimento demográfico da população mundial é uma realidade incontornável. Dados do início de 2024 da União Europeia, apontam para que mais de um quinto da população (21.6%) tenha 65 anos ou mais (Eurostat, 2025). Portugal reflete igualmente essa realidade, ou seja, 24.1% da população tem 65 ou mais anos (Eurostat, 2025). Para agravar ainda mais este cenário, prevê-se um aumento destes números. Assim, o envelhecimento populacional na União Europeia deverá caracterizar-se por um aumento do número de indivíduos octogenários, os quais apresentarão uma taxa de crescimento proporcional substancialmente superior à de qualquer outro grupo etário (Eurostat, 2025). De acordo com os últimos estudos demográficos, prevê-se que o peso relativo desta faixa etária (80 anos ou mais) no conjunto da população comunitária evolua de 6.1% em 2024 para 15.3% em 2100 (Eurostat, 2025).

1.2. Alterações associadas ao envelhecimento

O envelhecimento é um processo condicionado por fatores biológicos, sociais, económicos, culturais, ambientais e históricos, podendo ser definido como um processo progressivo de mudança biopsicossocial da pessoa durante todo o ciclo de vida (WHO, 2024). O envelhecimento compromete, de forma progressiva, as capacidades físicas e funcionais do idoso, estando diretamente associado ao desenvolvimento progressivo de doenças não transmissíveis (Kyu et al., 2018), as quais correspondem a aproximadamente 90% dos problemas de saúde nos idosos. Um dos principais comprometimentos resultantes do envelhecimento é a sarcopenia, ou seja., uma perda progressiva e generalizada de massa, força e função muscular (Cruz-Jentoft et al., 2019). Assim, esta redução da quantidade de massa muscular conduz a uma diminuição da capacidade de produzir força. Por outro lado, a degeneração das cartilagens articulares (artrose) é outra consequência do envelhecimento, levando a rigidez, dor e perda de mobilidade articular (Hunter & Bierma-Zeinstra, 2019). Em suma, os idosos apresentam uma redução das suas capacidades físicas e da sua funcionalidade, aumentando assim o risco de quedas (Cruz-Jentoft et al., 2019; Tinetti & Williams, 1998). Concomitantemente, verifica-se também uma redução da densidade mineral óssea (osteopenia/osteoporose), particularmente em mulheres pós-menopáusicas, aumentando desse modo o risco de fraturas como resultado das quedas (Kanis et al., 2019).

1.3. A problemática das quedas nos idosos

De acordo com a *World Health Organization* (WHO, 2021), as quedas em idosos configuram uma questão relevante de saúde pública, ocupando a segunda posição entre as causas de mortes acidentais por trauma. Para além disso, os idosos constituem o grupo com maior incidência e piores consequências das quedas, as quais vão aumentando com a idade (WHO, 2008). A literatura documenta diversos impactos negativos decorrentes das quedas, nomeadamente: comprometimento da qualidade de vida; sequelas psicológicas, como são o caso de desenvolvimento de medo em relação às quedas e da diminuição da autoconfiança; traumas físicos, como por exemplo, fraturas (Ambrose et al., 2015; Stenhagen et al., 2014; Yardley & Smith, 2002). Paralelamente, é também importante realçar o peso económico das quedas para as famílias, comunidades e sociedade. Nos Estados Unidos, em 2015, os custos médicos associados a quedas, fatais e não fatais, foram estimados em aproximadamente 50 mil milhões de dólares (Florence et al., 2018). Em Portugal, este fenómeno também é reconhecido como um dos mais significativos problemas de saúde relacionados com o envelhecimento da população, afetando tanto a morbilidade quanto a mortalidade em idosos. No ano de 2023, o sistema de Epidemiologia e Vigilância dos Traumatismos e Acidentes (EVITA) registou em Portugal 40.842 eventos de quedas em indivíduos com 65 anos ou mais, sendo que 31% destes ocorreram em pessoas com 85 anos ou mais (Alves et al., 2024).

De acordo com a literatura (American Geriatrics Society, 2001; Stenhagen et al., 2014; Yardley & Smith, 2002), as quedas em idosos dependem de fatores multifatoriais complexos, incluindo fatores intrínsecos e extrínsecos aos indivíduos. Relativamente aos fatores extrínsecos, devemos considerar a medicação utilizada (i.e., toma de quatro ou mais medicamentos) e os fatores ambientais (e.g., iluminação deficiente ou tapetes que deslizam). No que concerne aos fatores intrínsecos, devemos considerar a fraqueza muscular, os distúrbios de estabilidade, o comprometimento funcional e cognitivo, e os défices visuais.

Uma significativa percentagem de quedas nos idosos ocorre durante a marcha, uma atividade da vida diária fundamental nos idosos, sendo o tropeçar e escorregar os mecanismos causais mais prevalentes (Berg et al., 1997; Talbot et al., 2005). As quedas durante a marcha têm sido frequentemente associadas a fatores ambientais e a alterações da biomecânica da marcha no idoso (Rubenstein, 2006), sendo estas alterações resultado, em grande medida, da redução das suas capacidades físicas e funcionalidade.

1.4. Parâmetros biomecânicos da marcha associados às quedas

A marcha dos idosos tem sido amplamente analisada de forma a encontrar relações entre as quedas e parâmetros biomecânicos da marcha. Desta forma, a análise dos parâmetros biomecânicos da marcha relacionados com quedas nos idosos assume particular relevância para a categorização do nível de risco, podendo facilitar tanto a deteção precoce de casos de maior vulnerabilidade como a implementação de intervenções mais personalizadas e adequadas para a prevenção de quedas em idosos (Schwartz & Rozumalski, 2008). Como já referido anteriormente, o tropeçar e o escorregar constituem os mecanismos mais comuns de quedas durante a marcha (Berg et al., 1997) e, por isso, parâmetros associados aos mesmos têm sido dos mais estudados.

Em relação ao tropeçar, a distância mínima entre o dedo do pé e o solo (*minimum toe clearance*) surgiu como um parâmetro biomecânico da marcha relacionado a esse tipo de queda. Uma revisão sistemática anterior abordou esse tema e não encontrou diferenças entre pessoas com e sem historial de quedas no que diz respeito à *minimum toe clearance* (Barrett et al., 2010), embora a literatura disponível fosse escassa aquando da realização da mesma. Por outro lado, essa revisão sistemática constatou que os indivíduos com historial de quedas apresentavam maior variabilidade da *minimum toe clearance*.

Os parâmetros biomecânicos relacionados com o escorregar são, naturalmente, diferentes. Nesse sentido, a velocidade ântero-posterior do calcanhar no isntante do contato com o solo e o ângulo do pé com o solo têm sido parâmetros biomecânicos da marcha associados ao escorregar (Aleixo & Abrantes, 2015; Baba et al., 2023). Neste sentido, o controlo dos movimentos do pé assume particular relevância durante o contacto do calcanhar com o solo.

Os parâmetros biomecânicos da marcha mais estudados, no que concerne à sua associação ao historial de quedas em idosos, têm sido os parâmetros espaço-temporais. Estes parâmetros podem refletir a redução das capacidades físicas e funcionalidade dos idosos, bem como um aumento do seu medo de cair (Maki, 1997; Uemura et al., 2012, Ayoubi et al., 2014). Assim, de acordo com alguma literatura, os parâmetros biomecânicos da marcha associados às quedas são: velocidade da marcha e cadência (Callisaya et al., 2011; Verghese et al., 2009); comprimento do passo, duração da fase de duplo apoio, e variabilidade no comprimento do passo (Verghese et al., 2009); variabilidade no comprimento do passo e na fase de duplo apoio (Callisaya et al., 2011).

Como referido num parágrafo anterior, o controlo do pé assume particular relevância na estabilidade articular e postural durante a sua fase de apoio durante a marcha (Aleixo et al. 2019). Este controlo pode ser dividido em três subfases distintas, cada uma com objetivos específicos: (1) subfase de flexão plantar controlada – que visa amortecer o impacto do pé com o solo, estando diretamente associada ao contacto do calcanhar com o solo; (2) subfase de dorsiflexão controlada – que garante a estabilidade do pé e permite a progressão do corpo; (3) subfase de flexão plantar propulsiva – responsável pela impulsão do membro inferior para a fase aérea (Aleixo et al., 2018; Aleixo et al., 2019). A estabilidade do tornozelo revela-se crítica durante a subfase de dorsiflexão controlada, sendo a rigidez articular um fator determinante para a manutenção da estabilidade articular (Docherty et al., 2004). A literatura estabelece a rigidez dinâmica articular como o parâmetro de referência para a sua quantificação (Aleixo et al., 2021). A literatura apontou para uma maior rigidez dinâmica articular em mulheres pós-menopáusicas com artrite reumatoide sem historial de quedas quando comparadas com aquelas que apresentavam historial de quedas (Aleixo et al., 2017b). Igualmente determinante é a subfase de flexão plantar propulsiva no ciclo da marcha (Aleixo et al., 2018; Aleixo et al., 2019). O pico de potência do tornozelo durante esta fase também permitiu discriminar mulheres pós-menopáusicas com e sem historial de quedas em diferentes populações clínicas, i.e., com osteoporose (Stief et al., 2016) e artrite reumatoide (Aleixo et al., 2017a), observando-se valores inferiores nas mulheres com historial de quedas.

Contudo, apesar da reconhecida importância de associar as quedas nos idosos a parâmetros biomecânicos da marcha, constata-se que, até à data, não tinha sido conduzida nenhuma revisão sistemática que abordasse de forma abrangente e metodologicamente robusta esta questão específica. Esta lacuna justifica a necessidade urgente de investigação que sistematize o conhecimento existente e valide parâmetros biomecânicos da marcha para a avaliação do risco de quedas em idosos, otimizando também, estratégias preventivas para a ocorrência das mesmas.

A maioria dos estudos que analisaram a marcha de idosos avaliou a marcha em testes de curta duração, ou seja, numa duração inferior a um minuto. No entanto, o aumento da duração da marcha pode conduzir à fadiga, e esta induzir instabilidade na marcha e alterar os seus parâmetros biomecânicos (Helbostad et al., 2010). Portanto, a marcha de idosos também deve ser avaliada em marcha de longa duração. Nesse sentido, um estudo anterior mostrou que os idosos apresentavam maior assimetria e variabilidade na cinemática dos tornozelos, ou seja, uma maior instabilidade da mesma, durante uma marcha de 30 minutos (Wong et al., 2020). Assim, alterações no padrão de marcha podem ocorrer durante a marcha de longa duração, expondo os idosos a um aumento no risco de quedas. No entanto, há poucos estudos sobre as alterações que podem ocorrer nos parâmetros biomecânicos de idosos durante marcha de longa duração. Assim, identificar essas mudanças ajudaria na criação de programas de treino que visassem aumentar a capacidade de locomoção dos idosos.

Na vida diária, os idosos recorrem frequentemente a passos de recuperação para preservar a sua estabilidade postural (Roger set al., 2021). Estes passos funcionam como mecanismos compensatórios para restabelecer a estabilidade postural perdida durante atividades na posição bípede (Aleixo & Abrantes, 2024). Do ponto de vista biomecânico, visam reposicionar a vertical do centro de massa dentro da base de suporte. De acordo com a literatura (Batcir et al., 2020), idosos com historial de quedas exibem um maior deslocamento do centro de massa, maior duração do início do passo e maior duração do passo.

1.5. Como avaliar parâmetros biomecânicos da marcha em idosos

De acordo com o descrito em pontos anteriores, será importante conduzir uma revisão sistemática que sistematize o conhecimento relativamente à associação entre as quedas e os parâmetros biomecânicos da marcha. No entanto, partindo da literatura consultada, é possível estabelecer alguma relação com alguns parâmetros cinemáticos e alguns parâmetros espaço-temporais da marcha.

Os parâmetros cinemáticos da marcha podem ser avaliados através de sistemas de análise tridimensional do movimento, considerados o *gold standard* para avaliações cinemáticas (Di Paolo et al., 2021; Springer & Seligmann, 2016; Müller et al., 2017). Contudo, sistemas com sensores inerciais também permitem de forma objetiva avaliar a cinemática da marcha (Picerno, 2017). Assim, vários estudos utilizaram sistemas com sensores inerciais para analisar a marcha de idosos (Drover et al., 2017; Galán-Mercant et al., 2019; Grimpampi et al., 2015; Howcroft et al., 2017; Waugh et al., 2019).

Os parâmetros espaço-temporais da marcha (e.g, velocidade da marcha, cadência, comprimento do passo ou passada, duração do passo ou passada, largura do passo, duração ou percentagens das várias fases do ciclo de marcha) podem ser recolhidos através de plataformas de força ou pressão (Jeon & Cho 2020; Kressig et al., 2006; Svoboda et al., 2017). Assim, este tipo de equipamentos permite uma análise objetiva, reprodutível e comparável dos parâmetros espaço-temporais da marcha (Kressig et al., 2006).

Foi também referido num ponto anterior que seria importante avaliar a marcha de idosos em ensaios de longa duração. Segundo o American College of Sports Medicine (2022), as recomendações internacionais de atividade física para idosos preconizam a realização de 30 minutos diários de exercício de intensidade moderada (e.g., caminhada rápida), distribuídos por, no mínimo, cinco dias por semana, podendo estes ser acumulados em blocos de 10 minutos ou mais. Contudo, evidências demonstram que a maioria dos idosos não cumpre estas diretrizes (Jefferis et al., 2014), sugerindo que os seus padrões habituais de deslocação envolvem períodos de marcha inferiores a 10 minutos. Neste contexto, o *six-minute walk test* (6MWT) surge como um instrumento válido para a avaliação da marcha em idosos (Storm et al., 2020), apesar do mesmo ter sido desenvolvido para avaliar a capacidade funcional de indivíduos com doenças pulmonares crónicas (Ubuane et al., 2018). Adicionalmente, o 6MWT destaca-se pela sua natureza não invasiva, baixo custo e elevada reprodutibilidade (Storm et al., 2020), características que o tornam particularmente adequado para populações idosas.

1.6. Como avaliar o medo de cair em idosos

Como referido anteriormente, o desenvolvimento do medo de cair constitui uma consequência direta da ocorrência de quedas em idosos e é um determinante para a ocorrência de novas quedas (Delbaere et al., 2010; Friedman et al., 2002; Tinetti et al., 1990). Neste contexto, a avaliação do medo de cair revela-se fundamental nesta população. Existem diversos questionários validados e adaptados para a população portuguesa que cumprem este propósito, nomeadamente a *Falls Efficacy Scale – Inte*rnational, FES-I (Figueiredo & Santos, 2017) e a Cultural and Linguistic *Adaptation of the Fall Risk Questionnaire – Portuguese Version* (Monteiro et al., 2023). A FES-I é uma ferramenta altamente fiável para medir o medo de cair nos idosos, sendo utilizada tanto em investigação como na prática clínica (Figueiredo & Santos, 2017). Por outro lado, Yardley et al (2005) refere que a FES-I tem excelentes propriedades psicométricas e avalia as preocupações dos indivíduos relativamente a atividades diárias básicas, tanto físicas como sociais.

1.7. A prevenção de quedas em idosos

A prevenção de quedas pode envolver diferentes estratégias, dependendo do tipo de fator que se pretende modificar. Por exemplo, nos programas multifatoriais poderemos ter uma avaliação individualizada do risco de queda, com modificações do ambiente físico e a revisão da medicação em cuidados primários (Gillespie et al., 2012). Por outro lado, existem programas que visam apenas modificar apenas um dos fatores que podem influenciar as quedas, como é o caso dos programas de exercício (Gillespie et al., 2012).

De acordo com Sherrington (2019), os programas de exercício mais eficazes na prevenção de quedas devem combinar treino de estabilidade postural, exercícios funcionais e de fortalecimento muscular. Por outro lado, os mesmos autores apontam também para que atividades que desafiam a locomoção sejam igualmente importantes. Assim, a implementação de programas de exercícios para a prevenção de quedas deve adotar uma abordagem multimodal, incorporando estas diferentes vertentes de exercício (Sherrington et al., 2019),

O programa de exercícios desenvolvido por Aleixo & Abrantes (2024) representa uma proposta inovadora, com o foco no pilar da locomoção e especificamente desenhada para modificar os parâmetros espaço-temporais da marcha associados às quedas. Este programa incorpora os tipos de exercício anteriormente definidos como os mais eficazes para a prevenção de quedas, i.e., exercícios propriocetivos, funcionais e de fortalecimento muscular (Aleixo & Abrantes, 2024). Para além disso, os exercícios foram também desenvolvidos em função dos parâmetros biomecânicos associados às quedas, anteriormente descritos nesta Introdução.

Os exercícios propriocetivos estimulam os mecanorreceptores articulares, musculares e tendinosos, visando otimizar o feedback aferente para o sistema nervoso central (Gollhofer, 2008). Conforme referido numa revisão sistemática sobre a eficácia de exercícios propriocetivos na função motora (Amam et al., 2015), programas com duração mínima de seis semanas podem promover melhorias na proprioceção e nas capacidades somatossensoriais. Por outro lado, o *American College of Sports Medicine* estabelece que a frequência ótima para a obtenção de benefícios na prevenção de quedas em idosos através do treino proprioceptivo situa-se entre 2 e 3 sessões semanais, conforme evidenciado nas suas diretrizes de prescrição de exercício (ACSM, 2022).

Os exercícios funcionais e de força visam melhorar a capacidade neuromuscular para atividades da vida diária. Neste contexto, Santana, (2016) definiu um importante conceito, i.e., a força funcional – força aplicável em movimentos quotidianos, enfatizando padrões de movimento eficientes em vez de carga máxima. Estudos anteriores demonstraram benefícios do treino funcional de força em diferentes grupos populacionais. Em raparigas não treinadas, observaram-se melhorias na mobilidade articular, estabilidade postural, força e potência (Liao et al., 2019). Em jovens tenistas foram reportadas melhorias na mobilidade articular, estabilidade postural e potência (Yildiz et al., 2019), enquanto em jovens adultos se registaram ganhos na agilidade, força e potência (Distefano et al., 2013). Em jovens meninos com experiência de treino, notou-se uma melhoria na estabilidade postural e na coordenação (Tomljanović et al., 2011), e em jogadores de futebol jovens adultos, a estabilidade postural foi também melhorada (Plenzler et al., 2014). Resultados semelhantes foram observados também em jovens adultos, com progressos na estabilidade postural e força (Weiss et al., 2010). Já em adultos de meia-idade e idosos, constatou-se uma melhoria na mobilidade articular e estabilidade postural (Pacheco et al., 2013), bem como na força, velocidade da marcha e capacidade funcional em idosos com deficiência (Krebs et al., 2007), e em parâmetros espaço-temporais da marcha em idosos com demência (Schwenk et al., 2014). Importa ainda referir que, de acordo com alguns desses autores, os estudos indicaram que o treino funcional de força pode ser mais eficaz do que o treino de força tradicional em determinados indicadores físicos, tais como: mobilidade articular, estabilidade postural, força e potência (Liao et al., 2017); mobilidade articular, estabilidade postural e potência (Yildiz et al., 2018); agilidade, força e potência (Distefano et al., 2013); estabilidade postural e coordenação (Tomljanović et al., 2011); velocidade da marcha e capacidade funcional (Krebs et al., 2007).

De acordo com os autores do programa de exercícios (Aleixo & Abrantes, 2024), o programa foi estruturado para uma duração de 12 semanas, compreendendo 3 sessões semanais de 45 minutos cada. O aquecimento envolve exercícios de alongamentos, os quais são seguidos, na parte fundamental da sessão, por exercícios propriocetivos, funcionais e de força. A sessão termina com exercícios de alongamentos. Os exercícios podem ser vistos em http://elderly.falls.ulusofona.pt/. A intensidade e progressão dos exercícios são individualizadas, de acordo com a complexidade dos movimentos e a capacidade funcional de cada participante, garantindo assim uma adaptação segura e eficaz ao programa.

Embora o referido programa apresente fundamentação teórica robusta, a eficácia do mesmo relativamente à melhoria dos parâmetros biomecânicos da marcha associados às quedas ainda não foi testada.

2. OBJETIVOS DA TESE

Considerando o descrito nos pontos anteriores, a presente tese de doutoramento propôs-se responder aos seguintes objetivos:

- concretizar uma revisão sistemática para identificar e descrever os parâmetros biomecânicos da marcha associados às quedas em idosos;
- descrever as características da marcha de longa duração em mulheres idosas, recorrendo ao 6MWT para análise dos seus parâmetros espaço-temporais, bem como da cinemática angular das articulações dos membros inferiores;
- avaliar os efeitos de um programa de 12 semanas de exercícios proprioceptivos e de força, desenvolvido por Aleixo & Abrantes (2024), sobre parâmetros biomecânicos da marcha associados às quedas e medo de cair em idosos.

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CAPÍTULO II

ESTUDO I

GAIT BIOMECHANICAL PARAMETERS RELATED TO FALLS IN THE ELDERLY: A SYSTEMATIC REVIEW.

PARÂMETROS BIOMECÂNICOS DA MARCHA RELACIONADOS ÀS QUEDAS EM IDOSOS: UMA REVISÃO SISTEMÁTICA.

(Biomechanics, *4*(1), 165-218, https://doi.org/10.3390/biomechanics4010011)

ESTUDO I: Parâmetros biomecânicos da marcha relacionados às quedas em idosos: uma revisão sistemática

O primeiro artigo que forma parte deste estudo ***"Gait biomechanical parameters related to falls in the elderly: a systematic review"*** foi publicado na revista "*Biomechanics*".

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ABSTRACT

According to the World Health Organization, one-third of elderly people aged 65 or over fall annually, and this number increases after 70. Several gait biomechanical parameters were associated with a history of falls. This study aimed to conduct a systematic review to identify and describe the gait biomechanical parameters related to falls in the elderly. MEDLINE Complete, Cochrane, Web of Science, and CINAHL Complete were searched for articles on 22 November 2023, using the following search sentence: (gait) AND (fall*) AND ((elder*) OR (old*) OR (senior*)) AND ((kinematic*) OR (kinetic*) OR (biomechanic*) OR (electromyogram*) OR (emg) OR (motion analysis*) OR (plantar pressure)). This search identified 13,988 studies. From these, 96 were selected. Gait speed, stride/step length, and double support phase are gait biomechanical parameters that differentiate fallers from non-fallers. Fallers also tended to exhibit higher variability in gait biomechanical parameters, namely the minimum foot/toe clearance variability. Although the studies were scarce, differences between fallers and non-fallers were found regarding lower limb muscular activity and joint biomechanics. Due to the scarce literature and contradictory results among studies, it is complex to draw clear conclusions for parameters related to postural stability. Minimum foot/toe clearance, step width, and knee kinematics did not differentiate fallers from non-fallers.

Keywords: gait; falls; spatiotemporal parameters; kinematics; kinetics; systematic review

1. INTRODUCTION

According to the World Health Organization (WHO, 2021), the occurrence of falls in the elderly population is an important public health problem, representing the second leading cause of unintentional injury deaths worldwide. Several individual consequences of falls are described in the literature: reduced quality of life (Stenhagen et al., 2014), psychological effects, such as increased fear of falling and loss of confidence (Yardley & Smith, 2002), and fractures (Ambrose et al., 2015). The elderly are the group with the highest incidence and worst consequences of falls, which increase with aging (WHO, 2008). On the other hand, it is also important to highlight the economic burden of falls for families, communities, and society, e.g., falls among the elderly in the United States of America resulted in substantial medical costs (Florence et al., 2018).

Falls in the elderly are dependent on complex multifactorial risks such as (1) intrinsic risks, e.g., muscle weakness, stability disorders, functional and cognitive impairment, and visual deficits; (2) extrinsic risks, e.g., prescription of four or more medications; and (3) environmental risks, e.g., poor lighting or rugs that slide (American Geriatrics Society, 2001). Focusing our attention on intrinsic factors, it is important to highlight that the subjects' functional capacity and motor control play an important role in falls. This is particularly important during walking, one of the activities of daily life in which falls are most prevalent (Rubenstein, 2006). Moreover, the increment of knowledge about gait biomechanics related to falls (i.e., objective data of functional capacity and motor control) may help in the identification of subjects that present a high risk of falls and also in the development of interventions to decrease this risk (Creaby & Cole, 2018). In this context, tripping and slipping are the most frequent causes of falls during gait (Berg et al., 1997). Regarding tripping, the minimum toe clearance (MTC) emerged as one gait biomechanical parameter related to this kind of fall. A previous systematic review (Barrett et al., 2010) addressed this issue and found no differences between fallers and non-fallers regarding MTC, although the literature found was scarce. Furthermore, this systematic review also found that fallers had greater variability in MTC. Naturally, the biomechanical parameters related to slipping are different. In this way, the heel anteroposterior (AP) velocity at heel strike has been a biomechanical gait parameter related to slips (Aleixo & Abrantes, 2015). Finally, the gait spatiotemporal parameters were also associated with a history of falls, namely gait speed and cadence (Callisaya et al., 2011; Verghese et al., 2009); stride length, double support phase duration, and variability in the stride length and swing time (Verghese et al., 2009); and variability in the step length and double-support phase (Callisaya et al., 2011).

Systematic reviews can synthesize the state of knowledge on a specific topic, allowing the identification of knowledge gaps that can constitute priorities for future research (Page et al., 2021a). In our study, the synthesis of knowledge on the gait biomechanical parameters related to falls in the elderly may be useful for the stratification of severity (i.e., risk of fall) in future research and also helpful in developing more tailored and suitable assessments and interventions for this population (Schwartz & Rozumalski, 2008). Nonetheless, to the best of our knowledge, no systematic review has approached this issue. Therefore, the aim of this systematic review was to identify and describe the gait biomechanical parameters related to falls in elderly populations.

2. MATERIALS AND METHODS

This systematic review was developed in accordance with the Preferred Items for Reporting for Systematic Reviews and Meta-Analysis (PRISMA) statement (Page et al., 2021b). This review was registered in PROSPERO (ID–CRD42021271511).

2.1. Eligibility criteria

The present review included studies according to the following inclusion criteria: (1) articles comparing elderly fallers and non-fallers on data from gait biomechanical analyses (the distinction between fallers and non-fallers can occur through retrospective studies, based on a previous history of falls, and prospective studies based on a follow- up of a fall's occurrence); (2) articles that during their methodological set-up induced falls and compared the elderly who fell with the elderly who recovered, regarding gait biomechanical data. In the scope of this study, gait biomechanical analyses also comprised analyses on uneven terrain. Furthermore, data from biomechanical gait analyses included spatiotemporal, kinematic, kinetic, electromyography (EMG), and plantar pressure data. The WHO definition of elderly was also considered, i.e., subjects aged 60 or over (WHO, 2017). The following exclusion criteria were also defined: (1) articles assessing subjects under 60 years (or the mean age of the subjects less one standard deviation lower than 60 years); (2) articles assessing subjects that use any walking aid, with neurological or osteoarticular disease (e.g., stroke, Parkinson's disease, polyneuropathy, osteoarthritis, or rheumatoid arthritis), with dementia, who are amputees, or who are blind; (3) articles assessing subjects during dual-task, ascending or descending stairs, turning, or obstacle-crossing; and (4) case reports, reviews, or dissertations. No restrictions were imposed regarding language or publication date.

2.2. Search strategy and selection process

Systematic review was conducted independently by two researchers (J.S. and P.A.), using the following protocol: (1) a comprehensive search of articles was made on MEDLINE Complete, Cochrane, Web of Science, and CINAHL Complete for articles published until 22 November 2023, using the following search sentence- (gait) AND (fall*) AND ((elder*) OR (old*) OR (senior*)) AND ((kinematic*) OR (kinetic*) OR (biomechanic*) OR (electromyogram*) OR (emg) OR (motion analysis*) OR (plantar pressure)); (2) exclusion of duplicates—Mendeley was used to manage all references, removing duplicates; (3) selection of articles by title and abstract; (4) screening of articles by analyzing the full text; and (5) hand search for relevant articles. In the third and fourth points of the protocol, a third reviewer (T.A.) would be consulted if there were any disagreements between the two reviewers.

2.3. Data extraction and synthesis

Data were extracted by one reviewer (J.S.) using a predefined form: (1) authors and year of publication; (2) inclusion and exclusion criteria and definition of fall; (3) sample characteristics (sample size and sociodemographic data—age, gender, and type of population); (4) gait assessment; and (5) results (gait biomechanical parameters related or not related to falls). All information was cross-checked by a second reviewer (P.A.).

2.4. Risk of bias assessment

In this systematic review, the Quality Assessment Tool for Quantitative Studies, developed by the Effective Public Health Practice Project (EPHPP, 2003), was used to assess the methodological quality of studies. This assessment focused on 6 domains: (1) selection bias; (2) study design; (3) confounders; (4) blinding; (5) data collection method; and (6) withdrawals and dropouts. Each domain was evaluated with the following classification: “1” corresponds to a strong report in that domain; “2” corresponds to a reasonable report in that domain; and "3" corresponds to a weak report in that domain. The articles that met the inclusion criteria were assessed independently by two researchers (J.S. and P.A.). Any disagreements were resolved with a consensus discussion between them. If disagreements remained after discussion, a third reviewer was consulted (T.A.).

3. RESULTS

A total of 13,988 records were found from the following databases: MEDLINE Complete and CINAHL Complete (7144), Cochrane (887), and Web of Science (5957). Additional articles were also found by manual searching (12). Removal of duplicates resulted in 9425 eligible articles. After this first selection, 8512 articles were excluded by determining that their titles and abstracts were not relevant or did not meet the inclusion criteria. In this way, the full text of 913 records was reviewed. The eligibility process resulted in the inclusion of 96 articles in this systematic review. A flow diagram summarizing this selection process is shown in Figure 1.

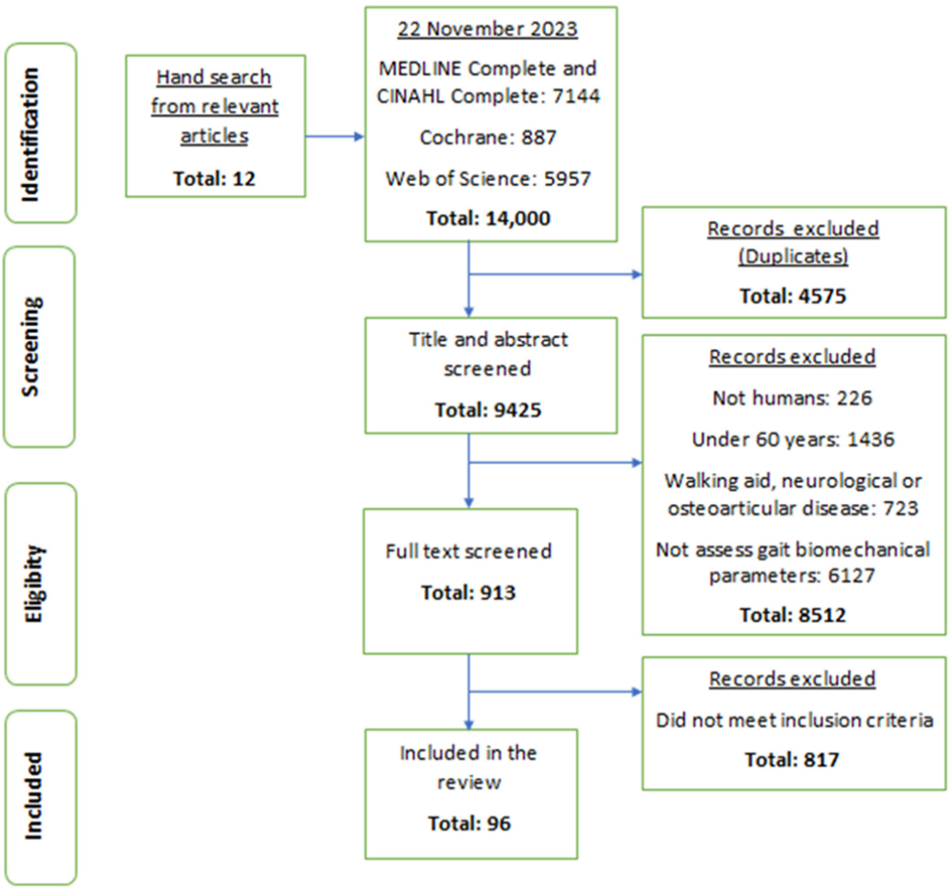

Figure 1. Study flow diagram.

3.1. Characteristics of the selected studies

This review included 96 studies. Of these, 84 studies (Allen & Franz, 2018; Auvinet et al., 2003; Ayoubi et al., 2014; Baba et al., 2023; Barak et al., 2006; Barelle et al., 2014; Barrett et al., 2008; Benson et al., 2018; Bhatt et al., 2011; Bizovska et al., 2017; Bounyong et al., 2016; Cebolla et al., 2015; Chen et al., 2013; Chen & Chou, 2013; Chiba et al., 2005; Chiu & Chou, 2013; de Melker Worms et al., 2017a; de Melker Worms et al., 2017b; Feltner et al., 1994; Figueiredo et al., 2022; Freire Júnior et al., 2017; Fritz et al., 2013; Fujimoto & Chou, 2016; Gehlsen & Whaley, 1990; Gillain et al., 2019; Gonzalez et al., 2020; Greany & Di Fabio, 2010; Greene et al., 2010; Hausdorff et al., 2001; Heitmann et al., 1989; Howcroft et al., 2016, 2018; Ihlen et al., 2016; Iwata et al., 2014; Karmakar et al., 2013; Karmakar et al., 2007; Kemoun et al., 2002; Kerrigan et al., 2000, 2001; Khandoker et al., 2008a; Khandoker et al., 2008b; Kirkwood et al., 2011; Kobayashi et al., 2014; König et al., 2014; Kwon et al., 2018; Lázaro et al., 2011; Lee & Kerrigan, 1999; Lockhart & Liu, 2008; Lugade et al., 2011; MacAulay et al., 2015; Mak et al., 2019; Maki, 1997; Marques et al., 2017, 2018; Marques et al., 2013a; Marques et al., 2013b; Mickle et al., 2010; Mignardot et al., 2014; Mbourou et al., 2003; Nascimento et al., 2022; Nelson et al., 1999; Newstead et al., 2007; Panzer et al., 2011; Pijnappels et al., 2005; Pol et al., 2021; Qiao et al., 2018; Rinaldi et al., 2017; Rinaldi & Moraes, 2016; Rispens et al., 2015; Sadeghi et al., 2021; Santos Bueno et al., 2019; Scanaill et al., 2011; Svoboda et al., 2017; Thompson et al., 2018; Toulotte et al., 2006; Uemura et al., 2012; Verghese et al., 2009; Wall et al., 2000; Watanabe, 2018; Weiss et al., 2013; Wolfson et al., 1995; Wright et al., 2015; Yamagata et al., 2021; Yamagata et al., 2019a; Yamagata et al., 2019b; Yoshida et al., 2022) comparing elderly fallers and non-fallers (Table 1).

Others 12 studies (Bhatt et al., 2011; Bruijn et al., 2022; Espy & Pai, 2007; Lockhart et al., 2003; Pavol et al., 1999, 2001; Pijnappels et al., 2005; Sawers et al., 2017; Sawers & Bhatt, 2018; Wang et al., 2022; Wang & Bhatt, 2023; Yang & Pai, 2014) that induced falls during their methodological set-up and compared the elderly who fell with the elderly who recovered (Table 2).

Table 1. Characteristics and data of the studies that compared fallers and non-fallers' gait.

Study	Inclusion and/or exclusion criteria Definition of fall	Sample characteristics	Gait assessment	Gait parameters related to falls (fallers *vs* non-fallers)	Gait parameters not related to falls (fallers *vs* non-fallers)
Heitmann et al., 1989	Exclusion criteria: Parkinson's disease, multiple sclerosis, or residual effects from a stroke. Inclusion criteria: able to walk 90 feet without an assistive device and to be independent in activities of daily living. Definition of fall: not reported.	Community-dwelling elderly women: 26 fallers (≥ 1 fall in past year; 75.1±7.7 years); 84 non-fallers (73.1±7.0 years).	Subjects walked on paper walkways making ink prints for step-width measurements; 3 trials were performed; the best one was used for analysis.		Step width (cm): 7.44 *vs* 6.54; step width variability (standard deviation; cm): 3.60 *vs* 3.35.
Gehlsen & Whaley, 1990	Exclusion criteria: uncontrolled hypertension, angina pectoris, recent myocardial infraction, disabling injury to legs and back. Definition of fall: not reported.	Community-dwelling elderly: 25 fallers (≥ 1 fall in past 10 months; 7 males; 72.4±4.7 years); 30 non-fallers (12 males; 71.3±4.4 years).	Subjects walked on a treadmill at 4 km/h and 6 km/h. They were filmed by two cameras (64 Hz; sagittal and frontal planes). MTC was analyzed.	6 km/h: heel width (cm): 7.39 *vs*. 6.41.	4 km/h: heel width (cm): 7.77 *vs*. 7.19. 4 km/h and 6 km/h: stride length (m): 0.58 *vs*. 0.59; 0.73 *vs*. 0.72; MTC (cm): 1.15 *vs*. 0.70; 0.77 *vs*. 0.68; single support phase (s): 0.49 *vs*. 0.50; 0.45 *vs*. 0.44; double support phase (s): 0.14 *vs*. 0.15; 0.11 *vs*. 0.11; swing phase (s): 0.35 *vs*. 0.35; 0.34 *vs*. 0.34; cadence (stride/s): 2.05 *vs*. 2.01; 2.26 *vs*. 2.21; hip displacement (◦): 65–104 *vs*. 64–105; knee displacement (◦): 9–62 *vs*. 8–63; 7–63 *vs*. 8–62; ankle displacement (◦): 98–120 *vs*. 97–120; 103–125 *vs*. 99–122.
Feltner et al., 1994	Exclusion and inclusion criteria: not reported. Definition of fall: event that results in a subject coming to rest inadvertently on the ground.	Community-dwelling elderly women: 6 fallers (≥ 1 fall in past year; 71.7±2.6 years); 11 non-fallers (74.4±1.7 years).	Subjects walked at their preferred gait speed across an 8.2 m walkway filmed by two cameras (60 Hz; sagittal and frontal planes). At least 3 trials were collected, and the trial with a complete stride in the side view camera footage was used for analysis. AP and ML velocities of CoM were calculated		Stride length (m): 1.12 *vs*. 1.16; right and left step length (m): 0.57 *vs*. 0.60, 0.54 *vs*. 0.56; step width (m): 0.22 *vs*. 0.22; stride time (s): 1.05 *vs*. 1.02; right and left step time (s): 0.59 *vs*. 0.53, 0.46 *vs*. 0.50; single support (%): 69.8 *vs*. 68.5; swing phase (%): 31.1 *vs*. 32.9; CoM AP velocity (m/s): 1.08 *vs*. 1.14; CoM ML velocity (m/s): −0.19 *vs*. −0.20; minimum and maximum hip position (◦): −6 *vs*. −10; 26 vs. 26; minimum and maximum knee position (◦): 175 *vs*. 175; 118 *vs*. 116; minimum and maximum ankle position (◦): 12 *vs*. 8; −12 *vs*. −14; width of the base of support (m): 0.14 *vs*. 0.15.

Table 1. Cont.

Study	Inclusion and/or exclusion criteria Definition of fall	Sample characteristics	Gait assessment	Gait parameters related to falls (fallers *vs* non-fallers)	Gait parameters not related to falls (fallers *vs* non-fallers)
Wolfson et al., 1995	Exclusion criteria: terminal illness, severe dementia, non-ambulatory status, required use of a walker, amputations, severe arthritis, major impairment due to neurologic disease, episodes of loss of consciousness. Definition of fall: not reported.	Community-dwelling elderly: 18 fallers (≥ 2 falls in past year; mean age 82.2 years); 15 non-fallers (mean age 84.6 years).	Not reported.	Gait speed (m/s): 0.37 *vs*. 0.64; stride length (m): 0.53 *vs*. 0.82.	
Maki, 1997	Inclusion criteria: able to walk 10-m with or without a walking aid; understand verbal instructions. Definition of fall: event that results in a subject coming to rest inadvertently on the ground.	Community-dwelling elderly: 43 fallers (≥ 1 fall in 1-year follow-up; 8 males; 82.8±6.2 years); 32 non-fallers (6 males; 81.0±6.7 years).	Subjects walked with their own footwear at their preferred gait speed across an 8 m walkway. Four trials were filmed but only the last two were included in the analysis.	Stride length variability (SD): higher values in fallers; double support phase variability (SD): higher values in fallers; gait speed variability (SD): higher values in fallers.	Stride length; stride time; double support phase; gait speed; stride width variability (SD); stride time variability (SD).
Lee & Kerrigan, 1999	Exclusion criteria: musculoskeletal, neurological, or cardiac diseases. Definition of fall: event that results in a subject coming to rest inadvertently on the ground or other lower level.	Community-dwelling elderly: 15 fallers (≥ 2 falls in past 6 months; 7 males; 77.0±9.0 years); 15 non-fallers (8 males; 75.0±5.0 years).	Subjects walked barefoot or with their shoes at a preferred gait speed across a 30-foot walkway. Kinematic data (using a 4-camera optoelectronic motion analysis system at 100 Hz) and ground reaction forces (using 2 force plates) were collected during 3 trials.	Gait speed (m/s): 0.41 *vs*. 0.82; cadence (steps/s): 86 *vs*. 111; step length (m): 0.24 *vs*. 0.40; hip flexion moment (Nm/kg): 0.96 *vs*. 0.44; hip adduction moment (Nm/kg): 1.49 *vs*. 0.69; knee varus moment (Nm/kg): 0.86 *vs*. 0.33; knee extension moment (Nm/kg): 0.40 *vs*. 0.21; ankle dorsiflexion moment (Nm/kg): 1.59 *vs*. 0.91; ankle plantarflexion moment (Nm/kg): 0.075 *vs*. 0.139; ankle eversion moment (Nm/kg): 0.43 *vs*. 0.13; knee power absorption (W/kg): 0.98 *vs*. 1.66; ankle power absorption (W/kg): 0.76 *vs*. 0.41.	Hip extension moment (Nm/kg): 0.67 *vs*. 0.74; knee flexion moment (Nm/kg): 0.59 *vs*. 0.46; ankle inversion moment (Nm/kg): 014 *vs*. 0.07; hip power generation (W/kg): 1.23 *vs*. 1.18; knee power generation (W/kg): 0.54 *vs*. 0.55; ankle power generation (W/kg): 2.03 *vs*. 2.04; hip power absorption (W/kg): 0.44 *vs*. 0.61.

Table 1. Cont.

Study	Inclusion and/or exclusion criteria Definition of fall	Sample characteristics	Gait assessment	Gait parameters related to falls (fallers *vs* non-fallers)	Gait parameters not related to falls (fallers *vs* non-fallers)
Nelson et al., 1999	Inclusion criteria: independent subjects. Definition of fall: not reported.	Community-dwelling elderly: 11 fallers (1 male; 79.4±8.7 years); 13 non-fallers (4 males; 80.1±6.0 years).	Subjects walked on an electronic walkway at their preferred gait speed and completed 4 trials.	Gait speed (m/s): 0.82 *vs*. 1.25; left and right step times (s): 0.61 *vs*. 0.53, 0.60 *vs*. 0.52; left and right heel to heel base of support (cm): 12.5 *vs*. 9.7, 12.4 *vs*. 9.6; left and right double support phase (%): 35.0 *vs*. 26.0, 34.0 *vs*. 26.0.	
Wall et al., 2000	Exclusion and inclusion criteria: not reported. Definition of fall: not reported.	Community-dwelling elderly: 10 fallers (≥ 2 falls in past 2 years; 75.8±9.3 years); 10 non-fallers (72.7±4.0 years).	Gait was assessed during an expanded Timed Up and Go test. A 10 m walkway was used. A stopwatch recorded the intervals between each phase.	Front walk: gait speed (m/s): 0.81 *vs*. 1.23. Return walk: gait speed (m/s): 0.78 *vs*. 1.23.	
Hausdorff et al., 2001	Exclusion criteria: unable to follow simple instructions; nursing home residents; life expectancy of less than 1 year. Definition of fall: not reported.	Community-dwelling elderly (16 males; 80.3±5.9 years): 20 fallers (≥ 1 fall in 1-year follow-up). 32 non-fallers.	Subjects walked at their preferred gait speed for up to 6 min, wearing force-sensitive insoles that measured the gait rhythm on a stride-to-stride basis.	Stride time variability (SD; s): 0.11 *vs*. 0.05; swing time variability (SD; s): 0.04 *vs*. 0.03.	Gait speed (m/s): 0.71 *vs*. 0.91 (statistical tendency for difference, p = 0.078).

Table 1. Cont.

Study	Inclusion and/or exclusion criteria Definition of fall	Sample characteristics	Gait assessment	Gait parameters related to falls (fallers *vs* non-fallers)	Gait parameters not related to falls (fallers *vs* non-fallers)
Kerrigan et al., 2000 Kerrigan et al., 2001	Exclusion criteria: acute medical illness; diagnosis or symptoms of unstable angina or congestive heart failure; pulmonary disease diagnosis or symptoms; neurologic disorders that impair mobility; major orthopedic diagnosis in the lower back, pelvis, or lower extremities; active joint or musculoskeletal pain. Additional exclusion criteria for fallers falls secondary to syncope, acute illness, or other specific causes including metabolic disorders, medication side effects, true vertigo, or neurologic or lower extremity orthopedic diagnoses. Definition of fall: event that results in a subject coming to rest inadvertently on the ground or other lower level.	Community-dwelling elderly: 16 fallers (≥ 2 falls in last 6 months; 8 males; 77.0±7.8 years); 23 non-fallers (10 males; 73.2±5.6 years).	Subjects walked barefoot at their preferred and fast gait speed across a 10 m walkway. Kinematic data were collected during 3 trials using an optoelectronic motion analysis system at 100 Hz and ground reaction forces using 2 force plates.	Preferred gait speed: gait speed (m/s): 0.89 *vs.* 1.21; stride length (m): 0.98 *vs.* 1.22; hip flexion moment (Nm/kg): 0.53 *vs.* 0.38; hip extension moment (Nm/kg): 0.22 *vs.* 0.54; hip power absorption (W/kg): 0.13 *vs.* 0.40; hip power generation during pre-swing (W/kg): 0.43 *vs.* 0.92; hip adduction moment (Nm/kg): 0.47 *vs.* 0.57; knee flexion moment during mid-stance (Nm/kg): 0.15 *vs.* 0.27; knee flexion moment during pre-swing (Nm/kg): 0.07 *vs.* 0.24; knee power absorption during pre-swing (W/kg): 0.31 *vs.* 1.29; ankle power generation during pre-swing (W/kg): 1.10 *vs.* 1.74; hip extension (◦): 11 vs. 14. Fast gait speed: gait speed (m/s): 1.34 *vs.* 1.57; stride length (m): 1.17 *vs.* 1.34; hip extension (◦): 12 *vs.* 14.	Preferred speed: cadence (steps/min): 107 *vs.* 120; hip flexion moment during swing (Nm/kg): 0.08 *vs.* 0.11; hip power generation during loading response (W/kg): 0.50 *vs.* 0.50; hip abduction moment (Nm/kg): 0.08 *vs.* 0.07; hip internal rotation moment (Nm/kg): 0.14 *vs.* 0.14; hip external rotation moment (Nm/kg): 0.09 *vs.* 0.12; knee extension moment during terminal stance (Nm/kg): 0.16 *vs.* 0.16; knee power absorption during loading response (W/kg): 0.14 *vs.* 0.27; knee power generation during mid-stance (W/kg): 0.25 *vs.* 0.35; knee varus moment (Nm/kg): 0.25 *vs.* 0.27; knee valgus moment (Nm/kg): 0.02 *vs.* 0.02; knee internal rotation moment (Nm/kg): 0.14 *vs.* 0.13; knee external rotation moment (Nm/kg): 0.10 *vs.* 0.11; ankle plantarflexion moment (Nm/kg): 0.06 *vs.* 0.09; ankle dorsiflexion moment (Nm/kg): 0.73 *vs.* 0.75; ankle power absorption (W/kg): 0.43 *vs.* 0.44; ankle inversion moment (Nm/kg): 0.02 *vs.* 0.05; ankle eversion moment (Nm/kg): 0.18 *vs.* 0.11; ankle internal rotation moment (Nm/kg): 0.17 *vs.* 0.16; ankle external rotation moment (Nm/kg): 0.09 *vs.* 0.09; hip flexion (◦): 21 *vs.* 26; knee flexion during stance (◦): 11 *vs.* 17; knee extension during stance (◦): 2 *vs.* 2; knee flexion during swing (◦): 52 *vs.* 58; knee extension during swing (◦): 2 *vs.* 3; ankle plantarflexion during initial stance (◦): 8 *vs.* 8; ankle dorsiflexion during mid-stance (◦): 8 *vs.* 9; ankle plantarflexion (◦): 14 *vs.* 15; ankle dorsiflexion during swing (◦): 2 *vs.* 2; peak anterior pelvic tilt (◦): 3 *vs.* 3. Fast gait speed: cadence (steps/min): 138 *vs.* 140; hip flexion (◦): 25 *vs.* 30; knee flexion during stance (◦): 16 *vs.* 21; knee extension during stance (◦): 3 *vs.* 2; knee flexion during swing (◦): 55 *vs.* 61; knee extension during swing (◦): 3 *vs.* 6; ankle plantarflexion initial during stance (◦): 8 *vs.* 7; ankle dorsiflexion during mid-stance (◦): 6 *vs.* 7; ankle plantarflexion (◦): 14 *vs.* 16; ankle dorsiflexion during swing (◦): 1 *vs.* 2; peak anterior pelvic tilt (◦): 4 *vs.* 4.

Table 1. Cont.

Study	Inclusion and/or exclusion criteria Definition of fall	Sample characteristics	Gait assessment	Gait parameters related to falls (fallers *vs* non-fallers)	Gait parameters not related to falls (fallers *vs* non-fallers)
Kemoun et al., 2002	Exclusion and inclusion criteria: not reported. Definition of fall: unexpected event when a subject falls to the ground from the same or an upper level (including falls on stairs and onto a piece of furniture).	Community-dwelling elderly (66.7±4.8 years): 16 fallers (≥ 1 fall in 1-year follow-up; 12 males); 38 non-fallers (26 males).	Subjects walked barefoot at their preferred gait speed across a 10 m walkway. Kinematic data were collected during 5 trials using a 5-camera optoelectronic motion analysis system at 50 Hz and ground reaction force using two integrated force platforms at 250 Hz.	Gait speed (m/s): 0.96 *vs*. 1.29; double support phase (%): 27.8 *vs*. 23.2; ankle moment peak (Nm/kg): 25 *vs*. 23; ankle plantarflexion during second double support (∘): 19 *vs*. 23; ankle dorsiflexion at beginning of swing (∘): 7 *vs*. 13; hip power variation (W/kg): 1.02 *vs*. 2.04; hip moment peak (Nm/kg): −0.54 *vs*. −0.97; hip moment variation (Nm/kg): 0.88 *vs*. 1.60; hip displacement (∘): 40 *vs*. 47.	Cadence (step/min): 99 *vs*. 108 (statistical tendency for difference, p = 0.059); stride length (m): 1.12 *vs*. 1.31; step length (m): 0.57 *vs*. 0.65; stride time (s): 1.20 *vs*. 1.11 (statistical tendency for difference, p = 0.058); single support phase (%): 37 *vs*. 38.2; step time (%): 49.3 *vs*. 50.0; single support start (%): 13.5 *vs*. 13.6; double support start (%): 50.7 *vs*. 50.0; swing start (%): 64.6 *vs*. 62.1 (statistical tendency for difference, p = 0.077); ankle power peak (W/kg): 2.5 *vs*. 3.1; ankle moment peak (Nm/kg): 1.58 *vs*. 1.54; knee power peak (W/kg): −0.81 *vs*. −1.35; knee power variation (W/kg): 0.91 *vs*. 1.42; knee moment peak (Nm/kg): −0.17 *vs*. −0.04; knee moment variation (Nm/kg): 0.74 *vs*. 0.74; knee position peak (∘): 62 *vs*. 63; knee displacement (∘): 50 *vs*. 52; hip power peak (W/kg): −0.93 *vs*. −1.23; hip position peak (∘): 57 *vs*. 61.
Auvinet et al., 2003	Inclusion criteria (fallers): recently hospitalized due to falls; living at home; no pelvic or leg length asymmetries. Inclusion criteria (non-fallers): no history of musculoskeletal, neurological, or gait disorder; living at home; no marked pelvic asymmetry or leg length differences. Definition of fall: not reported.	Community-dwelling elderly: 20 fallers (≥ 1 fall in past year; 2 males; 80.7±5.2 years). 33 non-fallers (18 males; 77.2 ± 6.5 years).	Subjects walked at their preferred gait speed across a 10 m walkway using their own shoes. Gait parameters were collected using an accelerometer sensor system (50 Hz).	Gait speed (m/s): 0.73 *vs*. 1.24; stride length (m): 0.86 *vs*. 1.28; stride frequency-cadence (Hz): 0.86 *vs*. 0.97; stride symmetry: 173 vs. 211.	
Mbourou et al., 2003	Exclusion criteria: Parkinson's disease; Alzheimer's disease. Inclusion criteria (fallers): living in a nursing home. Definition of fall: not reported.	Elderly: 9 fallers (≥ 1 fall in past year; mean age 80.0 years, range 74.0–91.0); 8 non-fallers (mean age 73.0 years, range 66.0–82.0).	Subjects were asked to initiate gait and walk at least 3 strides. The length of the first step and subsequent strides were collected using transducers. Gait parameters were derived from the displacement signal obtained from each foot. More than 10 trials were collected.	First step length (m): 0.30 *vs*. 0.53; first step length variability (SD; m): 0.13 *vs*. 0.06; first double support phase (%): 32 *vs*. 22; second stride length (m): 0.68 *vs*. 0.92; second stride length variability (SD; m): 0.10 *vs*. 0.05; double support phase for subsequent strides (%): 37 *vs*. 32.	

Table 1. Cont.

Study	Inclusion and/or exclusion criteria Definition of fall	Sample characteristics	Gait assessment	Gait parameters related to falls (fallers *vs* non-fallers)	Gait parameters not related to falls (fallers *vs* non-fallers)
Pijnappels et al., 2005	Exclusion and inclusion criteria: not reported. Definition of fall: when the vertical force in the ropes exceeded 200 N during trials that one obstacle appeared from the ground unexpectedly to catch the subject's swing limb.	Community-dwelling elderly: 7 fallers (when the vertical force in the ropes exceeded 200 N during trip trials; 1 male; 67.9 ± 2.6 years). 4 non-fallers (3 males; 66.5 ± 3.3 years).	Subjects walked at preferred gait speed over a platform. Kinematic and ground reaction force data were collected using a 4-camera optoelectronic motion analysis system and a force plate (100 Hz).		Stance time; double support time.
Chiba et al., 2005	Exclusion criteria: Mini-Mental Status Examination score < 24; arthritis in lower limbs; back, knee, or hip chronic pain; Parkinson's disease; Ménière's syndrome; cerebellar signs; peripheral neuropathy under standard neuropsychological assessment. Inclusion criteria: being medically stable; comprehending the nature of the study and our instructions; being able to stand up and walk independently without a assistance device. Definition of fall: a sudden unintentional change in position causing a subject to land at a lower level or ground.	Community-dwelling elderly: 25 fallers (≥ 2 falls in past year; 11 males; 76.0±6.6 years). 31 non-fallers (11 males; 74.9±7.2 years).	Subjects walked barefoot or with their own shoes on a 6 m walkway. During 2 continuous trials, kinematic data were collected using a 5-camera optoelectronic motion analysis system (60 Hz). MTC was analyzed.	Gait speed (m/s): 0.66 *vs.* 0.99; stride length (m): 0.77 *vs.* 1.06; stride time (s): 1.20 *vs.* 1.08; MTC (mm): 12.0 *vs.* 15.2; MTC variability (CV; %): 29 *vs.* 25; maximum foot angle with ground (◦): 7.4 *vs.* 14.3; variability in the maximum foot angle with ground (CV; %): 34 *vs.* 19; maximal ML displacement of trunk center (mm): 0.23 *vs.* 0.18; variability in the maximal ML displacement of trunk center (CV; %): 6 *vs.* 1.	
Barak et al., 2006	Exclusion criteria: cardiopulmonary, musculoskeletal, somatosensory, or neurological disorders; severe visual and vestibular loss. Definition of fall: not reported.	Community-dwelling elderly: 21 fallers (≥ 1 fall in last 6 months; 8 males; 73.8±6.4 years). 27 non-fallers (14 males; 72.1±4.9 years).	Subjects walked at their preferred gait speed; treadmill speed was gradually increased from 0.18 m/s to 1.52 m/s in steps of 0.225 m/s and then decreased. During 1 min in each step, kinematic data were collected using an optoelectronic motion analysis system (100 Hz). CoM was calculated.	Effects of gait speed: cadence: in all gait speeds; stride length: only in 1.3 m/s gait speed; CoM lateral sway: from 1.07 m/s gait speed; ankle plantarflexion: from 1.07 m/s gait speed; hip extension: from 0.85 m/s gait speed; hip flexion: from 0.85 m/s gait speed; hip flexion variability: only in 1.52 m/s gait speed. Effects of stride frequency: stride length: in 1.1 and 1.2 stride frequencies; lateral body sway: in 0.6–1.1 stride frequencies; hip extension: in 0.5–1.0 stride frequencies; hip extension variability: in 0.9–1.2 stride frequencies; hip flexion: in 1.0 stride frequency; hip flexion variability: in 0.9–1.2 stride frequency.	Effects of stride frequency: ankle plantarflexion.

Table 1. Cont.

Study	Inclusion and/or exclusion criteria Definition of fall	Sample characteristics	Gait assessment	Gait parameters related to falls (fallers *vs* non-fallers)	Gait parameters not related to falls (fallers *vs* non-fallers)
Toulotte et al., 2006	Exclusion criteria: lower limb fracture or surgery; use of walking aid or foot orthosis; cognitive disorders; auditory, ocular, or vestibular problems; head trauma with/without loss of consciousness; stroke; carpal tunnel syndrome; sores on lower limbs or corns. Inclusion criteria: ≥60 years; stable medical treatment (for at least 3 months). Definition of fall: any event that led to an unplanned contact with a supporting surface.	Community-dwelling elderly women: 21 fallers (≥ 1 fall in past 2 years; 70.4±6.4 years). 19 non-fallers (67.0±4.8 years).	Subjects walked at preferred gait speed across a 10 m walkway. During 10 trials, kinematic data were collected using an optoelectronic motion analysis system (50 Hz) and three force plates (250 Hz).		Cadence (steps/min): 116 *vs.* 119; gait speed (m/s): 1.08 *vs.* 1.12; stride time (s): 1.04 *vs.* 1.02; step time (s): 0.53 *vs.* 0.51; single support time (s): 0.48 *vs.* 0.48; stride length (m): 1.13 *vs.* 1.09; step length (m): 0.56 *vs.* 0.60.
Karmakar et al., 2007 Karmakar et al., 2012	Exclusion and inclusion criteria: not reported. Definition of fall: not reported.	Community-dwelling elderly women: 10 fallers (≥ 1 fall in past year; 72.2±3.1 years). 27 non-fallers (69.1±5.1 years).	Subjects walked on a treadmill at preferred gait speed. During the first 500 continuous gait cycles, MTC data were collected using a 2D motion analysis system and analyzed by an ApEn and a SampEn. ApEn was calculated with m = 3 and r from 0 to 90% of the calculated SD. SampEn was calculated with m varying from 2 to 4 and r from 0 to 90% of the calculated SD.	Gait speed (m/s): 0.91 *vs.* 1.29; MTC (cm): 2.02 *vs.* 1.25; MTC variability (SD; cm): 0.47 *vs.* 0.32. For $r < 0.26 * SD$, the mean MTC ApEn of fallers was higher than non-fallers. For $r \geq 0.26 * SD$, the mean MTC ApEn of fallers was smaller than non-fallers. MTC SampEn values of fallers were lower compared to non-fallers for all m and r.	
Newstead et al., 2007	Exclusion criteria: neurological or orthopedic conditions. Inclusion criteria: ≥ 60 years; be able to walk 1-mile nonstop; free of neurological or orthopedic impairments. Definition of fall: not reported.	Community-dwelling elderly: 18 fallers (≥ 1 fall in past year; 3 males; 78.1±7.2 years). 30 non-fallers (6 males; 75.8±5.1 years).	Subjects walked 5–7 trials at three different gait speeds (slow, preferred, and fast) across a 10 m walkway using laced walking shoes. Spatiotemporal data were collected using a 6-camera optoelectronic motion analysis system (60 Hz) and four force plates (250 Hz).	Preferred gait speed: gait speed (lower fallers); cadence (lower fallers); step length (lower fallers); stride length (lower fallers); single support time (lower fallers); double support time (higher fallers). Fast gait speed: stride length (lower fallers); cadence (lower fallers); gait speed (lower fallers).	Slow gait speed: gait speed; cadence; step length; stride length; single support time; double support time. Fast gait speed: step length; single support time; double support time.

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Study	Inclusion and/or exclusion criteria Definition of fall	Sample characteristics	Gait assessment	Gait parameters related to falls (fallers *vs* non-fallers)	Gait parameters not related to falls (fallers *vs* non-fallers)
Barrett et al., 2008	Exclusion criteria: limited pulmonary and cardiac function; use of pacemakers; cognitive impairment. Inclusion criteria: independent ambulation for at least 6 meters. Definition of fall: subject who had fallen from vertical to horizontal.	Community-dwelling elderly: 9 fallers (≥ 2 falls in past year; 5 males; 76.0±5.0 years). 10 non-fallers (5 males 69.0±5.0 years).	Subjects walked at preferred gait speed over a 6 m walkway. Gait events were detected using footswitches embedded in the left shoe. Three walks were recorded for analysis.	Stance time (higher fallers); stride time (higher fallers); stance phase (higher fallers); stance time variability (SD; higher fallers); stride time variability (SD; higher fallers).	Swing time; swing time variability (SD)
Khandoker et al., 2008a	Exclusion and inclusion criteria: not reported. Definition of fall: not reported.	Community-dwelling elderly: 10 fallers (≥1 fall; 72.2 ± 3.1 years). 14 non-fallers (71.0 ± 2.1 years).	Subjects walked 10–20 min on the treadmill. MTC data were collected using a 2D motion analysis system (50 Hz) and analyzed by ApEn and Poincaré Plot Indexes. ApEn was calculated with m = 3 and r from 0 to 90%. SampEn was calculated with m varying from 2 to 3 and r from 15%.	MTC ApEn values: 0.18 *vs*. 0.13; MFC variability (SD; cm): 0.48 *vs*. 0.35; Poincaré width: 0.72 *vs*. 0.51; Poincaré length: 1.15 *vs*. 0.89.	MFC (cm): 2.01 *vs*. 1.65; Poincaré width/Poincaré length: 0.64 *vs*. 0.64.
Khandoker et al., 2008b	Exclusion and inclusion criteria: not reported. Definition of fall: not reported.	Community-dwelling elderly women: 10 fallers (≥ 1 fall in past year; 72.2±3.1 years). 27 non-fallers (69.1±5.1 years).	Subjects walked 10 min on a treadmill at preferred gait speed. MTC data were collected using a 2D motion analysis system (50 Hz). The following variability indices were quantified: Poincaré plot indices (SD1, SD2, SD1/SD2); wavelet-based multiscale exponent; and detrended fluctuation analysis exponent to investigate the presence of long-range correlations in MTC time series.	MTC (cm): 2.02 *vs*. 1.25. Wavelet-based multiscale exponent, SD1/SD2, and SD2 of critical MTC parameters were found to be potential markers to be able to reliably identify fallers from non-fallers.	

Table 1. Cont.

Study	Inclusion and/or exclusion criteria Definition of fall	Sample characteristics	Gait assessment	Gait parameters related to falls (fallers *vs* non-fallers)	Gait parameters not related to falls (fallers *vs* non-fallers)
Lockhart & Liu, 2008	Exclusion and inclusion criteria: not reported. Definition of fall: not reported.	Community-dwelling elderly: 4 fallers (≥ 1 fall in past 6 months; 70.1±3.0 years). 4 non-fallers (71.3±6.5 years).	Subjects walked for 1 min on a treadmill at their preferred gait speed. One dual-axial accelerometer was placed on the right anterior superior iliac spine (125 Hz). Maximum Lyapunov exponent was used to analyze these data. Two infrared-reflective markers were placed bilaterally on the heels for kinematic capture with a 6-camera optoelectronic motion analysis system (120 Hz).	Maximum Lyapunov exponent: 2.39 *vs*. 1.99; step length (m): 0.33 *vs*. 0.60; gait speed (m/s): 0.57 *vs*. 1.16.	Heel contact velocity (m/s): 0.32 *vs*. 0.43; step duration (s): 1.19 *vs*. 1.04.
Verghese et al., 2009	Exclusion criteria: severe audiovisual loss; bed bound due to illness; institutionalization. Definition of fall: unintentionally coming down on the floor or to a lower level, not due to a major intrinsic or extrinsic event.	Community-dwelling elderly (227 males; mean age 80.6 years): 226 fallers (115 fell once and 111 had recurrent falls; mean age 81.1 years). 371 non-fallers (mean age 80.1 years).	Subjects walked at preferred gait speed during 2 trials on a computerized walkway with embedded pressure sensors using comfortable footwear. Generalized estimating equations with a binomial distribution to model the probability of fall.	Slower gait speed (risk ratio per 10 cm/s decrease 1.069, 95% confidence interval: 1.001–1.142) is associated with a higher risk of falls. Predicted fall risk: swing phase (RR 1.406, 95% confidence interval 1.027–1.926); double-support phase (RR 1.165, 95% confidence interval: 1.026–1.321); swing time variability–CV (RR 1.007, 95% confidence interval: 1.004–1.010); stride length variability–CV (RR 1.076, 95% confidence interval: 1.030–1.111).	
Greany & Di Fabio, 2010	Inclusion criteria: ≥ 70 years; living home; walk at least 30 feet without stopping; Mini Mental Status Examination score > 23; corrected visual acuity of at least 20/70; peripheral visual field of 30°. Definition of fall: unintentionally coming to rest on ground.	Community-dwelling elderly: 12 fallers (≥ 1 fall in past year; 3 males, 86.0±4.8 years). 21 non-fallers (7 males, 81.0±5.0 years).	Subjects walked quickly but safely along a walkway of four irregularly spaced stepping targets. During 6 trials, a video-based motion analysis system was used for collecting kinematic data.		Maximum foot AP velocity (m/s): 1.91 *vs*. 2.05; maximum foot vertical velocity (m/s): 0.54 *vs*. 0.53; average foot AP velocity (m/s): 0.36 *vs*. 0.36; step time (s): 1.64 *vs*. 1.51; step length (m): 0.76 *vs*. 0.83; swing time (s): 0.67 *vs*. 0.68; double support time (s): 0.45 *vs*. 0.35.

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Study	Inclusion and/or exclusion criteria Definition of fall	Sample characteristics	Gait assessment	Gait parameters related to falls (fallers *vs* non-fallers)	Gait parameters not related to falls (fallers *vs* non-fallers)
Greene et al., 2010	Inclusion criteria: ≥ 60 years; able to walk independently with or without help; able to provide informed consent. Definition of fall: unexpected loss of stability resulting in coming to rest on the floor or an object below the knee level.	Community-dwelling elderly: 207 fallers (≥ 1 fall in past 5 years; 44 males; 74.0±7.3 years). 142 non-fallers (59 males; 71.1±6.9 years).	Gait was assessed during the Timed Up and Go test through two wearable tri-axial accelerometer sensors placed on each shank.	Cadence (steps/min): 99 *vs*. 108; double support (s): 0.4 *vs*. 0.5; step time (s): 0.7 *vs*. 0.6; minimum shank ML angular velocity (lower fallers); mean shank ML angular velocity (lower fallers); maximum shank ML angular velocity (lower fallers); minimum shank AP angular velocity (lower fallers); mean shank AP angular velocity (lower fallers); maximum shank AP angular velocity (lower fallers).	Stance time (s): 0.8 *vs*. 0.8; single support time (s): 0.8 *vs*. 0.8; stride time (s): 1.2 *vs*. 1.2; swing time (s): 0.5 *vs*. 0.5; single support time variability (CV; %): 22.9 *vs*. 21.1; double support variability (CV; %): 80.7 *vs*. 82.6; swing time variability (CV; s): 28.1 *vs*. 31.0; stride time variability (CV; s): 24.0 *vs*. 23.4; step time variability (CV; s): 42.0 *vs*. 40.3; stance time variability (CV; s): 43.3 *vs*. 45.0.
Mickle et al., 2010	Inclusion criteria: ≥ 60 years; living independently in community; passed the Short Portable Mental Status Questionnaire; able to ambulate for at least 10 m with or without aid; no neurological diseases; own transport to a testing venue in community. Definition of fall: unintentionally coming to rest on ground or other lower level, not as result of a major intrinsic event (e.g., stroke).	Community-dwelling elderly: 107 fallers (≥ 1 fall in 1-year follow-up; 49 males; 71.6 years). 196 non-fallers (105 males; 71.2 years).	Five trials were recorded with a two-step gait initiation protocol at a preferred walking speed. A pressure platform was used.	Peak pressure (KPa): 776 *vs*. 699; pressure–time integral (KPa): 349 *vs*. 311.	
Bhatt et al., 2011	Exclusion criteria: Folstein Mini-Mental Status Examination score < 25; classified as osteopenic or osteoporotic. Definition of fall: if the force recorded on the safety harness load cell force exceeded 30% of the body weight.	Community-dwelling elderly (44 males): 59 fallers (the force recorded on the safety harness load cell force exceeded 30% of the body weight; 71.6±4.6 years). 56 recovers (71.4±5.1 years).	Subjects walked for 9–12 trials on a 7 m walkway using their own athletic shoes. Kinematic and ground reaction force data were collected during 5 trials using an 8-camera optoelectronic motion analysis system (120 Hz) and one force platform (600 Hz).		Absolute CoM velocity (m/s): 0.95 *vs*. 1.0; step length (m): 0.34 *vs*. 0.34.
Kirkwood et al., 2011	Exclusion criteria: orthopedic or neurological diseases that could affect gait performance. Inclusion criteria: female; ≥ 60 years; ability to walk without assistance. Definition of fall: unexpected event in which a subject comes to rest on a lower level.	Community-dwelling elderly women: 45 fallers (≥ 2 falls in past 12 months; 74.0±5.6 years). 44 non-fallers (absence of falls or 1 fall in past 12 months; 70.7±5.4 years).	Subjects walked barefoot on a 6 m rubber mat while EMG recorded soleus, tibialis anterior, and gastrocnemius muscle signals. Footswitches tracked gait events.	Gastrocnemius activity during stance phase (%): 16.9 *vs*. 19.8; stride time (s): 1.2 *vs*. 1.3.	Tibialis anterior activity during stance phase (%): 9.2 *vs*. 9.3; soleus activity during stance phase (%): 22.1 *vs*. 24.9; gastrocnemius latency activity (s): 0.30 *vs*. 0.30; tibialis anterior latency activity (s): 0.04 *vs*. 0.03; soleus latency activity (s): 0.30 *vs*. 0.30; swing phase (%): 40.2 *vs*. 39.7; stance phase (%): 59.8 *vs*. 60.3.

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Study	Inclusion and/or exclusion criteria Definition of fall	Sample characteristics	Gait assessment	Gait parameters related to falls (fallers *vs* non-fallers)	Gait parameters not related to falls (fallers *vs* non-fallers)
Lázaro et al., 2011	Exclusion criteria: ≥ 65 years; severe cognitive deterioration; unable to stand; terminal ill. Inclusion criteria (fallers): had visited their General Practitioner or Geriatrician due to the occurrence of falls. Definition of fall: not reported.	Community-dwelling elderly: 99 fallers (≥ 2 falls in past 6 months; 17 males; 78.0±5.0 years). 113 non-fallers (no falls in past 6 months)	Gait assessments of subjects were evaluated using the Walk Across test.	Gait speed (m/s): 0.34 *vs*. 0.50.	
Lugade et al., 2011	Inclusion criteria: no history of head trauma, neurological or heart diseases; muscle, joint, or orthopedic disorder; visual impairment that was uncorrected by glasses; persistent vertigo; lightheadedness. Definition of fall: not reported.	Community-dwelling elderly: 10 fallers (≥ 1 fall in past year; 78.9±4.9 years). 10 non-fallers (75.4±7.0 years).	Subjects walked barefoot at preferred gait speed along a 10 m walkway. Kinematic and ground reaction force data were collected during 5 trials using an 8-camera optoelectronic motion analysis system (60 Hz) and two integrated force platforms. CoM and CoP data were calculated.	Gait speed (m/s): 1.02 *vs*. 1.26; CoM–CoP AP distance at heel strike (cm): 41.6 *vs*. 52.4.	At heel strike (CoM inside base of support): CoM stability margin (cm): 3.9 *vs*. 3.5; distance to centroid (cm): 2.5 *vs*. 2.2; interaction of the CoM position and velocity distance to border (cm): 17.5 *vs*. 18.7; time to contact (s): 0.17 *vs*. 0.15; base of support (m^2): 0.40 *vs*. 0.43. At toe-off (CoM outside base of support): CoM separation (cm): 8.3 *vs*. 10.4; distance to centroid (cm): 21.4 *vs*. 23.4; time to contact (s): 0.12 *vs*. 0.11; base of support area (m^2): 0.23 *vs*. 0.22; CoM–CoP ML distance at heel strike (cm): 6.6 *vs*. 7.3.
Panzer et al., 2011	Exclusion criteria: Mini Mental Status Examination score < 24; body mass index ≥30 kg/m^2; blindness; neurologic, orthopedic, or visual disorders that impair mobility; non-English speaking. Definition of fall: not reported.	Community-dwelling elderly: 47 fallers (≥ 2 non-injury falls or ≥ 1 injury fall in past year; 80.1±6.2 years). 27 non-fallers (75.1±6.5 years).	Two self-paced out and back walks (8.1 m) were performed; average gait speed was calculated, and the fastest performance was used.	Average gait speed (m/s): 0.64 *vs* 0.86.	
Scanaill et al., 2011	Exclusion and inclusion criteria: not reported. Definition of fall: not reported.	Community-dwelling elderly: 182 fallers (> 1 fall in past year or ≥ 1 fall that resulted in a loss of consciousness, a fractured bone, or severe injury in past year; 40 males; 74.5±7.2 years). 139 non-fallers (60 males; 70.3±6.8 years).	Subjects walked at a preferred gait speed along a 6 m pressure-sensing walkway. Two kinematic sensors were worn on the subject's shanks.	Stride length (m): 1.08 *vs*. 1.23; stride width (m): 0.12 *vs*. 0.11; step length (m): 0.54 *vs*. 0.61; step width (m): 0.56 *vs*. 0.63.	Stride time (s): 1.23 *vs*. 1.20; stance time (s): 0.81 *vs*. 0.79; swing time (s): 0.51 *vs*. 0.50; step time (s): 0.66 *vs*. 0.66; single support (%): 75.9 *vs*. 78.2; double support (%): 34.6 *vs*. 34.3. Variability (CV): stride length (%): 8.6 *vs*. 7.8; stride width (%): 25.0 *vs*. 25.3; step length (%): 14.1 *vs*. 12.7; step width (%): 12.4 *vs*. 10.6; base width (%): 24.7 *vs*. 25.3; stride time (%): 19.2 *vs*. 18.6; stance time (%): 30.3 *vs*. 33.0; swing time (%): 32.4 *vs*. 31.0; step time (%): 34.2 *vs*. 31.8; single support (%): 21.4 *vs*. 20.1; double support (%): 61.4 *vs*. 62.6.

Table 1. Cont.

Study	Inclusion and/or exclusion criteria Definition of fall	Sample characteristics	Gait assessment	Gait parameters related to falls (fallers *vs* non-fallers)	Gait parameters not related to falls (fallers *vs* non-fallers)
Uemura et al., 2012	Exclusion criteria: severe cardiac, pulmonary or musculoskeletal disorders; diseases associated with a high risk of falling; inability to execute arithmetic tasks; serious visual impairment not correctable with spectacles; inability to follow multiple commands. Inclusion criteria: ≥ 65 years; minimal hearing and visual impairments; ability to ambulate independently. Definition of fall: an event that a subject unintentionally comes to rest on the ground or another lower level; falls resulting from extraordinary environmental factors were excluded.	Community-dwelling elderly (65–93 years): 22 fallers (≥ 1 fall in past year). 35 non-fallers.	Subjects walked along a 2 m walkway as quickly as possible after a visual cue. CoP data were collected by force plate during 3 trials. Step initiation—first ML deviation of CoP towards swing leg. Reaction phase—time from cue to step initiation. Anticipatory postural adjustment phase—time from step initiation to foot-off.		Reaction phase (s): 0.31 *vs.* 0.29; anticipatory postural adjustment phase (s): 0.46 *vs.* 0.44.
Chen & Chou, 2013	Inclusion criteria: walk without an assistive device; no history of neurological or musculoskeletal deficits (e.g., amputation, cerebral vascular accident, significant head trauma or Parkinson's disease); no uncorrectable visual impairment, vestibular dysfunction, or dementia. Definition of fall: unexpected event where subject falls to ground from an upper level; falls caused by syncope or major intrinsic events were excluded.	Community-dwelling elderly: 15 fallers (≥ 2 falls in past year; 4 males; 77.7±7.7 years). 15 non-fallers (6 males; 76.2±4.2 years).	Subjects performed the Timed Up and Go test while barefoot. Kinematic and CoM data and ground reaction force were collected during 4 trials using a 10-camera optoelectronic motion analysis system (600 Hz) and one force platform (960 Hz).	Step length (m): 0.42 *vs.* 0.52; CoM AP velocity at stance-off (lower fallers); AP inclination of CoM–ankle at stance-off (◦): −2.4 *vs.* −6.8; total CoM kinetic energy at swing-off (J): 6.6 *vs.* 10.4; total CoM kinetic energy at stance-off (J): 20.6 *vs.* 31.9.	Step width (m): 0.23 *vs.* 0.21; CoM AP velocity at swing-off; AP inclination of CoM–ankle at swing-off (◦): 7.7 *vs.* 6.9.
Chen et al., 2013	Inclusion criteria: walk without an assistive device; no history of neurological or musculoskeletal deficits (e.g., amputation, cerebral vascular accident, significant head trauma or Parkinson's disease); no uncorrectable visual impairment, vestibular dysfunction, or dementia. Definition of fall: unexpected event where subject falls to ground from an upper level; falls caused by syncope or major intrinsic events were excluded.	Community-dwelling elderly: 10 fallers (≥ 2 falls in past year; 2 males; 75.9±4.1 years). 10 non-fallers (3 males; 75.5±3.0 years).	Subjects performed the Timed Up and Go test while barefoot. Kinematic and CoM data and ground reaction force were collected during 4 trials using a 10-camera optoelectronic motion analysis system (600 Hz) and one force platform (960 Hz).	Braking force (N/kg): −0.83 *vs.* −0.43 propulsive force (N/kg): 3.48 *vs.* 5.04; ankle moment at swing-off: 0.11 *vs.* −0.03.	Trunk angle (◦): 32.9 *vs.* 31.4; hip moment at swing-off (Nm/kg): 0.45 *vs.* 0.48; knee moment at swing-off (Nm/kg): 0.42 *vs.* 0.54.

Table 1. Cont.

Study	Inclusion and/or exclusion criteria Definition of fall	Sample characteristics	Gait assessment	Gait parameters related to falls (fallers *vs* non-fallers)	Gait parameters not related to falls (fallers *vs* non-fallers)
Chiu & Chou, 2013	Inclusion criteria: no current histories of neurological or musculoskeletal deficits that affect walking; no uncorrectable visual impairment, vestibular dysfunction, dementia, or depression. Definition of fall: not reported.	Community-dwelling elderly: 15 fallers (≥ 2 falls in past year; 3 males; 72.9±4.1 years). 15 non-fallers (8 males; 75.7±4.7 years).	Subjects walked barefoot along a 10 m walkway at preferred gait speed. Kinematic data were collected during 5 trials using a 10-camera optoelectronic motion analysis system (60 Hz). SD is used to analyze variability.	Gait speed (m/s): 1.07 *vs*. 1.22; stance phase (%): 62.6 *vs*. 60.9; swing phase (%): 37.4 *vs*. 39.1; single support (%): 37.4 *vs*. 39.0; double support (%): 25.2 *vs*. 21.9. Variability in inter-joint coordination during stance phase (SD): knee–ankle (higher fallers); ankle (higher fallers). Variability inter-joint coordination during swing phase (SD): knee–ankle (higher fallers).	Cadence (steps/min): 115 *vs*. 116. Variability inter-joint coordination during stance phase (SD): hip; knee; hip–knee. Variability inter-joint coordination during swing phase (SD): hip; knee; ankle; hip–knee.
Fritz et al., 2013	Exclusion criteria: orthopedic or neurologic conditions that altered walking. Inclusion criteria: capable of walking unassisted for more than 10 feet and understood the study's objective. Definition of fall: not reported.	Community-dwelling elderly: 12 fallers (≥ 1 fall in past 6 months; 86.3±4.7 years). 50 non-fallers (85.4±7.1 years).	Subjects walked during 3 trials at a preferred gait speed along a 6 m pressure-sensing walkway.	Gait speed (m/s): 0.89 *vs*. 1.0; stride length (m): 0.85 *vs*. 1.02.	Base of support (cm): 12.3 *vs*. 10.2; swing phase (%): 31.5 *vs*. 33.4; stance phase (%): 68.4 *vs*. 66.6; double support (%): 37 *vs*. 33; step time variability (CV): 7.3 *vs*. 6.4.
Weiss et al., 2013	Exclusion criteria: previously clinically diagnosed with any gait or balance disorders and Mini-Mental Status Examination score < 24. Definition of fall: any stability disturbance that caused significant contact with the floor.	Community-dwelling elderly: 32 fallers (≥ 2 fall in past year; 35% males; 77.9±5.1 years). 39 non-fallers (< 2 fall in past year; 36% males; 78.8±4.4 years).	Subjects walked for 1 min at preferred gait speed (laboratory assessments). A portable tri-axial accelerometer sensor (100 Hz) was worn on the lower back. Subjects also wore a portable accelerometer sensor (100 Hz) for 3 days.	Laboratory assessment: gait speed (m/s): 0.97 *vs*. 1.19; step duration (s): 0.55 *vs*. 0.52. 3-day assessment: step time; stride time. Fallers presented higher variability in the lower back vertical axis and lower variability in the lower back ML axis.	

Table 1. Cont.

Study	Inclusion and/or exclusion criteria Definition of fall	Sample characteristics	Gait assessment	Gait parameters related to falls (fallers *vs* non-fallers)	Gait parameters not related to falls (fallers *vs* non-fallers)
Marques et al., 2013a Marques et al., 2013b	Exclusion criteria: Mini-Mental Status Examination score < 20; cardiovascular disease; Berg balance scale score < 36; hemiparesis; pain of the lower limbs or trunk; progressive motor disorder. Definition of fall: any stability disturbance that caused significant contact with the floor.	Community-dwelling elderly women: 15 fallers (≥ 1 fall in past year; 69.6±8.0 years). 22 non-fallers (66.1±6.2 years).	Subjects walked at preferred gait speed for 1 min on a walkway and for 10 min on a treadmill. Gait kinematic parameters and EMG activity were assessed using a 7-camera optoelectronic motion analysis system (100 Hz) and an 8-channel telemetry EMG system (2000 Hz).	Hip position at toe-off (◦): 9.5 *vs*. 5.4; muscle activation at initial stance: biceps femoris (%): 36.4 *vs*. 24.1; muscle activation at final stance: gluteus maximus (%): 86.4 *vs*. 52.3; muscle activation before heel contact: internal oblique (%): 8.3 *vs*. 15.7; biceps femoris (%): 45.5 *vs*. 31.3.	Gait speed on walkway (m/s): 1.1 *vs*. 1.3; gait speed on treadmill (m/s): 0.9 *vs*. 0.9; step time (s): 0.23 *vs*. 0.26; step length (m): 0.51 *vs*. 0.50; step width (m): 0.14 *vs*. 0.17; ankle angular position at heel contact (◦): 6.4 *vs*. 5.9. Muscle activation at initial stance: internal oblique (%): 97.2 *vs*. 100.3; rectus femoris (%): 143.8 *vs*. 130.6; tibialis anterior (%): 106.7 *vs*. 122.8; multifidus (%): 150.5 *vs*. 147.7, gluteus maximus (%): 154.7 *vs*. 179.9. Muscle activation at final stance: internal oblique (%): 117.5 *vs*. 105.1; rectus femoris (%): 89.5 *vs*. 80.1, multifidus (%): 76.1 *vs*. 82.8; biceps femoris (%): 43.8 *vs*. 50.1; gastrocnemius lateralis (%): 91.7 *vs*. 75.8. Muscle activation before heel contact: rectus femoris (%): 12.7 *vs*. 15.2; tibialis anterior (%): 40.0 *vs*. 30.1; multifidus (%): 16.4 *vs*. 18.4; gluteus maximus (%): 12.0 *vs*. 16.8; gastrocnemius lateralis (%): 7.2 *vs*. 14.9. Muscle activation after toe-off: internal oblique (%): 21.6 *vs*. 20.5; rectus femoris (%): 10.9 *vs*. 15.9; tibialis anterior (%): 35.1 *vs*. 31.9; gluteus maximus (%): 6.8 *vs*. 10.1; biceps femoris (%): 16.2 *vs*. 13.1; gastrocnemius lateralis (%): 7.9 *vs*. 12.2
Ayoubi et al., 2014	Exclusion criteria: < 65 years; institutionalization; non–French-speaking; acute medical illness during past month; diagnosis of dementia; score > 2 on item 22 of Unified Parkinson's Disease Rating Scale; severe orthopedic diagnoses of lumbar vertebra, pelvis or lower extremities; inability to walk 6-m unassisted. Definition of fall: subject unintentionally coming to rest on ground or other lower level, and not as the result of a major intrinsic event.	Community-dwelling elderly: 109 fallers with a fear of falling (24 males; 71 ± 5.2 years). 101 fallers with no fear of falling (29 males; 70.8 ± 5.5 years). 194 non-fallers with fear of falling (83 males; 70.5 ± 5.0 years). 619 non-fallers with no fear of falling (368 males; 70.3 ± 4.8 years).	Subjects walked 1 trial at their preferred gait speed along a 6 m pressure-sensing walkway	Fallers with fear of falling vs. non-fallers with no fear of falling: gait speed (m/s): 0.96 *vs*. 1.11; stride time variability (CV; %): 3.0 *vs*. 2.0.	Fallers with no fear of falling *vs*. non-fallers with no fear of falling: gait speed (m/s) 1.07 *vs*. 1.11; stride time variability (CV; %): 2.0 *vs*. 2.0. Fallers with no fear of falling *vs*. non-fallers with fear of falling: gait speed (m/s) 1.07 *vs*. 1.03; stride time variability (CV; %): 2.0 *vs*. 3.0. Fallers with fear of falling *vs*. non-fallers with fear of falling: gait speed (m/s) 0.96 *vs*. 1.03; stride time variability (CV; %): 3.0 *vs*. 3.0.

Table 1. Cont.

Study	Inclusion and/or exclusion criteria Definition of fall	Sample characteristics	Gait assessment	Gait parameters related to falls (fallers *vs* non-fallers)	Gait parameters not related to falls (fallers *vs* non-fallers)
Barelle et al., 2014	Exclusion criteria: vascular stroke with motor or sensory aftereffects; Parkinson's disease; hip or knee prosthesis; fracture of leg or ankle which would have impaired gait. Definition of fall: not reported.	Community-dwelling elderly: 6 fallers (≥ 1 fall in past 6 months; 68.0±4.0 years). 6 non-fallers (2 males; 69.0±3.0 years).	Subjects walked at preferred gait speed on a 10 m walkway. Gait kinematic parameters were assessed using an 8-camera optoelectronic motion analysis system (100 Hz).		Stride and step length (m): 1.13 *vs*. 1.18; 0.57 *vs*. 0.59; stride length (% height): 70 *vs*. 74; cadence (strides/s): 0.87 *vs*. 0.92; cadence (steps/s): 1.73 *vs*. 1.84; step length (% height): 35 *vs*. 37; cycle time (s): 1.17 *vs*. 1.09; gait speed (m/s): 0.99 *vs*. 1.08; hip, knee, ankle displacements (◦): 21 *vs*. 21; 58 *vs*. 58; 38 *vs*. 37.
Iwata et al., 2014	Exclusion and inclusion criteria: not reported. Definition of fall: any unintended contact with a supporting surface.	Community-dwelling elderly: 28 fallers (≥ 1 fall in past year; 9 males; 76.0±5.3 years). 84 non-fallers (19 males; 73.5±6.1 years).	Maximum gait speed was measured using a floor-based photocell gait analysis system over a 5 m course.		Maximum gait speed (m/s): 1.8 *vs* 1.9.
Kobayashi et al., 2014	Inclusion criteria: walk independently; normal or corrected-to-normal vision; no history of neuromuscular disease. Definition of fall: not reported.	Community-dwelling elderly: 18 fallers (≥ 1 fall in past year; 67.3±3.1 years). 19 non-fallers (67.1±3.3 years).	Subjects walked at preferred gait speed on a 10 m walkway, during 5 trials. Gait kinematic and ground reaction force data were assessed using an optoelectronic motion analysis system (200 Hz) and six force platforms (1000 Hz). Principal component analysis was used to analyze the relationship between the risk of falling and the joint kinematics of the lower limbs. MTC was analyzed.	Gait speed (m/s): 1.21 *vs*. 1.33; stance time variability (SD; s): 0.014 *vs*. 0.009. Fallers exhibited greater variability in the hip, knee, and ankle in all planes during the entire swing phase. Fallers exhibited greater variability in the hip and ankle in the frontal plane during the entire stance phase. Fallers exhibited smaller hip flexion and ankle dorsiflexion angles between the mid-stance and late-stance phases. Fallers exhibited larger ankle inversion between the mid-stance and late-stance phases. Fallers exhibited smaller hip abduction during the mid-stance phase. Variability in the joint kinematics is the key characteristic that affects the risk of falling while walking.	MTC (cm): 4.30 *vs*. 4.24; step length (m): 0.63 *vs*. 0.67; step width (m): 0.10 *vs*. 0.09; stance time (s): 0.60 *vs*. 0.58; swing time (s): 0.41 *vs*. 0.41; stance phase (%): 64.8 *vs*. 63.9; MTC variability (SD; cm): 0.27 *vs*. 0.29; gait speed variability (SD; m/s): 0.04 *vs*. 0.03; step length variability (SD; m): 17.8 *vs*. 13.5; step width variability (SD; cm): 16.3 *vs*. 16.8; swing time variability (SD; s): 0.02 *vs*. 0.01; stance phase variability (SD; %): 0.90 *vs*. 0.76.

Table 1. Cont.

Study	Inclusion and/or exclusion criteria Definition of fall	Sample characteristics	Gait assessment	Gait parameters related to falls (fallers *vs* non-fallers)	Gait parameters not related to falls (fallers *vs* non-fallers)
König et al., 2014	Exclusion criteria: body mass index < 18 or > 33 kg/m²; alcoholism; type-1 diabetes; cardiac infarct; chronic hepatitis; celiac and mal-absorption diseases; rheumatoid arthritis; cancer; treated for more than 3 months or under treatment with oral corticosteroids; hyperparathyroidism; hyperthyroidism; neurological diseases affecting neuromuscular system; peripheral neurologic diseases; fractures, or osteosyntheses; total hip replacement (less than 6-months); unable to follow instructions or unable to walk 10-m without a walking aid; participation in another study at the same time. Definition of fall: not reported.	Community-dwelling elderly: 38 fallers (≥ 1 fall in past year; 69.2±4.8 years). 42 non-fallers (68.9±4.5 years).	Subjects walked barefoot at preferred gait speed on a 10 m walkway during 6 trials. Gait kinematic parameters were assessed using an optoelectronic motion analysis system (200 Hz). Principal component analysis was used.	Temporal variability and mean spatial gait parameters.	
Mignardot et al., 2014	Exclusion criteria: refusal or lack of capacity to give consent; hospitalized at the time of screening. Inclusion criteria: 66-75 years; living at home; never fallen; ability to walk without assistance for at least 30 s. Definition of fall: unintentionally fall on the ground or lower level, not as a result of a major intrinsic event (e.g., as a stroke) or overwhelming hazard.	Community-dwelling elderly: 72 fallers (≥ 1 fall in 2-years follow-up; 35 males; 71.1±2.7 years). 187 non-fallers (72 males; 69.4±2.5 years).	Subjects walked with their own shoes at preferred gait speed along a 30 m walkway. A tri-axial accelerometer sensor was used (100 Hz). Principal component analysis was used to assess the relationship between gait variables and fall status.	PC1—global kinetics of gait pattern (mechanical power and spatiotemporal variables): fallers (+0 to +6 months) differed from non-fallers and fallers (+6 to +12 months); PC1 had predictive power for the first fall onset during the first six months after the initial screening. PC2—global gait regularity: fallers (+6 to +12 months) differed from non-fallers (+0 to +6 months); PC2 had predictive power for the first fall onset between the 6th and 12th months after initial screening.	PC3—stride time: there was no significant difference between fallers and non-fallers on PC3; PC3 did not have any predictive power for the first fall onset.
Cebolla et al., 2015	Inclusion criteria: ≥ 60 years; able to perform activities of daily living and walk independently; no orthopedic problems (e.g., surgery or fractures) or other health problems that impair physical tests. Definition of fall: unintentionally coming to rest on the ground or other lower level, whether or not it produced an injury.	Community-dwelling elderly (13 males): 20 fallers (≥ 1 fall in past year; 68.0±6.9 years). 42 non-fallers (65.5±4.1 years).	Subjects walked at preferred gait speed on an 8 m walkway during 10 trials. Gait kinematic parameters were assessed using a 6-camera optoelectronic motion analysis system (100 Hz). MTC was analyzed.	MTC (mm): 40 *vs.* 43.	Stride length (m): 1.11 *vs.* 1.17; stride time (s): 1.07 *vs.* 1.08; cadence (strides/s): 0.93 *vs.* 0.93; gait speed (m/s): 1.04 *vs.* 1.08; heel vertical velocity at heel strike (m/s): 0.70 *vs.* 0.76.

Table 1. Cont.

Study	Inclusion and/or exclusion criteria Definition of fall	Sample characteristics	Gait assessment	Gait parameters related to falls (fallers *vs* non-fallers)	Gait parameters not related to falls (fallers *vs* non-fallers)
MacAulay et al., 2015	Exclusion criteria: Geriatric Depression Scale score ≥ 6; neurologic or untreated health disorders (e.g., cerebrovascular disease, Parkinson's disease, traumatic brain injury). Definition of fall: subject unexpectedly lost his stability and unintentionally came unto rest on the ground or other object; events in which participants were able to regain their stability did not count as a fall.	Community-dwelling elderly (128 males): 81 fallers (≥ 1 fall in past year; 69.9±6.8 years). 312 non-fallers (70.1±6.6 years).	Subjects walked at preferred gait speed along a 6 m pressure-sensing walkway. Four trials were collected.	Stride length (lower fallers).	Step time (s): 1.08 *vs* 1.08.
Rispens et al., 2015	Inclusion criteria: Mini Mental Status Examination score > 18; walk at least 20 m with a walking aid. Definition of fall: event that resulted in unintentionally coming to rest on the ground or other lower level.	Community-dwelling elderly (33 males; 78.4±7.8 years): 41 fallers (≥ 1 fall in past year). 69 non-fallers.	Subjects wear a portable tri-axial accelerometer sensor (100 Hz) for 2 separate weeks. It was attached with an elastic belt around the waist and set along the lumbar spine. Subjects were instructed to wear the accelerometer at all times, except during water activities. Intra-class correlation was used.	Gait speed; gait speed variability (SD); stride time; stride time variability (SD); gait symmetry (harmonic ratio); and gait smoothness (index of harmonicity) were associated with the number of falls in the past year.	Cadence variability (SD).
Wright et al., 2015	Inclusion criteria: able to walk at least 100 m without the use of a gait aid; no neurological disease, head trauma, musculoskeletal impairment or visual impairment not correctable by lenses. Definition of fall: a loss of balance resulting in the body, or part of the body, coming to rest on the ground.	Community-dwelling elderly: 14 "trip" fallers (≥ 1 trip fall in past year; 4 males; 71±6 years). 10 "slip" fallers (≥ 1 slip fall in past year; 4 males; 68±5 years). 16 non-fallers (6 males; 72±5 years).	Subjects walked at preferred gait speed along a walkway. Kinematic and ground reaction forces data were collected during 3 trials using a 14-camera optoelectronic motion analysis system (60 Hz) and two force platforms (120 Hz). CoM and CoP data were calculated.	Differences between fallers (both groups) and non-fallers: CoM–CoP at heel strike (cm): 14.3 *vs.* 15.3 vs. 12.0. Differences between "slip" fallers and non-fallers: CoM–CoP at foot flat (cm): −14.9 *vs.* −10.3. Differences between "trip" fallers and "slip" fallers: CoM–CoP at mid-swing (cm): 0.9 *vs.* 1.2.	"Trip" fallers *vs*. "slip" fallers *vs*. non-fallers: gait speed (m/s): 1.19 *vs*. 1.22 *vs*. 1.14; stride time (s): 1.06 *vs*. 1.10 *vs*. 1.10; stride length (m): 1.26 *vs*. 1.34 *vs*. 1.26; CoM–CoP at toe-off (cm): −15.1 *vs*. −16.5 *vs*. −14.3; CoM–CoP at late swing (cm): 13.4 *vs*. 13.2 *vs*. 11.0; peak braking force (% body mass): −15.9 *vs*. −16.5 *vs*. −15.1; instant of peak braking force (% gait cycle): 10.8 *vs*. 11.2 *vs*. 10.9; peak propulsive force (% body mass): 17.3 *vs*. 19.3 *vs*. 17.1; instant of peak propulsive force (% gait cycle): 54.0 *vs*. 54.1 *vs*. 54.3.

Table 1. Cont.

Study	Inclusion and/or exclusion criteria Definition of fall	Sample characteristics	Gait assessment	Gait parameters related to falls (fallers *vs* non-fallers)	Gait parameters not related to falls (fallers *vs* non-fallers)
Bounyong et al., 2016	Exclusion and inclusion criteria: not reported. Definition of fall: not reported.	Community-dwelling elderly (8 males; 72.3±6.1 years): 17 fallers (≥ 1 fall in past year). 35 non-fallers	Subjects walked 6 trials at preferred gait speed along a 5 m walkway. EMG of rectus femoris, biceps femoris, tibialis anterior, and gastrocnemius were collected (1024 Hz). Co-contraction index was determined based on EMG.	Co-contraction index (between tibialis anterior and gastrocnemius) during stance phase (%): 61.8 *vs*. 57.5.	
Fujimoto & Chou, 2016	Inclusion criteria: no history or clinical evidence of neurological, musculoskeletal or other medical conditions (neurological pathology, head trauma, cerebrovascular accident, vestibular dysfunction, or visual impairment uncorrectable by lenses). Definition of fall: not reported.	Community-dwelling elderly: 15 fallers (≥ 2 falls in past year; 3 males; 71.9±4.3 years). 15 non-fallers (6 males; 70.0±3.2 years).	Subjects walked barefoot at preferred gait speed along a 10 m walkway. Kinematic data were collected during 6 trials using an 8-camera optoelectronic motion analysis system (60 Hz). CoM was calculated.	CoM position at toe-off (m/s): −0.30 *vs*. −0.47; CoM mean velocity (m/s): 1.03 *vs*. 1.29; CoM mean velocity at toe-off (m/s): 1.29 *vs*. 1.61; CoM acceleration peak prior to toe-off (m/s): 0.38 *vs*. 0.49; CoM AP acceleration peak (lower fallers).	
Ihlen et al., 2016	Exclusion and inclusion criteria: not reported. Definition of fall: not reported.	Community-dwelling elderly (78.4±4.7 years): 32 fallers (≥ 2 falls in past year). 39 non-fallers.	Subjects wear a tri-axial accelerometer (100 Hz) for 3 days over the lower back. The refined composite multiscale entropy and refined multiscale permutation entropy were applied to trunk acceleration and velocity signals in the AP, ML, and vertical directions.	Refined composite multiscale entropy is higher for non-fallers compared to fallers for trunk AP, ML, and vertical acceleration. Refined multiscale permutation entropy is higher for non-fallers compared to fallers for trunk ML acceleration in the intermediate and large scales. Refined multiscale permutation entropy is lower for non-fallers compared to fallers for trunk vertical acceleration in the intermediate and large scales.	

Table 1. Cont.

Study	Inclusion and/or exclusion criteria Definition of fall	Sample characteristics	Gait assessment	Gait parameters related to falls (fallers *vs* non-fallers)	Gait parameters not related to falls (fallers *vs* non-fallers)
Howcroft et al., 2016	Exclusion criteria: cognitive disorder (self-reported); unable to walk for 6 minutes without an assistive device. Inclusion criteria: ≥ 65 years. Definition of fall: event that results in a subject coming to rest unintentionally on the ground or other lower level, excluding falls resulting from a stroke or overwhelming hazard.	Community-dwelling elderly: 24 fallers (≥ 1 fall in past 6 months; 13 males; 76.3±7.0 years). 76 non-fallers (31 males; 75.3±6.6 years).	Subjects walked 7.62 m while wearing pressure-sensing insoles (120 Hz) and tri-axial accelerometers on the head, pelvis, and left and right shanks (50 Hz). CoP data were analyzed. Maximum Lyapunov exponent, ratio of even to odd harmonics, SD, and CV are used to analyze data variability.	Head variability (SD; higher fallers); ratio of even to odd harmonics pelvis AP (lower fallers).	CoP ML deviation time (s): 0.03 *vs*. 0.03; minimum CoP velocity (m/s): 0.03 *vs*. 0.03; mean CoP velocity (m/s): 0.30 *vs*. 0.30; median CoP velocity (m/s): 0.24 *vs*. 0.21; gait speed (m/s): 1.24 *vs*. 1.20; cadence (steps/min): 112 *vs*. 111; stride time (s): 1.09 *vs*. 1.09; stance time (s): 0.71 *vs*. 0.72; swing time (s): 0.38 *vs*. 0.38; stride time (CV; %): 3 *vs*. 3; stance time (CV; %): 5 *vs*. 6; swing time (CV; %): 8 *vs*. 11; stance phase (%): 64.6 *vs*. 65.9; double-support phase (%): 14.6 *vs*. 15.9; CoP AP displacement (CV; %): 495 *vs*. 463; CoP ML displacement (CV; %): 650 *vs*. 666; Impulse during foot-strike to first peak (Ns/kg): 1.20 *vs*. 1.20; Impulse during MTC to second peak (Ns/kg): 1.47 *vs*. 1.67; Impulse during second peak to foot-off (Ns/kg): 0.97 *vs*. 1.08; Impulse during foot-strike to MTC (Ns/kg): 2.35 *vs*. 2.40; Impulse during MTC to foot-off (Ns/kg): 2.36 *vs*. 2.67; Impulse during foot-strike to foot-off (Ns/kg): 4.65 *vs*. 4.99; maximum Lyapunov exponent.
Rinaldi & Moraes, 2016 Rinaldi et al., 2017	Exclusion criteria: Mini Mental Status Examination score < 24; vestibular dysfunction; unable to walk without assistance. Inclusion criteria: no history of neurological or musculoskeletal disorders; no incorrigible visual impairment. Definition of fall: event in which a subject comes unintentionally to the ground or to some lower level.	Community-dwelling elderly women: 15 fallers (≥ 1 fall in past year; 70.1±5.1 years). 15 non-fallers (71.8±5.8 years).	Subjects walked at preferred gait speed. Gait kinematic data were assessed using an 8-camera optoelectronic motion analysis system (100 Hz). CoM data were analyzed.	Gait speed (m/s): 1.06 *vs*. 1.23; step width (m): 0.09 *vs*. 0.06; step time (s): 0.62 *vs*. 0.52; gait speed (m/s): 0.64 *vs*. 0.93; CoM AP velocity (m/s): 0.39 *vs*. 0.75; percentage of CoM AP velocity (%): 60 *vs*. 30; margin of dynamic stability in AP direction (m): 0.07 *vs*. 0.02; margin of dynamic stability in ML direction (m): 0.04 *vs*. 0.01.	

Table 1. Cont.

Study	Inclusion and/or exclusion criteria Definition of fall	Sample characteristics	Gait assessment	Gait parameters related to falls (fallers *vs* non-fallers)	Gait parameters not related to falls (fallers *vs* non-fallers)
Bizovska et al., 2017	Exclusion criteria: musculoskeletal problems; injuries and surgical interventions that were performed within 2 years before the study. Inclusion criteria: ≥ 60 years; ability to stand and walk without any support. Definition of fall: unexpected event in which the participants come to rest on ground or lower level. Falls related to sports, such as skiing and cycling, and those caused by a great external force were excluded.	Community-dwelling elderly: 38 fallers (≥ 1 fall in 6 months follow-up; median 70.9 years). 101 non-fallers (median 70.6 years).	Subjects walked at preferred gait speed along a 30 m walkway for 5 min wearing comfortable sports shoes. Tri-axial accelerometers were attached to L5 and shanks (296.3 Hz). The index of complexity, the computed from multiscale entropy, and the Shannon entropy were used to analyze data variability	ShE: trunk AP direction: 0.34 *vs.* 0.31; ShE shanks ML direction: 0.41 *vs.* 0.37.	Gait speed (m/s): 1.22 *vs.* 1.23; stride time (s): 1.03 *vs.* 1.05. Shannon entropy: trunk vertical direction: 0.44 *vs.* 0.43; trunk ML direction: 0.16 *vs.* 0.17; shanks vertical direction: 0.59 *vs.* 0.57; shanks AP direction: 0.58 *vs.* 0.58. Index of complexity: trunk vertical direction: 12.5 *vs.* 12.4; trunk ML direction: 17.3 *vs.* 18.0; trunk AP direction: 9.9 *vs.* 10.2; shanks vertical direction: 9.0 *vs.* 8.6; shanks ML direction: 15.20 *vs.* 15.20; shanks AP direction: 8.5 *vs.* 8.5. Computed from multiscale entropy.
de Melker Worms et al., 2017a	Exclusion criteria: Mini-Mental Status Examination score < 25; rheumatoid arthritis in lower extremities; cerebral vascular disease; Parkinson's disease; peripheral neuropathy; cardiac arrest; bypass treatment; any other neurological or cardiovascular impairment; unable to walk for 10 min without walking aid. Definition of fall: event in which a subject unintentionally comes to rest on the ground or other lower level.	Community-dwelling elderly (8 males): 9 fallers (≥1 fall in past year; 70.4 ± 3.6 years). 19 non-fallers (69.3 ± 3.6 years).	Subjects walked at 1 m/s on a treadmill. Two bouts of 5 min of walking. Gait kinematic data were assessed using a 10-camera optoelectronic motion analysis system. CoM was analyzed.	Stance time (CV; %): 3.5 *vs.* 3.0; local divergence exponent of the CoM velocity: 0.97 *vs.* 0.88.	Step length (m): 0.51 *vs.* 0.55; step width (m): 0.15 *vs.* 0.13; stance time (s): 0.69 *vs.* 0.73; swing time (s): 0.38 *vs.* 0.41; step length (CV; %): 4.5 *vs.* 4.2; step width (CV; %): 15.6 *vs.* 18.6; swing time (CV; %): 4.9 *vs.* 4.4.
de Melker Worms et al., 2017b	Exclusion criteria: Mini-Mental State Examination score < 25. Inclusion criteria: ≥ 65 years; able to walk independently for 10 min. Definition of fall: event in which a subject unintentionally comes to rest on the ground or other lower level.	Community-dwelling elderly: 8 fallers (≥1 fall in past year). 17 non-fallers.	Subjects walked at 1 m/s on a treadmill. Two bouts of 5 min of walking and two slips were induced. Gait kinematic data were assessed using a 10-camera optoelectronic motion analysis system (100 Hz).		Step length of the recovery step; step width of the recovery step; step length variability in the recovery step (CV); step width variability in the recovery step (CV).

Table 1. Cont.

Study	Inclusion and/or exclusion criteria Definition of fall	Sample characteristics	Gait assessment	Gait parameters related to falls (fallers *vs* non-fallers)	Gait parameters not related to falls (fallers *vs* non-fallers)
Freire Júnior et al., 2017	Exclusion criteria: unable to walk without help; severe impairment of stability; Mini Mental Status Examination score < 13 for elderly illiterate, < 18 for 1–7 years of education, < 26 for ≥ 8 years of education. Definition of fall: event in which a subject comes to rest on ground or lower level.	Community-dwelling elderly: 27 fallers (1 fall in past 6 months; 1 male; 68.0±5.7 years). 35 non-fallers (11 males; 68.0±4.8 years).	Subjects walked at preferred gait speed during 3 trials along an 8 m pressure-sensing walkway		Gait speed (m/s): 1.12 *vs*. 1.27 (statistical tendency for difference, p = 0.060); cadence (steps/min): 113 *vs*. 112; step length (m): 0.60 *vs*. 0.63; stride time (s): 1.06 *vs*. 1.07; single support phase (%): 37.6 *vs*. 38.4; stride time variability (CV; %): 2.8 *vs*. 2.7.
Marques et al., 2017	Exclusion criteria: musculoskeletal pain, fractures, or severe soft tissue injury during the previous 6 months; neurological, cardiovascular or respiratory diseases. Definition of fall: any stability disturbance that caused a subject's body to have significant contact with the floor.	Community-dwelling elderly women: 16 fallers (≥ 1 injury fall in past year; 69.6±8.1 years). 19 non-fallers (66.1±6.2 years).	Subjects walked on a treadmill at preferred gait speed. Kinematic data were collected using a telemetry data acquisition system and gait phases using pressure sensors (2000 Hz). SDNN: SD of all time intervals. SDANN: SD of means of intervals taken every five strides. SDNNi: mean of SD of intervals. rMSSD: root-mean-square of differences between intervals. Triangular index: geometric method calculated based on a histogram of intervals.	Stance time: SDNN (higher fallers); SDNNi (higher fallers); rMSSD (higher fallers); CV (higher fallers). Swing time: SDANN (higher fallers). Step time: SDNN (higher fallers); SDNNi (higher fallers); rMSSD (higher fallers); triangular index (higher fallers).	Preferred gait speed (m/s): 0.90 *vs*. 0.90. Stance time: SDANN; triangular index. Swing time: SDNN; DNNi; rMSSD; CV; triangular index. Step time: SDANN; CV.

Table 1. Cont.					
Study	**Inclusion and/or exclusion criteria Definition of fall**	**Sample characteristics**	**Gait assessment**	**Gait parameters related to falls (fallers *vs* non-fallers)**	**Gait parameters not related to falls (fallers *vs* non-fallers)**
Svoboda et al., 2017	Exclusion criteria: neurological or vestibular diseases; surgery in lower limbs or spine during last 2 years. Inclusion criteria: ≥ 60 years; ability to walk without an assistive device; ability to stand unassisted without any support during common everyday activities. Definition of fall: unexpected event in which the subject comes to rest on the ground or lower level.	Community-dwelling elderly: 31 fallers (≥ 1 fall in past 6 months; 4 males; 70.9±6.2 years). 94 non-fallers (19 males; 70.4±6.6 years).	Subjects walked barefoot on a 10 m walkway. Each subject participated in 5 trials at preferred, defined (between 1.00 and 1.22 m/s), and fast gait speed. Ground reaction force data were collected using two force platforms. CV and SD were used to analyze variability. CoP ML and AP displacements were calculated.	Preferred gait speed: gait speed (CV; %): 5.9 *vs*. 5.0. Defined gait speed: gait speed (CV; %): 6.1 *vs*. 5.0; CoP ML displacement variability during pre-swing (SD; mm): 1.14 *vs*. 0.85. Fast gait speed: step width variability (CV; %): 27.7 *vs*. 22.7.	Preferred gait speed: step length: 0.58 *vs*. 0.59; step width (cm): 9.5 *vs*. 10.3; step time (s): 0.53 *vs*. 0.53; gait speed (m/s): 1.11 *vs*. 1.13; step length (CV; %): 3.1 *vs*. 3.1; step width (CV; %): 23.7 *vs*. 24.3; step time (CV; %): 4.1 *vs*. 3.5; CoP ML and AP displacements variabilities during loading response (mm): 3.11 *vs*. 3.20; 5.36 *vs*. 5.03; CoP ML and AP displacements variabilities during mid-stance (mm): 0.16 *vs*. 0.16; 0.45 *vs*. 0.47; CoP ML and AP displacements variabilities during terminal stance (mm): 0.15 *vs*. 0.15; 0.56 *vs*. 0.58; CoP ML and AP displacements variabilities during pre-swing (mm): 0.99 *vs*. 0.87; 3.16 *vs*. 2.37. Defined gait speed: step length: 0.58 *vs*. 0.59; step width (cm): 9.7 *vs*. 10.0; step time (s): 0.52 *vs*. 0.53; gait speed (m/s): 1.12 *vs*. 1.11; step length (CV; %): 3.3 *vs*. 3.0; step width (CV; %): 24.6 *vs*. 26.3; step time (CV; %): 4.1 *vs*. 3.7; COP ML and AP displacements variabilities during loading response (mm): 3.11 *vs*. 3.10; 6.03 *vs*. 5.18; CoP ML and AP displacements variabilities during mid-stance (mm): 0.15 *vs*. 0.16; 0.43 *vs*. 0.44; CoP ML and AP displacements variabilities during terminal stance (mm): 0.15 *vs*. 0.15; 0.57 *vs*. 0.57; CoP AP displacement variability during pre-swing (mm): 3.59 *vs*. 2.22. Fast gait speed: step length: 0.65 *vs*. 0.66; step width (cm): 9.6 *vs*. 10.4; step time (s): 0.43 *vs*. 0.44; gait speed (m/s): 1.53 *vs*. 1.50; step length (CV; %): 3.7 *vs*. 3.3; step time (CV; %): 3.8 *vs*. 3.6; gait speed (CV; %): 5.2 *vs*. 4.6; CoP ML and AP displacements variabilities during loading response (mm): 4.44 *vs*. 3.91; 8.54 *vs*. 8.06; CoP ML and AP displacements variabilities during mid-stance (mm): 0.25 *vs*. 0.23; 1.06 *vs*. 0.97; CoP ML and AP displacements variabilities during terminal stance (mm): 0.17 *vs*. 0.17; 0.81 *vs*. 0.69.

Table 1. Cont.

Study	Inclusion and/or exclusion criteria Definition of fall	Sample characteristics	Gait assessment	Gait parameters related to falls (fallers *vs* non-fallers)	Gait parameters not related to falls (fallers *vs* non-fallers)
Allen & Franz, 2018	Exclusion criteria: body mass index ≥ 30 kg/m²; sedentary lifestyle; neurologic or orthopedic diseases; taking medication that causes dizziness; normal or corrected to normal vision. Definition of fall: unintentionally coming to ground or some lower level, and other than as a sustaining violent blow, loss of consciousness, or sudden onset of paralysis.	Community-dwelling elderly: 10 fallers (≥ 1 fall in past year; 3 males; 77.7±7.7 years). 11 non-fallers (5 males; 75.1±5.8 years).	Preferred gait speed on a walkway was calculated using two photocells. Subjects walked at preferred gait speed on a treadmill. Kinematic data were assessed using a 14-camera optoelectronic motion analysis system (100 Hz). EMG of leg was recorded (1000 Hz).	Muscle synergy: 2.7 *vs*. 3.1. Variance in leg muscle recruitment accounted for by one module (larger fallers).	Preferred gait speed (m/s): 1.04 *vs*. 1.17 (statistical tendency for the difference, p = 0.060). Hip flexion and adduction angular position peaks; knee flexion and ankle dorsiflexion angular position peaks.
Benson et al., 2018	Exclusion criteria: able to walk without an assistive device for 5 min; Mini-Mental State Examination score < 22. Definition of fall: unintentionally coming to rest on ground.	Community-dwelling elderly: 10 fallers (≥ 1 fall in past 6 months; 5 males; 75.3 years). 10 non-fallers (3 males; 71.9 years).	Subjects walked at preferred gait speed on a treadmill with laboratory shoes. Kinematic data were assessed using a 10-camera optoelectronic motion analysis system (100 Hz).		Knee displacement; knee angle peak.
Howcroft et al., 2018	Exclusion criteria: cognitive disorder (self-reported); unable to walk for 6 minutes without an assistive device. Inclusion criteria: ≥ 65 years; without a fall in the 6 months before evaluation. Definition of fall: event that results in a subject coming to rest unintentionally on the ground or other lower level, excluding falls resulting from a stroke or overwhelming hazard.	Community-dwelling elderly: 28 fallers (≥ 1 fall in 6 months follow-up; 14 males; 75.0±8.2 years). 47 non-fallers (17 males; 75.3±5.5 years).	Subjects walked 7.62 m while wearing pressure-sensing insoles (120 Hz) and tri-axial accelerometers on the head, pelvis, and left and right shanks (50 Hz). CoP AP and ML displacements were calculated. Fast Fourier transform first quartile and CV were used to analyze data variability	Fast Fourier transform first quartile of left shank ML displacement was lower in fallers. Fast Fourier transform first quartile of right shank vertical displacement was lower in fallers.	Gait speed (m/s): 1.17 *vs*. 1.22; cadence (steps/min): 110 *vs*. 112; stride time (s): 1.11 *vs*. 1.09; stance time (s): 0.73 *vs*. 0.72; swing time (s): 0.38 *vs*. 0.37; stride time (CV; %): 3.0 *vs*. 3.0; stride time symmetry index: 2.13 *vs*. 2.18; lateral deviation length (mm): 0.9 *vs*. 1.0; ML deviation time (s): 0.03 *vs*. 0.03; CoP minimum velocity (m/s): 0.03 *vs*. 0.03; CoP mean velocity (m/s): 0.28 *vs*. 0.29; CoP median velocity (m/s): 0.25 *vs*. 0.25; CoP AP (CV; %): 4.9 *vs*. 4.5; CoP ML (CV; %): 6.6 *vs*. 6.7. Impulse foot-strike to 1st peak (Ns/kg): 1.22 *vs*. 1.20; Impulse 1st peak to minimum (Ns/kg): 1.22 *vs*. 1.27; impulse minimum to 2nd peak (Ns/kg): 1.83 vs. 1.58; impulse 2nd peak to foot-off (Ns/kg): 1.14 *vs*. 1.05; impulse foot-strike to minimum (Ns/kg): 2.36 *vs*. 2.44; impulse minimum to foot-off (Ns/kg): 2.89 *vs*. 2.56; impulse foot-strike to foot-off (Ns/kg): 5.19 *vs*. 4.89.

Table 1. Cont.

Study	Inclusion and/or exclusion criteria Definition of fall	Sample characteristics	Gait assessment	Gait parameters related to falls (fallers *vs* non-fallers)	Gait parameters not related to falls (fallers *vs* non-fallers)
Kwon et al., 2018	Exclusion criteria: not walking independently without assistance devices; any diseases that affected physical activity (e.g., musculoskeletal disease, neurological disease, and cardiovascular disorders). Definition of fall: not reported.	Community-dwelling elderly: 38 fallers (≥ 1 fall in past year; 10 males; 74.8±5.7 years). 38 non-fallers (74.5±5.0 years).	Subjects walked at preferred gait speed along a pressure-sensing walkway. Three trials were recorded for each subject. SD was calculated.	Gait speed (m/s): 1.01 *vs*. 1.09; swing phase (%): 36.6 *vs*. 37.7; stance phase (%): 63.4 *vs*. 62.4; double support (%): 26.6 *vs*. 24.5; step time variability (SD; s): 0.04 vs. 0.02; step length (m): 0.54 *vs*. 0.57; time peak force at maximal weight acceptance and mid-stance (s): 0.22 *vs*. 0.19; 0.37 *vs*. 0.34.	Single support (%): 36.9 *vs*. 37.5; step time (s): 0.55 *vs*. 0.53; step length variability (SD; cm): 2.6 *vs*. 2.7; foot progression angle (◦): 8.0 *vs*. 6.5; peak force at maximal weight acceptance, mid-stance, and push-off (N/kg): 1.07 *vs*. 1.07; 0.82 *vs*. 0.81; 1.02 *vs*. 1.01; time to reach push-off (s): 0.56 *vs*. 0.55.
Marques et al., 2018	Inclusion criteria: 60-80 years; no use of any gait assistive device; no history of progressive or non-progressive neurological disease; normal cognition; normal or corrected vision; no cardiovascular, metabolic or musculoskeletal dysfunction that could impact the safe performance of data collection. Definition of fall: not reported.	Community-dwelling elderly: 53 fallers (≥ 1 fall in past year; 67.6±5.3 years). 49 non-fallers (64.5±7.1 years).	Subjects walked at preferred gait speed along a 14 m walkway. Six to ten trials were recorded until the subjects completed 50 consecutive strides. Two footswitches were attached on the heel and on the base of the first metatarsus (1000 Hz).	Gait speed (m/s): 1.01 *vs*. 1.12; stance time (s): 0.58 *vs*. 0.48; swing time (s): 0.48 *vs*. 0.57; stride time (s): 1.11 *vs*. 1.02; double-support time (s): 0.15 *vs*. 0.10; stride length (m): 1.02 *vs*. 1.16; stance time variability (SD; s): 0.12 *vs*. 0.05	Swing time variability (SD; s): 0.25 *vs*. 0.17; stride time variability (SD; s): 0.23 *vs*. 0.21.
Thompson et al., 2018 Qiao et al., 2018	Exclusion criteria: body mass index ≥ 30 kg/m²; sedentary lifestyle; orthopedic or neurological condition; taking medication that causes dizziness. Definition of fall: unintentionally coming to ground or some lower level, and other than a violent blow, loss of consciousness, or sudden onset of paralysis.	Community-dwelling elderly: 11 fallers (≥ 1 fall in past year; 4 males; 78.3±7.6 years). 11 non-fallers (5 males; 75.3±5.4 years).	Subjects walked at preferred gait speed on a treadmill (in an immersive virtual environment). Kinematic data were assessed using a 14-camera optoelectronic motion analysis system (100 Hz). EMG of leg was recorded (1000 Hz).		Step length (m): 0.62 *vs*. 0.64; step length variability (SD; cm): 2.7 *vs*. 2.7; step width (m): 11.2 *vs*. 12.9; step width variability (SD; cm): 3.3 *vs*. 2.8. Lower leg antagonist co-activation
Watanabe, 2018	Exclusion criteria: women. Inclusion criteria: no history of any musculoskeletal or neurological disorder. Definition of fall: not reported.	Community-dwelling elderly males: 6 fallers (1 fall in past year; 69.0±3.7 years). 7 non-fallers (73.3±6.5 years).	Subjects walked on a treadmill at preferred gait speed for 20 min. Lower extremity kinematics were collected using a 6-camera optoelectronic motion analysis system (100 Hz). EMG data (rectus femoris muscle) were recorded. MTC was analyzed.	MTC decreased with time in non-fallers but not in fallers	Preferred gait speed (m/s): 1.28 *vs*. 1.33; 5–10 min: cadence (steps/min): 118 *vs*. 120; toe off (% gait cycle): 63.2 *vs*. 61.1; MTC (% gait cycle): 84.3 *vs*. 82.4. 15–20 min: cadence (steps/min): 116 *vs*. 117; toe off (% gait cycle): 63.3 *vs*. 61.2; MTC (% gait cycle): 84.0 *vs*. 82.3. Variability in the rectus femoris activation decreased with time in fallers and non-fallers.

Table 1. Cont.

Study	Inclusion and/or exclusion criteria Definition of fall	Sample characteristics	Gait assessment	Gait parameters related to falls (fallers *vs* non-fallers)	Gait parameters not related to falls (fallers *vs* non-fallers)
Santos Bueno et al., 2019	Inclusion criteria: woman; ≥ 65 years; independent walking without aids; absence of previous surgeries in lower limbs, pelvis, or spine; Mini Mental Status Examination score > 14; body mass index ≥ 30 kg/m²; rheumatoid arthritis; neuromuscular or neurodegenerative diseases; diabetes mellitus; no visual impairment. Definition of fall: unexpected event in which the subject comes to rest on ground or lower level (excluded coming to rest against furniture or wall).	Community-dwelling elderly women: 10 recurrent fallers (≥ 2 falls in past year; 71.0±6.8 years). 12 fallers (1 fall in past year; 72.7 ± 5.6 years). 27 non-fallers (72.5±6.8 years).	Subjects walked barefoot at preferred gait speed along a 9 m walkway. Kinematic data were collected using a 7-camera optoelectronic motion analysis system (120 Hz).		Fallers *vs*. Recurrent fallers *vs*. Non-fallers: gait speed (m/s): 1.02 *vs*. 0.99 *vs*. 1.00; cadence (step/min): 110 *vs*. 113 *vs*. 109; stride length (m): 1.10 *vs*. 1.04 *vs*. 1.02; hip flexion/extension (◦): 8.2 *vs*. 7.1 *vs*. 8.2; knee flexion/extension (◦): 7.1 *vs*. 8.1 *vs*. 7.6; ankle dorsiflexion/plantarflexion (◦): 4.7 *vs*. 4.5 *vs*. 4.5; hip adduction/abduction (◦): 4.7 *vs*. 5.2 *vs*. 4.2; hip rotation (◦): 6.4 *vs*. 6.9 *vs*. 6.6; foot progression angle (◦): 5.8 *vs*. 6.1 *vs*. 6.0.
Mak et al., 2019	Exclusion criteria: Mini Mental Status Examination score < 24; neurological impairment; acquired static visual acuity worse than 20/40; unable to walk independently indoors. Definition of fall: not reported.	Community-dwelling elderly (40 males; 70.3±4.8 years): 37 fallers (≥ 1 fall in past year; 7 males; 70.7±5.0 years). 97 non-fallers (33 males; 70.1±4.7 years).	Subjects walked along a 6 m walkway at preferred gait speed. Average muscle activity indices of lower limb co-contractions were measured using surface EMG	Shank and thigh muscle co-contractions were higher in fallers. Lower limb muscle co-contractions were higher in fallers.	
Gillain et al., 2019	Exclusion criteria: ≥ 1 fall in past year; use of a walking aid; gait disorders or an increased fall risk related to neurological or osteoarticular diseases; dementia; hip or knee prosthesis in the previous year; pain when walking; acute respiratory or cardiac illness; recent hospitalization; untreated or uncontrolled comorbidities; use of neuroleptic and sedative drugs; presence of a cardiac pacing device. Definition of fall: unexpected event in which subject comes to rest on ground.	Community-dwelling elderly (48 males; 71.3±5.4 years): 35 fallers (≥ 1 fall in 2 years follow-up; 18 males; 72.0±6.9 years). 61 non-fallers (30 males; 70.9±4.3 years).	Subjects walked with their own shoes at preferred and fast gait speed. Kinematic data were collected using a tri-axial accelerometer attached to the lumbar position and a 24-camera optoelectronic motion analysis system (120 Hz). Variability was analyzed using the CV. MTC was analyzed.	Preferred gait speed: stride length (m): 1.30 *vs*. 1.37. Fast gait speed: gait speed (m/s): 1.64 *vs*. 1.74; stride length (m): 1.47 *vs*. 1.60;	Preferred gait speed: gait speed (m/s): 1.24 *vs*. 1.31. Preferred gait speed and fast gait speed: cadence (stride/s): 0.96 *vs*. 0.96; 1.10 *vs*. 1.08; MTC (mm): 17.3 *vs*. 17.8; 18.0 *vs*. 20.6; median MTC (mm): 17.4 *vs*. 17.7; 18.7 *vs*. 20.8; MTC variability (SD; mm): 5.0 *vs*. 4.1; 4.5 *vs*. 4.5; MTC variability (CV; %): 27.0 *vs*. 24.3; 26.1 *vs*. 27.6; MTC-minimum (mm): 10.8 *vs*. 12.0; 9.8 *vs*. 9.1.

Table 1. Cont.

Study	Inclusion and/or exclusion criteria Definition of fall	Sample characteristics	Gait assessment	Gait parameters related to falls (fallers *vs* non-fallers)	Gait parameters not related to falls (fallers *vs* non-fallers)
Yamagata et al., 2019a	Exclusion criteria: neurological disorders or musculoskeletal injuries that would affect performance; inability to walk without assistance. Definition of fall: an unexpected event during which the subjects come to rest on ground or other lower level.	Community-dwelling elderly: 12 fallers (≥ 1 fall in 1 year follow-up; 78.0±4.7 years). 16 non-fallers (73.8±7.9 years).	Subjects walked at preferred gait speed on a 6 m walkway. Kinematic data were assessed by an 8-camera optoelectronic motion analysis system (100 Hz). CoM was calculated. SD analyzed variability.	Gait speed (m/s): 1.1 *vs*. 1.3; CoM distance at toe-off and at heel strike (cm): 22.9 *vs*. 25.3; 19.7 *vs*. 2.26; variability in right shank angle in the sagittal plane during mid-swing (SD; rad): 6.41 *vs*. 5.21.	Segment angles (foot, shank, thigh, pelvis); segment angles variability (foot, shank, thigh, pelvis). Step width during early swing, mid-swing, and late-swing (m): 0.13 *vs*. 0.14; 0.15 *vs*. 0.17; 0.14 *vs*. 0.16; step width variability during early swing, mid-swing, and late-swing (m): 0.018 *vs*. 0.023; 0.011 *vs*. 0.0127; 0.019 *vs*. 0.020.
Yamagata et al., 2019b	Exclusion criteria: neurological disorders or musculoskeletal injuries that would affect performance; inability to walk without assistance. Definition of fall: an unexpected event during which the subjects come to rest on ground or other lower level.	Community-dwelling elderly: 10 fallers (≥ 1 fall in past year; 78.0±2.7 years). 14 non-fallers (75.1±5.4 years).	Subjects walked at preferred gait speed on a 6 m walkway. Kinematic data were assessed by an 8-camera optoelectronic motion analysis system (100 Hz). SD is used to analyze variability. Uncontrolled manifold analysis was used to assess how variability in segmental configurations affects the frontal trajectory of the swing foot.	Step length (m): 0.52 *vs*. 0.56; right shank angle in early swing (lower fallers); shank angle variability during early and mid-swing (higher fallers); variability of the vertical distance between feet (higher fallers). Fallers: higher variability in segmental configurations in all phases; in ML direction, kinematic synergy was higher during the early and late swing; higher kinematic synergy in the vertical direction.	Gait speed (m/s) (statistical tendency for the difference, p = 0.060): 1.01 *vs*. 1.25; step width (m): 0.11 *vs*. 0.10; cadence (steps/min): 97 *vs*. 99; swing phase (%): 36.7 *vs*. 35.2; stride length ratio: 0.9 *vs*. 0.9. In all planes, there were no differences in segment angles (foot, shank, thigh, pelvis); segment angle variability (foot, shank, thigh, pelvis). Vertical and ML distances between feet. Variability ML distance between feet.
Gonzalez et al., 2020	Inclusion criteria: ability to walk one mile at any pace with minimum rest and body mass index = 18.5–24.9 kg/m2 or ≥30 kg/m2 . Exclusion criteria: use of an assistive device for walking; artificial joint replacement; history of diabetic peripheral neuropathy, neurological conditions that interfere with gait; body mass index = 25–29.9 kg/m2 ; compromised range of motion in the lower limb or trunk; untreated hypertension or cardiovascular diseases; or T-score ≤ 2.5 for the femoral neck. Definition of fall: not reported	Community-dwelling elderly: 16 fallers (≥ 1 fall in 1-year follow-up). 16 non-fallers.	Subjects walked on a treadmill for 10 min at preferred gait speed. Kinematic data of the 10th thoracic vertebra were assessed by an 8-camera optoelectronic motion analysis system (100 Hz). Short-term exponents were used to analyze the data variability for each direction (larger positive exponents indicate higher instability).		Short-term exponents of the ML, AP, or vertical displacements.

Table 1. Cont.

Study	Inclusion and/or exclusion criteria Definition of fall	Sample characteristics	Gait assessment	Gait parameters related to falls (fallers *vs* non-fallers)	Gait parameters not related to falls (fallers *vs* non-fallers)
Pol et al., 2021	Exclusion criteria: < 60 years; Short Portable Mental Status Questionnaire score < 7; unable to ambulate for at least 10 m without an assistive device; diabetic foot syndrome; neurological diseases; lower extremity surgery. Definition of fall: unintentionally coming to ground or other lower surface, not as result of a major intrinsic event or an overwhelming hazard.	Community-dwelling elderly: 74 fallers (≥ 1 fall in past year; 20 males; 71.9 ± 4.9 years). 113 non-fallers (61 males; 69.9 ± 5.5 years).	Three trials were recorded for each subject's dominant limb using a two-step gait initiation protocol at a comfortable walking speed. Foot function was assessed using barefoot plantar pressure analysis (50 Hz). CoP was calculated.	CoP excursion index (%): 14.69 *vs.* 17.58, total pressure–time integral (% body weight * second/cm²): 3.75 *vs.* 3.23; pressure–time integral of medial forefoot (% body weight * second/cm²): 1.84 *vs.* 1.39.	Pressure–time integral of medial heel (% body weight * second/cm²): 1.52 *vs.* 1.44; pressure–time integral of lateral heel (% body weight * second/cm²): 1.48 *vs.* 1.36; pressure–time integral of medial midfoot (% body weight * second/cm²): 0.99 *vs.* 0.87; pressure–time integral of lateral midfoot (% body weight * second/cm²): 1.30 *vs.* 1.21; pressure–time integral of central forefoot (% body weight * second/cm²): 1.73 *vs.* 1.71; pressure–time integral of lateral forefoot (% body weight * second/cm²): 1.75 *vs.* 1.79; pressure–time integral of hallux (% body weight * second/cm²): 2.35 *vs.* 1.80; pressure–time integral of second toe (% body weight * second/cm²): 0.90 *vs.* 0.78; pressure–time integral of lateral toes (% body weight * second/cm²): 0.84 *vs.* 0.73; Regional CoP velocity–heel, midfoot, forefoot, and toes (cm/s): 25.6 *vs.* 28.1; 16.1 *vs.* 18.8; 19.1 *vs.* 18.1; 43.8 *vs.* 48.4.
Sadeghi et al., 2021	Exclusion criteria: subjects who needed help for walking; difficulties in understanding instructions; receiving hospice care. Definition of fall: not reported.	Community-dwelling elderly: 13 fallers (> 1 fall in past year; 72.5 ± 7.1 years). 13 non-fallers (73.1 ± 7.1 years).	Subjects walk barefoot at preferred gait speed on a 10 m walkway. Kinematic data from 10 gait cycles were collected by a 10-camera optoelectronic motion analysis system (100 Hz).	Cadence (steps/min): 98 *vs.* 115; gait speed (m/s): 0.74 *vs.* 1.04; stride time (s): 1.27 *vs.* 1.05; stride length (m): 0.90 *vs.* 1.08; double support time (s): 0.30 *vs.* 0.26. Ankle-to-knee, knee-to-hip, and ankle-to-hip coordination patterns. Less coordination variability in fallers.	Step width (m): 0.10 *vs.* 0.10; ankle displacement (◦): 25 *vs.* 23; knee displacement (◦): 47 *vs.* 44; hip displacement (◦): 42 *vs.* 41.
Yamagata et al., 2021	Exclusion criteria: neurological disorders or musculoskeletal injuries that would affect performance; inability to walk without assistance. Definition of fall: an unexpected event during which the subjects come to rest on ground or other lower level.	Community-dwelling elderly: 10 fallers (≥ 1 fall in past year; 78.0±2.7 years). 14 non-fallers (75.1±5.4 years).	Subjects walked at preferred gait speed on a 6 m walkway. Kinematic data were assessed by an 8-camera optoelectronic motion analysis system (100 Hz). CoM was calculated. Variance is used to analyze variability.	CoM vertical direction variability (higher fallers).	CoM displacements. CoM ML direction variability.

Table 1. Cont.

Study	Inclusion and/or exclusion criteria Definition of fall	Sample characteristics	Gait assessment	Gait parameters related to falls (fallers *vs* non-fallers)	Gait parameters not related to falls (fallers *vs* non-fallers)
Figueiredo e al., 2022	Inclusion criteria: ≥80 years; any gender; ability to walk independently; and ability to understand the verbal commands to carry out assessment. Exclusion criteria: uncertain about their history of falls; had been hospitalized for >7 days in the 3 months before assessment; or had a severe orthopedic, neurological, respiratory, cardiovascular, visual, or hearing disease. Definition of fall: unexpected and unexplained event in which the subject inadvertently comes to the ground.	Community-dwelling elderly: 32 fallers (≥ 1 fall in past 6 months; 7 males; 89.9±4.4 years). 32 non-fallers (5 males; 88.6±4.1 years).	Subjects walked during the Timed Up and Go test. Kinematic data were collected using a tri-axial accelerometer attached between the L5 and S1 vertebrae. Spectral arc length metrics are used to quantify gait smoothness.		Spectral arc length in AP, ML, and vertical directions.
Nascimento et al., 2022	Inclusion criteria: residing in the community; 60-79 years; able to walk independently. Exclusion criteria: medical contraindications for submaximal exercise, according to American College of Sports Medicine guidelines; inability to understand or follow investigation protocols. Definition of fall: not reported.	Community-dwelling elderly: 225 fallers (> 1 fall in past year; 70.1±5.6 years). 394 non-fallers (69.2±5.4 years).	Subjects walked a distance of 30 feet at their preferred gait speed. Gait speed is calculated by dividing the distance walked by the time needed. Cadence is calculated by dividing the number of steps taken in space during the 30-foot walk test by the time taken to cover that distance.	Gait speed (m/s): 1.20 *vs* 1.28.	Cadence (steps/s): 1.90 *vs* 1.92.
Yoshida et al., 2022	Exclusion criteria: diagnosis of dementia, recent major illness or neurological, sensory, or mobility impairment; musculoskeletal disorders or injuries. Definition of fall: event that resulted in a person coming to rest unintentionally on ground or other lower level, not as the result of a major intrinsic event or an overwhelming hazard.	Community-dwelling elderly: 28 fallers (≥ 1 fall in past year; 7 males; 77.5±4.9 years). 28 non-fallers (12 males; 78.1±5.3 years).	Gait initiation was assessed using two force platforms (1024 Hz). CoP was calculated.	First step length (m): 0.61 *vs*. 0.66; CoP ML displacement during weight transfer (m): 0.13 *vs*. 0.12.	Weight transfer time (s): 0.99 *vs*. 0.96; forward progression time (s): 0.48 *vs*. 0.49; first step time (s): 0.55 *vs*. 0.57; ground contact time (s): 0.69 *vs*. 0.68; first step width (m): 0.17 *vs*. 0.17; CoP AP displacement during weight transfer (m): 0.043 *vs*. 0.048; CoP AP displacement during forward progress (m): 0.181 *vs*. 0.170; CoP ML displacement during forward progress (m): 0.023 *vs*. 0.023; CoP AP displacement during first step (m): 0.228 *vs*. 0.225; CoP ML displacement during first step (m): 0.023 *vs*. 0.021.

Table 1. Cont.

Study	Inclusion and/or exclusion criteria Definition of fall	Sample characteristics	Gait assessment	Gait parameters related to falls (fallers *vs* non-fallers)	Gait parameters not related to falls (fallers *vs* non-fallers)
Baba et al., 2023	Inclusion criteria: ≥ 65 years; ability to walk independently without using aids. Exclusion criteria: stroke diagnosis, Parkinson's disease, rheumatism; history of hip or knee surgery. Definition of fall: unintentional landing on the ground, floor, or lower level.	Community-dwelling elderly: 16 fallers (≥ 1 fall in past year; 4 males; 84.6±5.7 years). 34 non-fallers (3 males; 81.7±6.1 years).	Subjects walked barefoot on a walkway at preferred gait speed. Kinematic data were collected using an inertial sensor system.	Gait speed (m/s): 0.83 *vs* 0.92; foot angle with ground (°): 13.6 *vs* 18.3.	Stride time (s): 1.10 *vs*. 1.03; stride length (m): 0.87 *vs*. 0.96; cadence (steps/min): 114 *vs*. 117; stance phase (%): 65.0 *vs*. 64.7; single support (%): 35.4 *vs*. 35.9; double support (%): 21.2 *vs*. 21.0; maximum ankle plantarflexion: 10.8 *vs*. 9.0; maximum ankle dorsiflexion: 9.7 *vs*. 9.4; maximum knee flexion: 40.4 *vs*. 41.7; maximum knee extension: 0.5 *vs*. 0.5; maximum hip flexion: 25.2 *vs*. 27.3; maximum hip extension: 13.5 *vs*. 13.2.

AP—anteroposterior; ApEn—approximate entropy analysis; CoM—center of mass; CoP—center of pressure; CV—coefficient of variation; EMG—electromyography; ML—mediolateral; MTC—minimum toe clearance; rMSSD—root-mean-square of differences between intervals; SampEn—sample entropy analysis; SD—standard deviation; SDANN—standard deviation of means of intervals taken every five strides; SDNN—standard deviation of all time intervals; SDNNi—mean of standard deviations of intervals. *—it is the symbol of multiplication.

Table 2. Characteristics and data of the studies that compared elderly who fell during induced falls and elderly who did not.

Study	Inclusion and/or exclusion criteria Definition of fall	Sample characteristics	Gait assessment	Gait parameters related to falls (fallers *vs* non-fallers)	Gait parameters not related to falls (fallers *vs* non-fallers)
Pavol et al., 1999	Exclusion criteria: neurological, musculoskeletal, cardiovascular, pulmonary, cognitive, and other systemic disorders; history of repeated falling; and minimum bone mineral density of the femoral neck of 0.65 g/cm² (DXA).	Community-dwelling elderly: 10 fallers (body's subject being at least 50% supported by the safety harness); 39 recovers.	Subjects walked on a 7 m walkway at their preferred gait speed using a safety harness. One trip was induced using a mechanical obstacle (5.1 cm from the ground). Kinematic data were collected using a 6-camera optoelectronic motion analysis system (60 Hz).	Gait speed (m/s): 1.31 *vs.* 1.18; step time (s): 0.50 *vs.* 0.54; step length (% body mass): 43.1 *vs.* 39.9	Step width (cm): 8.9 *vs.* 9.2; trunk flexion (◦): 11 *vs.* 9; gait phase of trip (% stride length): 59 *vs*. 59.
Lockhart et al., 2003	Exclusion criteria: based on an exam conducted by a physician to ensure that they were in generally good physical health and a peripheral neuropathy examination (below 50% of the norm).	Community-dwelling elderly (7 males: 75.5±6.8 years): 7 fallers. 7 non-fallers.	Subjects walked on a 20 m circular track for 10 min using a safety harness. Two slips were induced. Four video cameras and two force plates were used to collect 3D data and the ground reaction forces (60 Hz).	Coefficient of friction after a heel strike (horizontal ground reaction force/vertical ground reaction force) was lower in fallers; horizontal heel contact velocity was higher in fallers.	

Table 2. Cont.					
Study	**Inclusion and/or exclusion criteria Definition of fall**	**Sample characteristics**	**Gait assessment**	**Gait parameters related to falls (fallers *vs* non-fallers)**	**Gait parameters not related to falls (fallers *vs* non-fallers)**
Pijnappels et al., 2005	Exclusion and inclusion criteria: not reported.	Community-dwelling elderly: 7 fallers (when the vertical force in the ropes exceeded 200 N during trials that one obstacle appeared from the ground unexpectedly to catch the subject's swing limb; 1male; 67.9±2.6 years). 4 non-fallers (3 males; 66.5±3.3 years).	Subjects walked at preferred gait speed over a platform and were tripped several times by an obstacle that appeared from the floor. A safety harness prevented subjects from falling. Kinematic and ground reaction force data were collected using a 4-camera optoelectronic motion analysis system and a force plate (100 Hz).	Total angular momentum; angular momentum at push-off.	Gait speed; stride length; obstacle contact phase; stance time of the support limb; double support time; swing phase time of the recovery limb; hip horizontal displacement; hip height at end push-off; rate of change of moment generation in ankle, knee, and hip; hip extension moment, knee flexion moment and ankle plantarflexion moment peak in the support limb.
Pavol et al., 2001	Exclusion criteria: neurological, musculoskeletal, cardiovascular, pulmonary, cognitive, and other systemic disorders; history of repeated falling; and minimum bone mineral density of the femoral neck of 0.65 g/cm², assessed by DXA.	Community-dwelling elderly. The recovery attempts were classified as a lowering or an elevating strategy. Elevating strategy: 1 faller; 11 recovers.	Subjects walked on a 7 m walkway at their preferred gait speed using a safety harness. One trip was induced using a mechanical obstacle (5.1 cm from the ground). Kinematic collected using a 6-camera optoelectronic motion analysis system (60 Hz). Ground reaction forces were collected by two force plates (1000 Hz).	Hip horizontal velocity at time of trip (% body height/s): 92.5 *vs*. 68.0; hip horizontal velocity at 0.1 s post-trip (%/s): 86.5 *vs*. 67.4; time from trip to follow-through toe-off (s): 0.40 *vs*. 0.45; ankle–hip angular position at time of loading (◦): 11.9 *vs*. 8.9; hip height at heel strike (% body height): 51.1 *vs*. 54.5; trunk inclination from vertical at heel strike (◦): 58.5 *vs*. 37.3; lumbar flexion at heel strike (◦): 45.2 *vs*. 23.1; minimum hip–ankle distance (% body height): 42.4 *vs*. 47.4; maximum trunk inclination from vertical (◦): 83.5 *vs*. 49.7; maximum lumbar flexion at heel strike (◦): 70.3 *vs*. 35.3.	Trunk inclination at time of trip (◦): 14.3 *vs*. 8.7; hip vertical velocity 0.1 s post-trip (% body height): −8.1 *vs*. −9.3; lumbar flexion at time of loading (◦): 17.2 *vs*. 6.7; recovery step length (% body height): 51.8 *vs*. 49.8; recovery stride length (% body height): 93.2 *vs*. 89.7; obstacle–ankle distance at heel strike (% body height): 32.6 *vs*. 32.2; minimum hip–ankle distance (% body height): 31.0 *vs*. 34.5; maximum ankle ground clearance (% body height): 24.0 *vs*. 22.1; time from trip-to-ground contact (s): 0.40 *vs*. 0.45; maximum horizontal ankle velocity (% body height/s): 203 *vs*. 225; average horizontal ankle velocity (% body height/s): 56 *vs*. 54; ankle–hip angle at heel strike (◦): 0.3 *vs*. −7.6; maximum hip vertical velocity (% body height/s): 20.7 *vs*. 29.1.

Table 2. Cont.

Study	Inclusion and/or exclusion criteria Definition of fall	Sample characteristics	Gait assessment	Gait parameters related to falls (fallers *vs* non-fallers)	Gait parameters not related to falls (fallers *vs* non-fallers)
Pavol et al., 2001	Exclusion criteria: neurological, musculoskeletal, cardiovascular, pulmonary, cognitive, and other systemic disorders; history of repeated falling; or minimum bone mineral density of the femoral neck of 0.65 g/cm².	Community-dwelling elderly. The recovery attempts were classified as a lowering or an elevating strategy. Lowering strategy: 5 fallers during-step fall (body's subject being at least 50% supported by safety harness). 3 fallers after-step fall (body's subject being at least 50% supported by safety harness). 26 recoveries.	Subjects walked on a 7 m walkway at their preferred gait speed using a safety harness. One trip was induced using a mechanical obstacle (5.1 cm from the ground). Kinematic data were collected using a 6-camera optoelectronic motion analysis system (60 Hz). Ground reaction forces were collected by two force plates (1000 Hz).	Fallers during-step fall *vs.* recoveries: hip horizontal velocity at trip (% body height/s): 91.3 *vs.* 68.2; hip horizontal velocity at 0.1 s post-trip (% body height/s): 94.5 *vs.* 72.9; time from trip to support limb loading (s): 0.27 *vs.* 0.16; ankle–hip angle at time of loading (◦): 23.6 *vs.* 9.8; recovery step length (% body height): 36.9 *vs.* 49.4; recovery stride length (% body height): 51.4 *vs.* 59.9; obstacle–ankle distance at ground contact (% body height): 32.0 *vs.* 39.6; recovery step time (s): 0.21 *vs.* 0.27; hip height at ground foot contact (% body height): 47.2 *vs.* 54.5; ankle–hip angle at heel strike (◦): 12.7 *vs.* −10.1; trunk inclination from vertical at heel strike (◦): 48.3 *vs.* 36.0; maximum lumbar flexion at heel strike (◦): 23.1 *vs.* 35.6. Fallers after-step fall *vs.* recoveries: trunk inclination at trip (◦): 18.8 *vs.* 9.1; trunk inclination from vertical at ground foot contact (◦): 55.2 *vs.* 36.0; lumbar flexion at ground foot contact (◦): 38.7 *vs.* 23.5; maximum hip vertical velocity (% body height): −0.4 *vs.* 32.2; minimum hip–ankle distance (% body height): 41.0 *vs.* 47.3; maximum trunk inclination from vertical at ground foot contact (◦): 74.6 *vs.* 46.6; maximum lumbar flexion at ground foot contact (◦): 54.4 *vs.* 35.6.	Fallers during-step fall *vs.* recoveries: trunk inclination at time of trip (◦): 7.5 *vs.* 9.1; hip vertical velocity at 0.1 s post-trip (body height/s): −11.8 *vs.* −9.8; time from trip to follow-through toe-off (s): 0.49 *vs.* 0.50; lumbar flexion at time of loading (◦): 6.4 *vs.* 6.1; minimum hip–ankle distance at recovery step (% body height): 31.8 *vs.* 33.0; maximum ankle ground clearance (% body height): 23.8 *vs.* 24.7; time from trip to recovery foot toe-off (s): 0.28 *vs.* 0.26; time from trip to ground contact (s): 0.49 *vs.* 0.52; maximum horizontal ankle velocity (% body height/s): 227 *vs.* 263; average horizontal ankle velocity (% body height/s): 109 *vs.* 115; lumbar flexion at ground foot contact (◦): 22.1 *vs.* 23.5; Fallers after-step fall *vs.* recoveries: hip horizontal velocity at time of trip (% body height/s): 79.4 *vs.* 68.2; hip horizontal velocity at 0.1 s post-trip (% body height/s): 82.2 *vs.* 72.9; hip vertical velocity at 0.1 s post-trip (% body height/s): −7.2 *vs.* −9.8; time from trip to support limb loading (s): 0.14 *vs.* 0.16; time from trip to follow-through toe-off (s): 0.52 *vs.* 0.50; ankle–hip angle at time of loading (◦): 9.1 *vs.* 9.8; lumbar flexion at time of loading (◦): 15.4 *vs.* 6.1; recovery step length (% body height): 49.1 *vs.* 49.4; recovery stride length (% body height): 61.7 *vs.* 59.9; obstacle–ankle distance at heel strike (% body height): 40.0 *vs.* 39.6; minimum hip–ankle distance (% body height): 28.8 *vs.* 33.0; time from trip to recovery foot toe-off (s): 0.24 *vs.* 0.26; time from trip to heel strike (s): 0.51 *vs.* 0.52; recovery step duration (s): 0.26 *vs.* 0.270; maximum horizontal ankle velocity (% body height/s): 264 *vs.* 263; average horizontal ankle velocity (% body height/s): 117 *vs.* 115; hip height (% body height): 50.9 *vs.* 54.5, ankle–hip angle (◦): −7.8 *vs.* −10.1

Table 2. Cont.

Study	Inclusion and/or exclusion criteria Definition of fall	Sample characteristics	Gait assessment	Gait parameters related to falls (fallers *vs* non-fallers)	Gait parameters not related to falls (fallers *vs* non-fallers)
Espy & Pai, 2007	Inclusion criteria: ≥ 65 years.	Community-dwelling elderly: 19 fallers (subjects who fell during an unexpected induced slip). 15 non-fallers (subjects who recover during an unexpected induced slip).	Subjects walked on an instrumented walkway while wearing a safety harness. After 10 unperturbed trials, an unexpected slip was induced under the right heel. Motion data were used to calculate frontal plane variables.		Step width; CoM lateral position; CoM velocity.
Bhatt et al., 2011	Exclusion criteria: Folstein Mini-Mental Status Examination score < 25; classified as osteopenic or osteoporotic.	Community-dwelling elderly (44 males): 59 fallers (the force recorded on the safety harness load cell force exceeded 30% of the body weight; 71.6±4.6 years). 56 recovers (71.4±5.1 years).	Subjects walked for 9–12 trials on a 7 m walkway using their own athletic shoes and were then exposed to one unannounced slip. Kinematic and ground reaction force data were collected during 5 trials using an 8-camera optoelectronic motion analysis system (120 Hz) and one force platform (600 Hz).	Dynamic gait stability: −0.16 *vs*. −0.13.	
Yang & Pai, 2014	Exclusion criteria: any known neurological, musculoskeletal, or other systemic disorders that would have affected their postural control.	Community-dwelling elderly: 98 fallers (the force recorded on the safety harness load cell force exceeded 30% of the body weight; 22 males; 71.8±5.5 years). 89 recovers (37 males; 71.9±4.8 years).	Subjects walked for 20 trials on a 7 m instrumented walkway at preferred gait speed and were then exposed to one unannounced slip. Kinematic data were collected using an 8-camera optoelectronic motion analysis system (120 Hz) and ground reaction force using four force platforms (600 Hz).	Step width (SD; m): 0.031 *vs*. 0.027; dynamic stability of CoM against backward falling: −0.18 *vs*. −0.16.	Step length (SD; m): 0.070 *vs*. 0.062; step time (SD; s): 0.044 *vs*. 0.041; margin of stability: 0.039 *vs*. 0.051; Floquet multiplier: 0.422 *vs*. 0.432; Lyapunov exponent (short-term): 0.671 *vs*. 0.737; Lyapunov exponent (long-term): 0.034 *vs*. 0.026.

Table 2. Cont.

Study	Inclusion and/or exclusion criteria Definition of fall	Sample characteristics	Gait assessment	Gait parameters related to falls (fallers *vs* non-fallers)	Gait parameters not related to falls (fallers *vs* non-fallers)
Sawers et al., 2016	Inclusion criteria: participants who experienced a "split" slip with the slipping and trailing feet traveling apart were included.	Community-dwelling elderly: 15 fallers (unable to regain their stability after an unexpected induced slip; 2 males; 71.0±2.0 years). 13 recovers (able to recover their stability and continue walking after an unexpected induced slip; 8 males; 72.0±5.0 years).	Subjects walked on a 7 m walkway at their preferred gait speed using a safety harness. One unexpected slip was induced. Kinematic collected using an optoelectronic motion analysis system (120 Hz). EMG of TA, MG, VL, and BF were recorded (600 Hz).	Slip distance (m): 0.78 *vs*. 0.61; EMG onset latencies/slip leg (s): VL (right): 0.239 *vs*. 0.186; BF (right): 0.170 *vs*. 0.120. Muscle synergies recruited during slip and non-slip trials: 3.7 *vs*. 4.7.	Slip time (s): 0.82 *vs*. 0.94; peak slip velocity (m/s): 2.00 *vs*. 1.84; dynamic stability: −0.18 *vs*. −0.16; gait speed (m/s): 0.89 *vs*. 1.00; shank angle (◦): 74 *vs*. 73. EMG onset latencies/slip leg (s): TA (right): 0.173 *vs*. 0.151; MG (right): 0.234 *vs*. 0.232; EMG onset latencies/nonslip leg (s): TA (left): 0.162 *vs*. 0.157; MG (left): 0.215 *vs*. 0.198, VL (left): 0.165 *vs*. 0.154; BF (left): 0.150 *vs*. 0.155; EMG onset peak magnitude/slip leg: TA (right): 2.30 *vs*. 2.28; MG (right): 2.32 *vs*. 2.32; VL (right): 2.09 *vs*. 2.36; BF (right): 3.45 *vs*. 3.87; EMG Onset peak magnitude/nonslip leg: TA (left): 2.86 *vs*. 2.58; MG (left): 1.64 *vs*. 1.87; VL (left): 4.75 *vs*. 3.56; BF (left): 3.75 *vs*. 3.22.
Sawers & Bhatt, 2018	Inclusion criteria: participants who experienced a feet-forward slip (with both feet moving forward were included.	Community-dwelling elderly: 12 fallers (when peak force recorded by the load cell in line with the overhead harness exceeded 30% of the subject's body weight; 2 males; 73.0±4.9 years). 13 recovers (7 males; 74.0±4.1 years).	Subjects walked on a 7 m walkway at their preferred gait speed using a safety harness. One unexpected slip was induced. Kinematic data were collected using an optoelectronic motion analysis system (120 Hz). Ground reaction forces were collected (600 Hz).	Lower limb joint angle: knee flexion (higher flexion fallers). Number of muscle synergies recruited: 4 *vs*. 5.	Peak slip velocity (m/s): 2.28 *vs*. 2.14; slip duration (s): 0.68 *vs*. 0.70; slip distance (m): 0.74 *vs*. 0.62; shank angle (◦): 75.8 *vs*. 75.0; step length (m): 0.30 *vs*. 0.32; dynamic stability: −0.124 *vs*. −0.155; gait speed (m/s): 1.13 *vs*. 1.02 (statistical tendency for the difference, $p = 0.093$). Lower limb joint angle: hip flexion/extension; knee extension; ankle dorsiflexion/plantar-flexion.
Bruijn et al., 2022	Exclusion criteria: orthopedic, neuromuscular, cardiac or visual problems.	Community-dwelling elderly: 5 fallers. 11 recovers.	Subjects walked on a 12 m walkway at their preferred gait speed using a safety harness. One unexpected slip was induced. Kinematic data were collected using an optoelectronic motion analysis system (50 Hz). Ground reaction forces were collected (1000 Hz).	Sagittal plane forward body rotation at touchdown.	Gait speed (m/s): 1.48 *vs*. 1.43; time between impact and touchdown (s): 0.46 *vs*. 0.50; arm movements.

Table 2. Cont.

Study	Inclusion and/or exclusion criteria Definition of fall	Sample characteristics	Gait assessment	Gait parameters related to falls (fallers *vs* non-fallers)	Gait parameters not related to falls (fallers *vs* non-fallers)
Wang et al., 2022	Inclusion criteria: ≥ 60 years. Exclusion criteria: recently (≤ 6 months) self-reported diagnosed neurological, musculoskeletal, or other systemic disorder.	Community-dwelling elderly: 229 falls (the recovery foot landing posterior to the sliding foot based on the location of heel markers). 569 recovers.	Subjects walked with their own shoes on a 12 m walkway at their preferred gait speed using a safety harness. Unexpected slips were induced. Kinematic data were collected using an 8-camera optoelectronic motion analysis system (120 Hz). Ground reaction forces were collected (600 Hz).	Stride length (m): 0.41 *vs*. 0.70; slip distance (m): 0.31 *vs*. 0.08; slip velocity (m/s): 1.12 *vs*. −0.34; trunk angle (∘): 4.9 *vs*. −1.5.	
Wang & Bhatt, 2023	Inclusion criteria: ≥ 60 years. Exclusion criteria: recently (≤ 6 months) self-reported diagnosed neurological, musculoskeletal, or other systemic disorder.	Community-dwelling elderly: 61 fallers (the peak moving average force of the load cell over 1s period was ≥ 4.5% of body weight). 56 recovers.	Subjects walked with their own shoes on a 12 m walkway at their preferred gait speed using a safety harness. Unexpected slips were induced. Kinematic data were collected using an 8-camera optoelectronic motion analysis system (120 Hz). Ground reaction forces were collected (600 Hz). CoM was calculated.	Margin of stability at tripping foot touchdown: 1.39 *vs*. 0.95; maximum step length (m): 0.11 *vs*. 0.04; maximum CoM velocity (m/s): 0.59 *vs*. 0.21; peak trunk angle (∘): 23.7 *vs*. 6.9.	Margin of stability at tripping foot lift-off: 1.03 *vs*. 0.96; margin of stability at pre-tripping foot touchdown: 2.38 *vs*. 2.24.

BF—biceps femoris long head; CoM—center of mass; EMG—electromyography; MG—medial gastrocnemius; SD—standard deviation; TA—tibialis anterior; VL—vastus lateralis

Out of the 86 selected studies that compared elderly fallers and non-fallers, 72 (83.7%) were retrospective, and 12 (14%) were prospective; the remaining two studies compared the elderly who fell from induced falls with the elderly who recovered during unperturbed gait trials. Among the retrospective studies, fifteen evaluated the history of falls during the previous 6 months, one during the previous 10 months, forty-nine during the previous year, two during the previous 2 years, and one during the previous 5 years; four studies did not report this information. Among the prospective studies, two evaluated the occurrence of falls during a 6-month follow-up, eight during a 1-year follow-up, and two during a 2-year follow-up. Additionally, 38 of the studies (44.2%) did not provide a definition of the term “fall”.

Regarding the selected retrospective studies, 50 analyzed the subjects’ gait on a walkway (forty-four during level ground, one during unleveled ground, and five during gait initiation); 19 on a treadmill (18 during level gait and 1 during gait initiation); and 3 during real-life scenarios. Concerning the prospective studies, 11 analyzed the subjects’ level gait on a walkway and 1 on a treadmill.

The elderly’s gait was analyzed on a walkway in all studies that induced falls during their methodological set-up (three studies induced trips and nine induced slips).

3.2. Risk of bias assessment

Out of the 96 studies, 5 studies had a global classification of moderate, and 91 studies had a global classification of weak (Table 3). Thus, 77 out of the 96 studies were classified as weak regarding the selection bias domain because the subjects were not representative of the study population, i.e., the samples were convenience samples; the remaining 19 studies were classified as moderate because the sample was representative of the population and the studies were completed by 80–100% of the initially included subjects. Regarding the study design domain, the 96 studies were classified as weak since their study design was cross-sectional and the subject selection was not randomized. Relating to the confounders domain, 78 studies were classified as weak because the potential confounders were not shown, and 18 studies were classified as strong because the potential confounders were controlled. Concerning the blinding domain, 24 studies were classified as strong because the investigators were blinded to the status of the subjects, and the subjects were also blinded to the research question, while 72 studies were classified as moderate. Regarding the data collection methods domain, two studies were classified as weak because those methods were not reliable, or the validity and reliability of the instruments were not shown; the remaining 94 studies were classified as strong because it was shown that the instruments were valid and reliable. With respect to the withdrawals and dropouts domain, 84 studies were classified as moderate because the studies were retrospective; in this component, only 12 studies were classified as strong because the percentage of subjects that completed the study was 80% or more.

Table 3. Methodological quality evaluation of the included studies using the Quality Assessment Tool for Quantitative Studies.

Study	Selection Bias	Study Design	Confounders	Blinding	Data Collection Methods	Withdrawals and Dropouts	Global
Heitmann et al.,1989	3	3	3	2	3	2	3
Gehlsen & Whaley, 1990	3	3	3	2	1	2	3
Feltner et al., 1994	3	3	3	2	1	2	3
Wolfson et al., 1995	3	3	3	2	3	2	3
Maki, 1997	3	3	1	1	1	1	3
Lee & Kerrigan, 1999	3	3	3	2	1	2	3
Nelson et al., 1999	3	3	3	2	1	2	3
Pavol et al., 1999	3	3	1	1	1	2	3
Wall et al., 2000	3	3	3	2	3	2	3
Hausdorff et al., 2001	3	3	3	1	1	1	3
Kerrigan et al., 2000	3	3	3	2	1	2	3
Kerrigan et al., 2001	3	3	3	2	1	2	3
Pavol et al., 2001	3	3	1	1	1	2	3
Kemoun et al., 2002	3	3	3	1	1	1	3
Auvinet et al., 2003	3	3	3	2	1	2	3
Mbourou et al., 2003	3	3	3	2	1	2	3
Lockhart et al., 2003	3	3	3	1	1	2	3
Chiba et al., 2005	3	3	1	2	1	2	3
Pijnappels et al., 2005	3	3	3	1	1	2	3
Barak et al., 2006	3	3	3	2	1	2	3
Toulotte et al., 2006	3	3	1	2	1	2	3
Espy & Pai, 2007	3	3	3	1	1	2	3
Karmakar et al., 2007	3	3	3	2	1	2	3
Newstead et al., 2007	3	3	1	2	1	2	3
Barrett et al., 2008	3	3	3	2	1	2	3
Khandoker et al., 2008a	3	3	3	2	1	2	3
Khandoker et al., 2008b	3	3	3	2	1	2	3
Lockhart & Liu, 2008	3	3	3	2	1	2	3
Verghese et al., 2009	2	3	1	1	1	1	2
Greany & Di Fabio, 2010	3	3	3	2	1	2	3
Greene et al., 2010	2	3	3	2	1	2	3
Mickle et al., 2010	2	3	1	1	1	1	3
Bhatt et al., 2011	3	3	3	1	1	2	3
Kirkwood et al., 2011	3	3	3	2	1	2	3
Lázaro et al., 2011	2	3	3	2	3	2	3
Lugade et al., 2011	3	3	3	2	1	2	3
Panzer et al., 2011	3	3	3	2	3	2	3
Scanaill et al., 2011	2	3	3	2	1	2	3
Karmakar et al., 2012	3	3	3	2	1	2	3
Uemura et al., 2012	3	3	1	2	1	2	3
Chen & Chou, 2013	3	3	3	2	1	2	3

Table 3. Cont.							
Chen et al., 2013	3	3	3	2	1	2	3
Chiu & Chou, 2013	3	3	3	2	1	2	3
Fritz et al., 2013	3	3	3	2	1	2	3
Marques, et al., 2013a	3	1	3	2	1	2	3
Marques, et al., 2013b	3	1	3	2	1	2	3
Weiss et al., 2013	3	3	1	2	1	2	3
Ayoubi et al., 2014	2	3	3	2	1	2	3
Barelle et al., 2014	3	3	3	2	1	2	3
Iwata et al. 2014	3	3	3	2	1	2	3
Kobayashi et al., 2014	3	3	3	2	1	2	3
König et al., 2014	3	3	1	2	1	2	3
Mignardot et al., 2014	2	3	1	1	1	1	2
Yang & Pai, 2014	2	3	3	1	1	2	3
Cebolla et al., 2015	3	3	3	2	1	2	3
MacAulay et al., 2015	2	3	3	2	1	2	3
Rispens et al., 2015	3	3	3	2	1	2	3
Wright et al., 2015	3	3	3	2	1	2	3
Bounyong et al., 2016	3	3	3	2	1	2	3
Fujimoto & Chou, 2016	3	3	3	2	1	2	3
Howcroft et al., 2016	2	3	3	2	1	2	3
Ihlen et al., 2016	3	3	3	2	1	2	3
Rinaldi et al., 2016	3	3	3	2	1	2	3
Sawers et al., 2016	3	3	3	1	1	2	3
Bizovska et al., 2017	2	3	3	1	1	1	3
de Melker Worms et al., 2017a	3	3	3	2	1	2	3
de Melker Worms et al., 2017b	3	3	3	2	1	2	3
Marques et al., 2017	3	3	1	2	1	2	3
Freire Júnior et al., 2017	3	3	3	2	1	2	3
Rinaldi et al., 2017	3	3	3	2	1	2	3
Svoboda et al., 2017	2	3	3	2	1	2	3
Allen & Franz, 2018	3	3	3	2	1	2	3
Benson et al., 2018	3	3	3	2	1	2	3
Howcroft et al., 2018	3	3	3	1	1	1	3
Kwon et al., 2018	3	3	3	2	1	2	3
Marques et al., 2018	3	3	1	2	1	2	3
Qiao et al., 2018	3	3	3	2	1	2	3
Sawers & Bhatt, 2018	3	3	3	1	1	2	3
Thompson et al., 2018	3	3	3	2	1	2	3
Watanabe et al., 2018	3	3	3	2	1	2	3
Santos Bueno et al., 2019	3	3	3	2	1	2	3
Gillian et al., 2019	2	3	1	1	1	1	2
Mak et al., 2019	2	3	3	2	1	2	3
Yamagata et al., 2019a	3	3	3	1	1	2	3
Yamagata et al., 2019b	3	3	3	1	1	1	3
Gonzalez et al., 2020	3	3	3	2	1	1	3
Pol et al., 2021	2	3	1	2	1	2	2
Sadeghi et al., 2021	3	3	3	2	1	2	3
Yamagata et al., 2021	3	3	3	1	1	1	3
Bruijn et al., 2022	3	3	3	1	1	2	3
Figueiredo et al., 2022	3	3	1	2	1	2	3
Nascimento et al., 2022	2	3	1	2	3	2	2
Wang et al., 2022	1	3	3	1	1	2	3
Yoshida et al., 2022	2	3	3	2	1	2	3
Baba et al., 2023	3	3	3	2	1	2	3
Wang & Bhatt, 2023	1	3	3	1	1	2	3

1–strong methodological quality; 2—moderate methodological quality; 3—weak methodological quality.

3.3. Gait spatiotemporal parameters

The spatiotemporal parameters analyzed among the studies comprised gait speed; cadence; stride and step length; stride and step time; stride and step width; stance phase; swing phase; single support phase; double support phase; and base of support.

3.3.1. Gait speed

Gait speed Gait speed was the parameter most analyzed, namely in 50 studies that compared fallers and non-fallers. Regarding these studies, 29 reported the fallers' gait speed was lower than non- fallers (Auvinet et al., 2003; Ayoubi et al., 2014; Baba et al., 2023; Chiba et al., 2005; Chiu & Chou, 2013; Fritz et al., 2013; Gillain et al., 2019; Karmakar et al., 2013; Kemoun et al., 2002; Kerrigan et al., 2001; Kobayashi et al., 2014; Kwon et al., 2018; Lázaro et al., 2011; Lee & Kerrigan, 1999; Lockhart & Liu, 2008; Lugade et al., 2011; Marques et al., 2018; Nascimento et al., 2022; Nelson et al., 1999; Newstead et al., 2007; Panzer et al., 2011; Rinaldi et al., 2017; Rispens et al., 2015; Sadeghi et al., 2021; Verghese et al., 2009; Wall et al., 2000; Weiss et al., 2013; Wolfson et al., 1995; Yamagata et al., 2019a). Although another 17 studies observed lower values of gait speed in fallers, no statistically significant differences were yielded (Allen & Franz, 2018; Ayoubi et al., 2014; Barelle et al., 2014; Bizovska et al., 2017; Cebolla et al., 2015; Feltner et al., 1994; Freire Júnior et al., 2017; Gillain et al., 2019; Hausdorff et al., 2001; Howcroft et al., 2018; Iwata et al., 2014; Maki, 1997; Marques et al., 2013a; Svoboda et al., 2017; Toulotte et al., 2006; Watanabe, 2018; Yamagata et al., 2019b). No study reported higher values of gait speed in fallers.

Four studies analyzed gait speed variability using linear measures: one used the coefficient of variation and standard deviation (Svoboda et al., 2017), while three only used the standard deviation (Kobayashi et al., 2014; Maki, 1997; Rispens et al., 2015). Of these studies, three reported higher values in fallers (Maki, 1997; Rispens et al., 2015; Svoboda et al., 2017), while one reported no differences between fallers and non-fallers (Kobayashi et al., 2014).

Three studies analyzed gait speed during induced slips (Bruijn et al., 2022; Sawers et al., 2017; Sawers & Bhatt, 2018) and two during induced trips (Pavol et al., 1999; Pijnappels et al., 2005). Four studies reported no differences between falls and recoveries (Bruijn et al., 2022; Pijnappels et al., 2005; Sawers et al., 2017; Sawers & Bhatt, 2018), while only one reported that the gait speed of the elderly who fell was higher than the elderly who recovered from an induced trip (Pavol et al., 1999).

3.2.2. Cadence

Cadence was evaluated in 22 studies that compared fallers with non-fallers. Among these, six studies reported the fallers' cadence was lower (Auvinet et al., 2003; Greene et al., 2010; Lee & Kerrigan, 1999; Newstead et al., 2007; Rispens et al., 2015; Sadeghi et al., 2021). Although another 10 studies observed lower values of cadence in fallers, no statistically significant difference was yielded (Baba et al., 2023; Barelle et al., 2014; Chiu & Chou, 2013; Howcroft et al., 2018; Kemoun et al., 2002; Kerrigan et al., 2001; Nascimento et al., 2022; Toulotte et al., 2006; Watanabe, 2018; Yamagata et al., 2019b). No study reported higher values of cadence in fallers.

One study analyzed cadence variability (using the standard deviation) and observed no differences between fallers and non-fallers (Rispens et al., 2015).

3.3.3. Stride and step length

Stride or step length was analyzed in 39 studies that compared fallers and non-fallers. Nineteen studies reported the fallers' stride or step length was lower (Auvinet et al., 2003; Mbourou et al., 2003; Barak et al., 2006; Chen & Chou, 2013; Chiba et al., 2005; Fritz et al., 2013; Gillain et al., 2019; Kerrigan et al., 2001; Kwon et al., 2018; Lee & Kerrigan, 1999; Lockhart & Liu, 2008; MacAulay et al., 2015; Marques et al., 2018; Nascimento et al., 2022; Newstead et al., 2007; Sadeghi et al., 2021; Scanaill et al., 2011; Wolfson et al., 1995; Yamagata et al., 2019b). Although another 13 studies observed lower values of stride or step length in fallers, no statistically significant difference was yielded (Baba et al., 2023; Barelle et al., 2014; Cebolla et al., 2015; de Melker Worms et al., 2017a; Feltner et al., 1994; Freire Júnior et al., 2017; Gehlsen & Whaley, 1990; Greene et al., 2010; Kemoun et al., 2002; Kobayashi et al., 2014; Maki, 1997; Svoboda et al., 2017; Toulotte et al., 2006). No study reported higher values of stride or step length in fallers.

Stride or step length variability was studied using the coefficient of variation (de Melker Worms et al., 2017a; Scanaill et al., 2011; Svoboda et al., 2017; Verghese et al., 2009) and standard deviation (Mbourou et al., 2003; Kobayashi et al., 2014; Kwon et al., 2018; Maki, 1997; Marques et al., 2018). Three studies reported that fallers yielded higher values (Mbourou et al., 2003; Maki, 1997; Verghese et al., 2009), while six reported no differences (de Melker Worms et al., 2017a; Kobayashi et al., 2014; Kwon et al., 2018; Scanaill et al., 2011; Svoboda et al., 2017; Thompson et al., 2018).

Step or stride lengths were also analyzed in studies that induced slips (Sawers & Bhatt, 2018; Wang et al., 2022; Yang & Pai, 2014) and trips (Pavol et al., 1999, 2001; Pijnappels et al., 2005) during their methodological set-up. Of these, one study reported the stride and step length of the elderly who fell were higher than the elderly who recovered from the induced trip (Pavol et al., 1999), while two studies reported the stride and step length of the elderly who fell were lower than the subjects who recovered from the induced trips (Pavol et al., 2001) and induced slips (Wang et al., 2022). The other three studies reported no differences between falls and recoveries (Pijnappels et al., 2005; Sawers & Bhatt, 2018; Yang & Pai, 2014).

3.3.4. Stride and step time

Stride and step time were evaluated in 37 studies that compared fallers and non-fallers. Nine studies reported the fallers' stride or step time was higher (Barrett et al., 2008; Chiba et al., 2005; Greene et al., 2010; Marques et al., 2018; Nelson et al., 1999; Rinaldi & Moraes, 2016; Rispens et al., 2015; Sadeghi et al., 2021; Weiss et al., 2013). Although another 10 studies reported higher values of stride or step time in fallers, no statistically significant differences were yielded (Feltner et al., 1994; Greany & Di Fabio, 2010; Howcroft et al., 2018; Kemoun et al., 2002; Kwon et al., 2018; Lockhart & Liu, 2008; Maki, 1997; Mignardot et al., 2014; Scanaill et al., 2011; Toulotte et al., 2006). Only one study reported lower values of stride time in fallers (Kirkwood et al., 2011).

Stride and step time variability were analyzed using the coefficient of variation (Ayoubi et al., 2014; Freire Júnior et al., 2017; Fritz et al., 2013; Greene et al., 2010; Howcroft et al., 2016, 2018; Marques et al., 2017; Scanaill et al., 2011; Svoboda et al., 2017) and standard deviation (Barrett et al., 2008; Hausdorff et al., 2001; Kwon et al., 2018; Maki, 1997; Marques et al., 2017, 2018; Rispens et al., 2015). Six studies reported that fallers yielded higher values (Ayoubi et al., 2014; Barrett et al., 2008; Hausdorff et al., 2001; Kwon et al., 2018; Marques et al., 2017; Rispens et al., 2015), while 10 reported no differences (Ayoubi et al., 2014; Freire Júnior et al., 2017; Fritz et al., 2013; Greene et al., 2010; Howcroft et al., 2016, 2018; Maki, 1997; Marques et al., 2018; Scanaill et al., 2011; Svoboda et al., 2017).

Step or stride time was also analyzed in studies that induced trips during their methodological set-up (Pavol et al., 1999, 2001). These two studies reported the step time of the elderly who fell was lower than the elderly who recovered from induced trips.

3.3.5. Stride and step width

Stride and step width were analyzed in 18 studies that compared fallers and non-fallers. Three studies showed that fallers' stride or step width was higher (Gehlsen & Whaley, 1990; Rinaldi & Moraes, 2016; Scanaill et al., 2011), while one study observed lower values of step width in fallers (Scanaill et al., 2011). The other studies showed no differences between fallers and non-fallers (Chen & Chou, 2013; de Melker Worms et al., 2017a; de Melker Worms et al., 2017b; Feltner et al., 1994; Gehlsen & Whaley, 1990; Heitmann et al., 1989; Kobayashi et al., 2014; Maki, 1997; Marques et al., 2013b; Sadeghi et al., 2021; Svoboda et al., 2017; Thompson et al., 2018; Yamagata et al., 2019a; Yamagata et al., 2019b; Yoshida et al., 2022).

Stride and step width variability was evaluated using the coefficient of variation (de Melker Worms et al., 2017a; de Melker Worms et al., 2017b; Scanaill et al., 2011; Svoboda et al., 2017) and standard deviation (Heitmann et al., 1989; Kobayashi et al., 2014; Maki, 1997; Thompson et al., 2018). All studies reported no differences between fallers and non-fallers.

Step width was also analyzed in studies that induced slips (Espy & Pai, 2007) and trips (Pavol et al., 1999) during their methodological set-up. Both reported no differences between fallers and those who recovered (Pavol et al., 1999). Step width variability was also evaluated (using standard deviation) in one study (Yang & Pai, 2014), which verified higher values in fallers.

3.3.6. Stance phase

The stance phase was evaluated in 13 studies that compared fallers and non-fallers. Four studies reported the fallers' stance phase was higher (Barrett et al., 2008; Chiu & Chou, 2013; Kwon et al., 2018; Marques et al., 2018). The other studies showed no differences between fallers and non-fallers (Baba et al., 2023; de Melker Worms et al., 2017a; Fritz et al., 2013; Greene et al., 2010; Howcroft et al., 2016, 2018; Kirkwood et al., 2011; Kobayashi et al., 2014; Scanaill et al., 2011).

The stance phase variability was evaluated using the coefficient of variation (de Melker Worms et al., 2017a; Greene et al., 2010; Howcroft et al., 2016; Marques et al., 2017; Scanaill et al., 2011) and standard deviation (Barrett et al., 2008; Kobayashi et al., 2014; Marques et al., 2018). Five studies reported that fallers yielded higher values (Barrett et al., 2008; de Melker Worms et al., 2017a; Kobayashi et al., 2014; Marques et al., 2017, 2018), while three reported no differences (Greene et al., 2010; Howcroft et al., 2016; Scanaill et al., 2011).

The stance phase was also evaluated in one study that induced trips during its methodological set-up (Pijnappels et al., 2005), which showed no differences between fallers and those who recovered.

3.3.7. Swing phase

The swing phase was analyzed in 18 studies that compared fallers and non-fallers. Five studies observed the fallers' swing phase was lower than non-fallers (Chiu & Chou, 2013; Kemoun et al., 2002; Kwon et al., 2018; Marques et al., 2018; Verghese et al., 2009). In the other 13 studies, no statistically significant difference was yielded (Barrett et al., 2008; de Melker Worms et al., 2017a; Feltner et al., 1994; Fritz et al., 2013; Greany & Di Fabio, 2010; Greene et al., 2010; Howcroft et al., 2016, 2018; Kirkwood et al., 2011; Kobayashi et al., 2014; Scanaill et al., 2011; Verghese et al., 2009; Yamagata et al., 2019b).

The swing phase variability was studied using the coefficient of variation (de Melker Worms et al., 2017a; Greene et al., 2010; Howcroft et al., 2016; Scanaill et al., 2011; Verghese et al., 2009) and standard deviation (Barrett et al., 2008; Hausdorff et al., 2001; Kobayashi et al., 2014; Marques et al., 2017, 2018). Three studies reported that fallers yielded higher values (Hausdorff et al., 2001; Marques et al., 2017; Verghese et al., 2009), while seven reported no differences (Barrett et al., 2008; de Melker Worms et al., 2017a; Greene et al., 2010; Howcroft et al., 2016; Kobayashi et al., 2014; Marques et al., 2018; Scanaill et al., 2011).

The swing phase was analyzed in one study that induced trips during its methodological set-up (Pijnappels et al., 2005), which reported no differences between fallers and those who recovered.

3.3.8. Single support phase

The single support phase was evaluated in 10 studies that compared fallers and non-fallers. The fallers' single support phase was lower than non-fallers in two studies (Chiu & Chou, 2013; Newstead et al., 2007). The other eight studies showed no differences between fallers and non-fallers (Feltner et al., 1994; Freire Júnior et al., 2017; Gehlsen & Whaley, 1990; Greene et al., 2010; Kemoun et al., 2002; Kwon et al., 2018; Scanaill et al., 2011; Toulotte et al., 2006).

The single support phase variability was also analyzed in two studies using the coefficient of variation (Greene et al., 2010; Scanaill et al., 2011), which observed no differences between fallers and non-fallers.

3.3.9. Double support phase

The double support phase was analyzed in 18 studies that compared fallers and non-fallers. Of these, nine studies reported the fallers' double support phase was higher (Mbourou et al., 2003; Chiu & Chou, 2013; Kemoun et al., 2002; Kwon et al., 2018; Marques et al., 2018; Nelson et al., 1999; Newstead et al., 2007; Sadeghi, et al., 2021; Verghese et al., 2009), while one observed exactly the contrary (Greene et al., 2010). The other eight studies showed no difference between fallers and non-fallers (Baba et al., 2023; Fritz et al., 2013; Gehlsen & Whaley, 1990; Greany & Di Fabio, 2010; Howcroft et al., 2016; Maki, 1997; Pijnappels et al., 2005; Scanaill et al., 2011).

The double support phase variability was studied using the standard deviation (Maki, 1997) and coefficient of variation (Greene et al., 2010; Scanaill et al., 2011). One study reported that fallers yielded higher values (Maki, 1997), while two reported no differences (Greene et al., 2010; Scanaill et al., 2011).

The double support phase was also evaluated in one study that induced trips during its methodological set-up (Pijnappels et al., 2005), which reported no differences between falls and recoveries.

3.3.10. Base of support during gait

The base of support during gait was analyzed in four studies that compared fallers and non-fallers. Of these, two studies reported the fallers' base of support was higher (Fritz et al., 2013; Nelson et al., 1999). The other two studies showed no differences between fallers and non-fallers (Feltner et al., 1994; Lugade et al., 2011).

The margin of dynamic stability was evaluated in one study that compared fallers and non-fallers (Rinaldi & Moraes, 2016); the authors found higher values in fallers. This parameter was also analyzed in one study that induced slips during its methodological set-up (Yang & Pai, 2014). In this study, the authors found higher values in fallers.

3.3.11. Other parameters

The time of toe-off occurrence (% of the gait stride) was analyzed in one study that compared fallers and non-fallers (Watanabe, 2018). This study reported no differences between fallers and non-fallers regarding this parameter.

3.4. Kinematic parameters

The kinematics parameters analyzed among the studies comprised the following: minimum foot/toe clearance; center of mass (CoM); center of pressure (CoP); head, trunk, pelvis, and lower limb kinematics; and slip kinematic parameters.

3.4.1. Minimum foot/toe clearance

The minimum foot/toe clearance was analyzed in nine studies that compared fallers and non-fallers. Two studies reported the fallers' minimum foot/toe clearance was lower (Cebolla et al., 2015; Chiba et al., 2005). Nonetheless, three studies reported contrary results, i.e., fallers' minimum foot/toe clearance was higher (Karmakar et al., 2007; Khandoker et al., 2008b; Watanabe, 2018). On the other hand, four studies reported no differences between fallers and non-fallers (Gehlsen & Whaley, 1990; Gillain et al., 2019; Khandoker et al., 2008a; Kobayashi et al., 2014).

The minimum foot/toe clearance variability was studied using linear measures (i.e., coefficient of variation (Chiba et al., 2005; Gillain et al., 2019) and standard deviation (Gillain et al., 2019; Karmakar et al., 2007; Kobayashi et al., 2014) and nonlinear measures (i.e., approximate entropy (Karmakar et al., 2013; Khandoker et al., 2008a), sample entropy (Karmakar et al., 2013), wavelet-based multiscale exponent (Khandoker et al., 2008b), detrended fluctuation analysis exponent (Khandoker et al., 2008b), and Poincaré plot indexes (Khandoker et al., 2008a; Khandoker et al., 2008b). Five studies reported that fallers yielded higher variability (Chiba et al., 2005; Karmakar et al., 2007, 2013; Khandoker, et al., 2008a; Khandoker et al., 2008b), while two studies reported no differences between fallers and non-fallers (Gillain et al., 2019; Kobayashi et al., 2014).

3.4.2. CoM

Differences between fallers and non-fallers regarding CoM position were found in two studies (Fujimoto & Chou, 2016; Yamagata et al., 2019a), while one showed no differences (Lugade et al., 2011). One study found no differences regarding CoM displacement (Yamagata et al., 2021), while another found differences regarding CoM lateral sway (Barak et al., 2006). Three studies observed lower values of the fallers' CoM velocity during gait (Chen & Chou, 2013; Fujimoto & Chou, 2016; Rinaldi & Moraes, 2016), namely AP velocity (Chen & Chou, 2013; Rinaldi & Moraes, 2016), while one found no differences (Pavol et al., 1999). Regarding CoM acceleration, one study found lower values in fallers (Fujimoto & Chou, 2016).

CoM variability was analyzed in one study using the variance (Yamagata et al., 2019b). In this study, higher values were found in fallers regarding the variability in the CoM vertical displacement; however, concerning the variability in the CoM mediolateral (ML) displacement, no differences were observed between fallers and non-fallers. On the other hand, one study using the local divergence exponent found higher values in fallers, i.e., higher variability (de Melker Worms et al., 2017a).

CoM was also analyzed in one study that induced trips during its methodological set-up, which reported the CoM position and velocity of the elderly who fell were not different than the elderly who recovered from the induced trip (Espy & Pai, 2007).

The dynamic stability of CoM was analyzed in one study that induced slips during its methodological set-up (dynamic stability is the relative motion state between CoM and the base of support). This study found no differences between the elderly who fell and the elderly who recovered from the induced slip (Yang & Pai, 2014). The dynamic stability was also analyzed in three studies that induced slips during their methodological set-up. Of this, one study reported the fallers' dynamic stability was higher (Bhatt et al., 2011). The other two studies showed no differences (Sawers et al., 2017; Sawers & Bhatt, 2018).

3.4.3. CoP kinematics

One study reported that the fallers' CoP excursion index was lower than non-fallers (Pol et al., 2021). Moreover, one study found higher CoP ML displacement in fallers (Yoshida et al., 2022). On the other hand, four studies reported the CoP AP displacement and/or velocity presented no differences between fallers and non-fallers (Howcroft et al., 2016, 2018; Pol et al., 2021; Yoshida et al., 2022).

The variability in the CoP AP and ML displacements was evaluated in two studies using the standard deviation (Svoboda et al., 2017) and coefficient of variation (Howcroft et al., 2016). Their authors reported no differences between fallers and non-fallers.

3.4.4. CoM-CoP relation

Two studies that compared fallers and non-fallers analyzed the CoM–CoP relation. Their results are contradictory. While one study reported the fallers' CoM–CoP AP distance was lower (Lugade et al., 2011), the other observed higher values (Wright et al., 2015). On the other hand, CoM–CoP ML distance presented no difference between fallers and non-fallers in one study (Lugade et al., 2011).

3.4.5. Head, trunk, and pelvis linear kinematics

Trunk linear kinematics were evaluated in one study that compared fallers and non-fallers (Chiba et al., 2005), they found higher maximal ML displacement of the trunk center in fallers.

One study used the refined composite multiscale entropy and the refined multiscale permutation entropy regarding lower back velocity and acceleration (Ihlen et al., 2016), they found higher complexity in fallers. The computed multiscale entropy and the Shannon entropy were also used to analyze the complexity of the trunk AP and ML displacement (Bizovska et al., 2017); data pointed out the inability of the multiscale entropy to distinguish fallers and non-fallers, whereas Shannon entropy seemed to be sufficient in fall risk prediction. On the other hand, fallers presented higher variability in the lower back vertical axis and lower variability in the lower back ML axis (Weiss et al., 2013).

One study used the short-term exponents of the trunk ML, AP, and vertical displacement to analyze gait variability. No differences were yielded between fallers and non-fallers (Gonzalez et al., 2020). One study that during their methodological set-up induced slips (Yang & Pai, 2014) also analyzed the variability in the trunk through nonlinear measures, i.e., using the maximum Lyapunov exponent and Floquet multiplier. Their authors found no differences between fallers and those who recovered.

The maximum Lyapunov exponent was also used in two studies in order to evaluate the gait variability. Contradictory results were found in these two studies, i.e., one found higher variability in the right anterior superior iliac spine in fallers (Lockhart & Liu, 2008), while the other did not find differences between fallers and non-fallers regarding the head and pelvis (Howcroft et al., 2016). One of these studies also analyzed variability using the ratio of even to odd harmonics, having found differences between fallers and non-fallers regarding the pelvis (Howcroft et al., 2016).

3.4.6. Lower limb linear kinematics

Two studies analyzed the foot velocity and heel vertical velocity at heel strike (Cebolla et al., 2015; Greany & Di Fabio, 2010). They found no differences between fallers and non-fallers.

One study used the fast Fourier transform first quartile on the shank displacement (Howcroft et al., 2018); they found higher variability in fallers.

The hip horizontal displacement (Pijnappels et al., 2005), the hip–ankle distance, the obstacle–ankle distance, the ankle horizontal velocity, and the hip vertical velocity (Pavol et al., 2001) were analyzed in two studies that induced trips during their methodological set-up. No differences were found between fallers and those who recovered.

The hip height was analyzed in two studies that induced trips during their methodological set-up (Pavol et al., 2001; Pijnappels et al., 2005). Of this, one study reported the fallers' hip height at ground foot contact was lower (Pavol et al., 2001). The other study showed no differences between the elderly who fell or recovered from the induced trips (Pijnappels et al., 2005).

3.4.7. Slip kinematics parameters

The slip distance was analyzed in three studies that induced slips during their methodological set-up (Sawers et al., 2017; Sawers & Bhatt, 2018; Wang et al., 2022). Of these, two studies reported the fallers' slip distance was higher (Sawers et al., 2017; Wang et al., 2022). The other study showed no differences (Sawers & Bhatt, 2018). The peak slip velocity was also evaluated in these three studies. Of these, one study reported the fallers' peak slip velocity was higher (Wang et al., 2022); the other two studies showed no differences (Sawers et al., 2017; Sawers & Bhatt, 2018). One of these three studies also assessed the slip duration (Sawers & Bhatt, 2018). In this study, no differences were found between fallers and recoverers.

3.5. Angular kinematics parameters

The angular kinematics analyzed among the selected studies comprised the lower limb joints (hip, knee, and ankle), foot progression angle, and foot angle with the ground, trunk, pelvis, thigh, and shank.

3.5.1. Hip

Five studies reported differences between fallers and non-fallers regarding hip angular position or displacement (Barak et al., 2006; Kemoun et al., 2002; Kerrigan et al., 2000; Kobayashi et al., 2014; Marques et al., 2013a). On the other hand, eight studies found no differences regarding hip angular position or displacement (Allen & Franz, 2018; Baba et al., 2023; Barelle et al., 2014; Feltner et al., 1994; Gehlsen & Whaley, 1990; Kemoun et al., 2002; Kerrigan et al., 2000; Sadeghi et al., 2021).

Fallers exhibited greater variability in the hip in the frontal plane during the entire stance phase (Kobayashi et al., 2014).

Hip angular position was also analyzed in two studies that induced trips (Pavol et al., 2001) and slips (Sawers & Bhatt, 2018) during their methodological set-up. The first one found differences between fallers and those who recovered, while the other did not.

3.5.2. Knee

Knee kinematics were evaluated in 10 studies that compared fallers and non-fallers. These studies reported no differences regarding knee angular position or displacement (Allen & Franz, 2018; Baba et al., 2023; Barelle et al., 2014; Benson et al., 2018; Feltner et al., 1994; Gehlsen & Whaley, 1990; Kemoun et al., 2002; Kerrigan et al., 2001; Sadeghi et al., 2021; Santos Bueno et al., 2019).

Fallers exhibited greater variability in the knee during the entire swing phase (Kobayashi et al., 2014).

Knee angular position was also analyzed in one study that induced slips during its methodological set-up (Sawers & Bhatt, 2018). Data yielded higher values of knee flexion in fallers but no differences regarding knee extension.

3.5.3. Ankle

Ankle angular position or displacement yielded no differences between fallers and non-fallers in nine studies (Allen & Franz, 2018; Baba et al., 2023; Barelle et al., 2014;

Feltner et al., 1994; Gehlsen & Whaley, 1990; Kerrigan et al., 2001; Marques et al., 2013a; Sadeghi et al., 2021; Santos Bueno et al., 2019). On the other hand, differences between fallers and non-fallers regarding ankle kinematics were found in three studies (Barak et al., 2006; Kemoun et al., 2002; Kobayashi et al., 2014).

Fallers exhibited greater variability in the ankle in the frontal plane during the entire stance phase (Kobayashi et al., 2014).

Ankle angular position was analyzed in one study that induced slips during its methodological set-up (Sawers & Bhatt, 2018). No differences were found between fallers and non-fallers.

3.5.4. Foot progression angle

Foot progression angle was analyzed in three studies that compared fallers and non-fallers. These studies supported no differences between fallers and non-fallers (Kwon et al., 2018; Santos Bueno et al., 2019; Yamagata et al., 2019b).

Foot progression angle variability was also studied using the standard deviation (Yamagata et al., 2019a; Yamagata et al., 2019b). No differences were found between fallers and non-fallers.

3.5.5. Foot angle with ground

Differences between fallers and non-fallers regarding the foot angle with the ground were found in two studies (Baba et al., 2023; Chiba et al., 2005). While one study observed higher values in fallers (Chiba et al., 2005), the other found lower values (Baba et al., 2023).

The variability in the maximum foot angle with the ground was also studied using the coefficient of variation (Chiba et al., 2005). In this study, higher values were found in fallers.

3.5.6. Trunk

Trunk angular position was analyzed in one study that compared fallers and non-fallers; no differences were found (Chen et al., 2013).

Trunk angular position was also evaluated in three studies that induced trips (Pavol et al., 1999, 2001) and slips (Wang & Bhatt, 2023) during their methodological set-up. Two of these studies observed differences between fallers and non-fallers (Pavol et al., 2001; Wang & Bhatt, 2023), while the other did not (Pavol et al., 1999).

3.5.7. Pelvis

Pelvis angular position was analyzed in three studies that compared fallers and non-fallers. All studies reported no differences between fallers and non-fallers (Kerrigan et al., 2001; Yamagata et al., 2019a; Yamagata et al., 2019b).

The variability in pelvis angular position was studied using the standard deviation (Yamagata et al., 2019a; Yamagata et al., 2019b); however, no differences were yielded between fallers and non-fallers.

3.5.8. Thigh

Thigh angular position was analyzed in two studies that compared fallers and non-fallers (Yamagata et al., 2019a; Yamagata et al., 2019b), which reported no differences between these groups.

The variability in thigh angular position was studied using the standard deviation (Yamagata et al., 2019a; Yamagata et al., 2019b). No differences between fallers and non-fallers were found.

3.5.9. Shank

Three studies that compared fallers and non-fallers reported differences between fallers and non-fallers regarding shank angular position (Greene et al., 2010; Yamagata et al., 2019a; Yamagata et al., 2019b).

The variability in the shank angular position was studied using the standard deviation (Yamagata et al., 2019a; Yamagata et al., 2019b). Differences between fallers and non-fallers were found, with higher values in fallers.

Shank angular position was also analyzed in two studies that induced slips during their methodological set-up (Sawers et al., 2017; Sawers & Bhatt, 2018). No differences between fallers and non-fallers were yielded.

3.5.10. Other parameters

AP CoM–ankle inclination was evaluated in one study that compared fallers and non-fallers (Chen & Chou, 2013); the authors found higher inclinations in fallers.

The ankle–hip inclination at the time of loading was analyzed in one study that induced trips during its methodological set-up (Pavol et al., 2001). In this study, differences between fallers and those who recovered were found, i.e., higher inclinations in fallers.

Two studies analyzed the variability in inter-joint coordination. One study used the standard deviation for this purpose (Chiu & Chou, 2013) and found higher variability in fallers regarding the knee–ankle coordination (during stance and swing phase); however, the variability in hip–knee coordination yielded no differences between fallers and non-fallers (Chiu & Chou, 2013). In addition, another study reported lower variability in the lower limb coordination in fallers, indicating an inconsistency in neuromuscular control (Sadeghi et al., 2021).

3.6. Kinetics parameters

3.6.1. Ground reaction force

The ground reaction force was analyzed in five studies that compared fallers and non-fallers (Chen et al., 2013; Howcroft et al., 2016, 2018; Kwon et al., 2018; Wright et al., 2015). The peak braking force and the peak propulsive force (calculated from the AP component) presented no differences between fallers and non-fallers (Kwon et al., 2018; Wright et al., 2015). On the other hand, differences regarding braking force and propulsive force were found in another study (Chen et al., 2013). On the other hand, the impulse during the gait cycle presented no differences in two studies (Howcroft et al., 2016, 2018).

Ground reaction force was also evaluated in one study that induced slips during its methodological set-up (Yoshida et al., 2022). This study reported the fallers' coefficient of friction (horizontal ground reaction force/vertical ground reaction force after heel contact) was lower than in those who recovered.

3.6.2. Plantar pressure

Peak plantar pressure and total pressure–time integral presented higher values in fallers (Mickle et al., 2010; Pol et al., 2021). On the other hand, the pressure–time integral regarding different foot regions (medial and lateral heel, medial and lateral midfoot, central and lateral forefoot, hallux, second and lateral toe) showed no difference between fallers and non-fallers; only the pressure–time integral of medial forefoot yielded higher values in fallers (Sadeghi et al., 2021).

3.7. Dynamic parameters

3.7.1. Hip moment

The hip moment was analyzed in four studies that compared fallers and non-fallers (Chen et al., 2013; Kemoun et al., 2002; Kerrigan et al., 2001; Lee & Kerrigan, 1999). Three studies point out differences, namely in the sagittal plane (Kemoun et al., 2002; Kerrigan et al., 2001; Lee & Kerrigan, 1999). Only one study reported no differences between fallers and non-fallers (Chen et al., 2013). Moreover, one study also evaluated other planes of movement (Kerrigan et al., 2001); they found differences regarding the hip adduction moment but no differences concerning hip abduction, external, and internal moments.

The hip moment was analyzed in one study that induced trips during its methodological set-up (Pijnappels et al., 2005), which reported no differences between fallers and those who recovered.

3.7.2. Knee moment

The knee moment was analyzed in four studies that compared fallers and non-fallers. Two studies yielded differences between fallers and non-fallers (Kerrigan et al., 2001; Lee & Kerrigan, 1999), while the other two reported no differences (Chen et al., 2013; Kemoun et al., 2002).

The knee moment was also evaluated in one study that induced trips during its methodological set-up (Pijnappels et al., 2005). In this study, no differences were yielded.

3.7.3. Ankle moment

The ankle moment was evaluated in four studies that compared fallers and non-fallers. Two studies yielded differences between fallers and non-fallers (Chen et al., 2013; Lee & Kerrigan, 1999), while the other two reported no differences (Kemoun et al., 2002; Kerrigan et al., 2001).

Ankle moment was also analyzed in one study that induced trips during its methodological set-up (Pijnappels et al., 2005). The authors reported no differences between fallers and non-fallers.

3.7.4. Hip, knee, and ankle power absorption and generation

One study found differences between fallers and non-fallers regarding hip power absorption and generation, namely with lower values in fallers (Kerrigan et al., 2001). However, another two studies reported no differences between fallers and non-fallers (Kemoun et al., 2002; Lee & Kerrigan, 1999).

Two studies reported the knee power absorption of fallers was lower than non-fallers; however, the knee power peak and power generation presented no differences (Kerrigan et al., 2001; Lee & Kerrigan, 1999).

Ankle power absorption and generation were analyzed in three studies that compared fallers and non-fallers (Kemoun et al., 2002; Kerrigan et al., 2001; Lee & Kerrigan, 1999). One study reported the ankle power generation of fallers was lower than non-fallers (Kerrigan et al., 2001), while another observed higher values of ankle power absorption in fallers (Lee & Kerrigan, 1999). On the other hand, another study reported the ankle power peak presented no differences between fallers and non-fallers (Kemoun et al., 2002).

3.7.5. Other parameters

One study found differences between fallers and non-fallers regarding total CoM kinetic energy (at swing-off), namely with lower values in fallers (Chen & Chou, 2013).

Angular momentum was also evaluated in one study that induced trips during its methodological set-up (Pijnappels et al., 2005). This study reported the fallers' angular momentum at push-off and total momentum are predictors of falls.

3.8. EMG parameters

3.8.1 Muscle activity

Muscle activity was analyzed in 10 studies using EMG measures. Eight studies compared elderly fallers and non-fallers (Allen & Franz, 2018; Bounyong et al., 2016; Kirkwood et al., 2011; Mak et al., 2019; Marques et al., 2013b; Qiao et al., 2018; Watanabe, 2018; Yamagata et al., 2019b), while two studies compared the elderly who fell with the elderly who recovered from induced slips (Sawers et al., 2017; Sawers & Bhatt, 2018).

The fallers' internal oblique activity before heel contact was lower than non-fallers. On the other hand, the same study observed no significant differences in internal oblique activity at the initial stance, final stance, and after toe-off (Marques et al., 2013b).

The gluteus maximus was analyzed in one study that compared fallers and non-fallers. This study reported the fallers' gluteus maximus activity at the final stance is higher than non-fallers. On the other hand, no significant differences in gluteus maximus activity were observed at the initial stance, before heel contact, and after toe-off (Marques et al., 2013b).

The fallers' biceps femoris activity at initial stance and before heel contact is higher than non-fallers. On the other hand, no significant differences in biceps femoris activity were observed at the final stance and after toe-off (Marques et al., 2013b).

The biceps femoris long head was analyzed in one study that induced slips during its methodological set-up. Their authors pointed out the higher onset latencies of fallers. On the other hand, no differences were observed regarding the onset latencies of the nonslip leg and the peak magnitude of the slip and nonslip leg (Sawers et al., 2017).

The gastrocnemius was analyzed in two studies that compared fallers and non-fallers (Kirkwood et al., 2011; Marques et al., 2013b). One of these studies reported the fallers' gastrocnemius activity during the stance phase was lower than non-fallers (Kirkwood et al., 2011). On the other hand, no differences were observed in gastrocnemius activity at the initial stance, before heel contact, and after toe-off (Kirkwood et al., 2011; Marques et al., 2013b).

The medial gastrocnemius yielded differences in onset latencies and peak magnitude when the elderly who fell and the elderly who recovered from an induced slip were compared (Sawers et al., 2017).

The vastus lateralis was analyzed in one study that induced slips during its methodological set-up. The authors reported the fallers' onset latencies of the slip leg were higher than in those who recovered. On the other hand, no differences in onset latencies of the nonslip leg and peak magnitude of the slip and nonslip leg were reported (Sawers et al., 2017).

No differences between fallers and non-fallers were found regarding soleus activity and onset latency (Kirkwood et al., 2011), tibialis anterior activity (Marques et al., 2013b; Sawers et al., 2017), latency (Kirkwood et al., 2011; Sawers et al., 2017), peak magnitude (Sawers et al., 2017), multifidus activity (Marques et al., 2013b; Sawers et al., 2017), or rectus femoris activity (Marques et al., 2013b; Sawers et al., 2017).

The variability in central locus activation of the rectus femoris was studied using the coefficient variation (Sadeghi et al., 2021). No differences between fallers and non-fallers were found.

3.8.2. Muscle synergies and co-contraction

The co-contraction index (between tibialis anterior and gastrocnemius) and lower limb muscle co-contractions of fallers were higher than non-fallers (Bounyong et al., 2016; Marques et al., 2013b).

The muscle synergies were analyzed in two studies that compared fallers and non-fallers. One study reported the fallers' muscle synergies were lower than non-fallers (Allen & Franz, 2018). On the other hand, fallers' kinematic synergy during the early and late swings was higher than non-fallers (Yamagata et al., 2019b).

The muscle synergies were also evaluated in two studies that induced slips during their methodological set-up. In both studies, it was reported that the fallers' muscle synergies were lower than in those who recovered (Sawers et al., 2017; Sawers & Bhatt, 2018).

3.9. Gait symmetry and gait smoothness

Two studies found differences between fallers and non-fallers regarding gait symmetry, which expressed the similarity of craniocaudal movements on the left and the right independently from fluctuations in successive craniocaudal movements of each limb (Auvinet et al., 2003; Rispens et al., 2015).

The two studies that analyzed gait smoothness — a quality that reflects the continuousness or non-intermittency of walking (Figueiredo et al., 2022; Rispens et al., 2015) — found different results, i.e., one study reported that gait smoothness was associated with the number of falls (Rispens et al., 2015), while the other did not find differences between fallers and non-fallers (Figueiredo et al., 2022).

4. DISCUSSION

The aim of the present study was to conduct a systematic review to identify and describe the gait biomechanical parameters related to falls in the elderly population.

According to the results of this systematic review, the gait spatiotemporal parameters were the most analyzed data when elderly fallers and non-fallers were compared, especially the gait speed. The majority of the selected studies for this systematic review reported lower gait speed in elderly fallers, pointing out that this can be a gait biomechanical parameter that differentiates elderly fallers from non-fallers. This lower gait speed in fallers may be the result of reduced functional capacity, fear of falling, or both. Concerning functional capacity, the data compiled in this systematic review may provide some clues: differences between elderly fallers and non-fallers were found regarding lower limb muscular activity and lower limb joints biomechanics (i.e., joints moments and powers), although the number of studies on these topics has been scarce. On the other hand, gait speed has been associated with a fear of falling (Ayoubi et al., 2014; Maki, 1997; Uemura et al., 2012). In this way, 63.4% of the retrospective studies (i.e., studies in which fallers had already suffered a fall at the time of gait assessment) that analyzed gait speed reported a lower gait speed in fallers, while only 33.3% of the prospective studies (i.e., studies in which fallers had not suffered a fall at the time of gait assessment) reported a lower gait speed in fallers. These numbers also suggest an effect of fear of falling again on the elderly gait, namely on gait speed. Other parameters were also referenced as related to the fear of falling, such as the stride/step length and the double support phase (Maki, 1997). According to the data in this systematic review, these parameters have also presented the ability to differentiate elderly fallers from non-fallers, i.e., fallers tended to present a reduced stride/step length and an increased double support phase. Therefore, these data point to the importance of interventions in the elderly who restore and improve their functional capacity and self-confidence during activities of daily living.

Gait speed is dependent on cadence and step length (Fukuchi et al., 2019). According to data from this systematic review, the lower gait speed shown by fallers seems to be more sensitive to a reduction in step length than in cadence, although several studies have also found a lower cadence in fallers. On the other hand, stride and step time were other spatiotemporal parameters associated with gait speed (Fukuchi et al., 2019); according to our data, these parameters showed lower ability than gait speed to differentiate fallers from non-fallers. Finally, stride/step width and foot progression angle were gait biomechanical parameters that clearly did not differentiate fallers from non-fallers.

Tripping is one of the most frequent causes of falls in the elderly (Creaby & Cole, 2018), while the minimum foot/toe clearance has been a gait biomechanical parameter associated with trips (Barrett et al., 2010). Regarding this parameter, our data point to contradictory and non-differentiating results, suggesting the minimum foot/toe clearance may not be a consistent differentiator between fallers and non-fallers. In contrast, the minimum foot/toe clearance variability, using both linear and nonlinear measures, appears as a potential parameter associated with a history of falls in the elderly. This is in line with a previous systematic review (Barrett et al., 2010), which concluded that higher minimum foot clearance variability may contribute to an increased risk of trips.

The minimum foot/toe clearance is sensitive to alterations in the angular positions of the swing limb joints, i.e., hip, knee, and ankle (Moosabhoy & Gard, 2006). Previous research pointed to a higher sensitivity to the ankle angular position, then to the hip angular position, and lastly to the knee angular position (Aleixo et al., 2019; Bhudarally et al., 2020; Moosabhoy & Gard, 2006). Thus, the elderly can adjust minimum foot/toe clearance by controlling these joint angles. In this way, the analysis of lower limb joint kinematics among fallers and non-fallers is an important issue. Although it was not transversal to all studies selected for this systematic review, some of them identified differences between fallers and non-fallers regarding hip and ankle angular position or displacement. Thus, the need for interventions that improve the motor control of the lower limb joints is a very important aspect to explore. In this regard, a program of proprioceptive and functional strength exercises seems to be a good solution for improving motor control of the lower limb joints (Aleixo et al., 2022; Aleixo & Abrantes, 2024). On the other hand, knee kinematics do not seem to have the ability to differentiate fallers from non-fallers.

Studies involving gait with induced stability perturbations were relatively scarce and analyzed a large disparity of variables (with low frequency in the various studies). Among the studies that induced trips during their methodological set-up, a lowering strategy, characterized by a faster gait speed and delayed support limb loading, was linked to falls during a step (Pavol et al., 2001). On the other hand, elevating strategy falls were marked by an accelerated gait speed and excessive lumbar flexion. Moreover, fallers exhibited an insufficient reduction in angular momentum during push-off, improper recovery limb placement, and reduced rates of moment generation in support limb joints. Due to the fact that research on this issue is scarce, the extraction of conclusions is largely limited.

Slip falls are a growing health concern for the elderly (Wang et al., 2022). Heel velocity and foot angle with the ground at heel strike were gait biomechanical parameters associated with slip falls (Aleixo & Abrantes, 2015; Baba et al., 2023; Chiba et al., 2005). According to data from this systematic review, the literature is scarce regarding these parameters. Moreover, foot angle with the ground at the heel strike revealed contradictory results, and heel velocity at the heel strike showed no differences between fallers and non-fallers. Moreover, the studies that induced slips during their methodological set-up assessed other gait biomechanical parameters, such as the coefficient of friction, the slip distance, the peak slip velocity, and the slip duration. Once again, the studies that analyzed these issues are scarce; nonetheless, their data indicated the fallers' coefficient of friction (horizontal ground reaction force/vertical ground reaction force, after heel contact) was lower than in those who recovered. Regarding the other parameters, there seems to be no great ability to differentiate fallers from those who recovered.

Postural stability can be defined as the ability to maintain adequate sustainability of the body along the movement (Aleixo et al., 2021). The CoM and CoP have been used to analyze postural stability in previous studies (Aleixo et al., 2018; Caron et al., 2000; Takeda et al., 2017). The literature is scarce concerning the relation between falls and CoM and CoP; however, the contradictory findings across studies emphasize the complexity of assessing postural control and stability during gait, especially regarding the comparison between fallers and non-fallers. Moreover, the analysis of the base of support during gait as well as the margin of dynamic stability also revealed diverse findings, making it impossible to draw clear conclusions.

The variability in the gait biomechanical parameters was studied using linear and nonlinear measures. Overall, fallers tend to exhibit higher variability in the gait pattern. According to previous research (Maki, 1997), this higher gait variability can be linked with lower motor control. As described in a previous paragraph, exercise programs can be good options in order to improve motor control and, as a result, to reduce the risk of falls.

The majority of the included studies were classified as weak in the global assessment, reflecting concerns about their quality. Selection bias was a domain that influenced this classification, with the majority of studies categorized as weak. The dependence on convenience samples has raised concerns regarding the generalizability to broader populations, restricting the external validity of these studies. Additionally, all studies were rated as weak in the study design domain, predominantly attributable to the cross-sectional nature of the investigations and the nonrandomized selection of the subjects. This is not precisely a problem, as our study aimed to compare the gait biomechanical parameters between elderly fallers and non-fallers. Other limitations identified across the various studies include the definition of a fall, the timeframe considered for the fall's occurrence, and the gait assessment on a treadmill. Approximately 55% of the selected studies presented a definition of fall and these definitions were quite similar. However, nearly half of the studies did not provide any explicit definition, which may impact the reliability of the reported results. According to data from this systematic review, approximately 21% of the selected studies conducted the gait assessment on a treadmill. Walking on the treadmill does not reflect everyday gait as it imposes a different gait pattern (Schmitt et al., 2021). In this way, the obtained results may be influenced by this methodological constraint.

Practical and clinical implications arise from this study. In this way, healthcare workers and clinicians must pay attention to some gait biomechanical parameters (i.e., gait speed, stride/step length, and double support phase) when evaluating elderly gait and during interventions that aim to prevent the occurrence of falls.

Some of the gait biomechanical analysis methods used in the selected studies are not considered the gold standard methods to assess gait, i.e., optoelectronic gait analysis systems and force plates (Di Paolo et al., 2021; Müller et al., 2017; Springer & Seligmann, 2016). Nonetheless, most of the other equipment used in the various studies is presented in the literature as validated and reliable. This heterogeneity observed between the reviewed studies regarding the gait biomechanical analysis methods used may limit our conclusions, contributing to different values for the same parameter. Therefore, this is one of the reasons why no meta-analysis was carried out. Therefore, it is preferable for future investigations to use gold-standard methods to assess gait in the elderly.

Indeed, the scarce literature regarding some parameters limited the ability of this study to yield strong conclusions. In this way, further work is needed to understand the association between the gait biomechanical parameters and falls in the elderly. An example is the need for research that comprises parameters associated with motor control, such as muscular activity. Another aspect that we did not see addressed in the studies selected for this systematic review was joint stability. One parameter used to study joint stability is dynamic joint stiffness (Aleixo et al., 2021), which has been used to differentiate fallers and non-fallers in certain clinical populations (Aleixo et al., 2017).

5. CONCLUSIONS

The results of this systematic review pointed out that the gait speed, stride/step length, and double support phase are biomechanical parameters of gait that play a distinctive role in differentiating fallers from non-fallers. In this way, these are parameters that healthcare workers and clinicians must pay attention to when evaluating elderly gait and during interventions that aim to prevent the occurrence of falls. Elderly fallers also tend to exhibit higher variability; the variability in the minimum foot/toe clearance is an important example due to its relation with trips. Although studies on lower limb muscular activity and joint biomechanics are limited, the available research indicated that differences in these aspects may also be associated with the propensity for falls. However, it is crucial to highlight the complexity of drawing clear conclusions due to the scarcity of literature and contradictory results among studies, namely parameters related to postural stability. Parameters such as minimum foot/toe clearance, step width, and knee kinematics did not demonstrate a discriminative ability between fallers and non-fallers. Therefore, despite advancements in understanding the biomechanics of gait concerning falls, further research is needed at some points to provide a more comprehensive and consistent understanding of these complex relationships.

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CAPÍTULO III
ESTUDO II

GAIT CHARACTERISTICS OVER THE SIX-MINUTE WALK TEST IN OLDER WOMEN OF A SPECIFIC PORTUGUESE COMMUNITY: A CROSS-SECTIONAL STUDY.

CARACTERÍSTICAS DA MARCHA NO TESTE DE MARCHA DE SEIS MINUTOS EM MULHERES IDOSAS DE UMA COMUNIDADE PORTUGUESA ESPECÍFICA: UM ESTUDO TRANSVERSAL.

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ESTUDO II: Características da marcha no teste de marcha de seis minutos em mulheres idosas de uma comunidade portuguesa específica: um estudo transversal

O segundo artigo que forma parte deste estudo ***"Gait Characteristics over the six-minute walk test in older women of a specific portuguese community: a cross-sectional study"*** foi publicado na revista "*Current Aging Science*".

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ABSTRACT

Introduction and Objective: There is limited research on the changes that can occur in the gait biomechanical parameters of older adults over long-distance walking. Thus, this study aimed to evaluate the gait characteristics of older women of a specific Portuguese community over the six-minute walk test (6MWT) along with gait spatial and temporal parameters and angular kinematics of the lower limb joints.

Materials and Methods: Twenty-six older women voluntarily participated. Each woman per- formed the 6MWT, and during this, their spatial and temporal parameters were collected through plantar pressure data (100Hz) and angular kinematics through an inertial sensor system (100Hz). The 6MWT was divided into four intervals, and the Friedman test was used to compare them. The median age of the women was calculated, and the Mann-Whitney test was used to compare women above and below the median age value.

Results: An increase in gait speed, stance phase, and double stance phase along the intervals was observed, as well as larger angular displacements of the hip, knee, and ankle ($p<0.05$). Women below or above the median age value also yielded these behaviours. Gait speed, cadence, stride length, and step length were higher in women below the median age value, while stride and step duration were lower ($p<0.05$).

Conclusion: Older women yielded changes in gait spatial and temporal parameters along the 6MWT, as well as larger angular displacements of the lower limb joints. Older women (compared to younger ones) yielded lower gait speed, cadence, stride length, and step length, higher stance and double stance phases, and shorter angular displacements of the lower limb joints.

Keywords: Older women, gait spatial and temporal parameters, gait angular kinematics.

1. INTRODUCTION

A subject aged 65 years or over can be considered an older adult (American College of Sports Medicine et al., 2022). However, older adults aged 65 to 74 years are referred to as "early older adults" and those over 75 as "late older adults" (Orimo et al., 2006). The biological changes that occur during aging lead to a decrease in the functional capacity and quality of life of older adults (Wang et al., 2019). As a potential result of the decreased functional capacity, the number of falls increases with age (Smee et al., 2012; Todd & Skelton, 2004; Ungar et al., 2013). Moreover, older women have a higher prevalence of falls than older men (Siqueira et al., 2011; Todd & Skelton, 2004). Indeed, menopause was reported to be associated with some inherent risk factors for falls, such as decreased physical function (Hita-Contreras et al., 2016). Therefore, women undergo a special physiological phase after menopause (Zhao et al., 2020).

Gait is a common daily living activity among older adults, and a large percentage of their falls occur during gait (Prince et al., 1997). Most studies that analyzed the gait of older adults have used trials lasting less than one minute (Silva et al., 2024), i.e., low-distance walking. However, fatigue can induce gait instability and altered gait parameters (Helbostad et al., 2010). Therefore, the gait of older adults should also be evaluated over longer distances, which may induce fatigue. According to the literature, walking for 30 minutes can be considered a long distance for the elderly (Elhadi et al., 2017; Wong et al., 2020). A previous study showed that older adults yielded higher asymmetry and variability at the ankles during a 30-minute walk, i.e., higher instability (Wong et al., 2020). Thus, changes in the gait pattern can occur over the performance of higher distances, exposing older adults to a probable larger fall risk. Nonetheless, there is limited research on the changes that can occur in gait biomechanical parameters in older adults over long-distance walking. Therefore, identifying changes in gait biomechanical parameters over long distances would assist in creating gait training interventions that aim to increase the gait capacity of older adults.

The physical activity guidelines for older adults have pointed to 30 minutes a day (that can be achieved by accumulating periods of 10 minutes or more), 5 days a week, and moderate-intensity activity, such as brisk walking (American College of Sports Medicine et al., 2022). However, few older adults attain current physical activity guidelines (Jefferis et al., 2014), indicating that their usual walking periods are less than 10 minutes. This way, the six-minute walk test (6MWT) can be a good option for assessments of gait deficits because of its relatively long duration (Storm et al., 2020). In other words, the test is not too long and different from the older adults' daily tasks, nor is it too short that it does not induce fatigue processes. The 6MWT is a test that measures functional capacity (Ubuane et al., 2018). This test was used mainly in adults with chronic respiratory diseases until 1985 (Ubuane et al., 2018). Then, its utility was extended beyond the cardiopulmonary domain to individuals with other conditions and disorders, such as older adults and individuals with neuromuscular and rheumatic disorders (Ubuane et al., 2018). The 6MWT evaluates the distance that an individual can walk in 6 minutes along a 30m course at a self-selected speed (ATS Committee, 2002; Rikli & Jones, 2013). In accordance, the 6MWT is non-invasive and repeatable (Storm et al., 2020).

Moreover, it should be useful to assess gait biomechanical parameters. According to a recent systematic review (Storm et al., 2020), gait analysis during the 6MWT using wearable inertial sensors has already been attempted and proved to be technically feasible. This way, some studies have used wearable inertial sensors for the assessment of older adults' gait during the 6MWT (Drover et al., 2017; Galán-Mercant et al., 2019; Howcroft et al., 2017; Waugh et al., 2019), and some of them used these instruments to create models and classifications that predict falls in this population (Drover et al., 2017; Howcroft et al., 2017).

According to a recent systematic review (Silva et al., 2024), the gait spatial and temporal parameters are related to the history of falls in older adults. This way, gait speed, stride/step length, and double support phase have differentiated fallers from non-fallers. Moreover, fallers also tend to exhibit higher variability in gait spatial and temporal parameters. On the other hand, angular kinematics of the lower limb joints also present differences between fallers and non-fallers (Kemoun et al., 2002). According to the authors, in fallers, the ranges of motion at the hip and ankle are reduced, and a change in the walking pattern is observed, i.e., a delay in the ankle dorsiflexion at the beginning of the swing phase.

Based on the above-mentioned findings, the aim of our research was to evaluate the gait characteristics of older women of a specific portuguese community over the 6MWT regarding gait spatial and temporal parameters as well as angular kinematics of the lower limb joints. In addition, an analysis of the effect of age was also carried out.

2. METHODS

2.1. Study design

This cross-sectional study followed the principles of experimental procedures in accordance with the Declaration of Helsinki. The study was also approved by the Ethical Committee of the Faculdade de Educação Física e Desporto – Universidade Lusófona (Ref. No. J1621A).

2.2. Participants

Twenty-six older women voluntarily participated in this study (age: between 65.0 and 91.0 years, 72.5 ± 6.6 years; height: 1.54 ± 0.05 m; body mass: 70.2 ± 10.5 kg). They were selected from the community of Marrazes, Leiria, Portugal, with the support of the respective town council and the local Sport Clube Leiria Marrazes. This way, posters and information leaflets were distributed throughout the community. Subjects were required to be aged 65 years or older and were excluded if they: 1) presented any rheumatic or neurologic disease; 2) presented heart disease, chronic obstructive pulmonary disease, or cancer; 3) had the need for some device to assist during walking – e.g., cane or walker; 4) presented cognitive impairment – Mini-Mental Status Examination (MMSE) score < 26 (Santana et al., 2016); or 5) participated in any physical exercise program in the last three months. All participants signed an informed consent statement prior to the assessment.

2.3. Assessments

2.3.1. Evaluation of the demographic and clinical characteristics

Regarding demographic and clinical characteristics, the participants were assessed using a form. The Portuguese version of the MMSE was also applied to test cognitive impairment (Guerreiro et al., 1994). This questionnaire comprises a 30-item test (if the patient does not respond or responds incorrectly to each question – score "0"; if the patient responds correctly to each question – score "1"), which includes questions about orientation, attention, recall, and language (Freitas et al., 2015; Santana et al., 2016). A score of 26 out of 30 is recommended as the cut-off value for cognitive impairment (Santana et al., 2016).

2.3.2. Six-minute walk test (6MWT)

Each participant performed the 6MWT over a 30 m flat course in a rectangular shape (10 m x 5 m), with cones as ground markers in each corner and every 1 m marked with tape (Figure 1). Participants were instructed to walk as fast as possible for 6 minutes. They were warned that if they felt tired during the test, they could walk more slowly or stop and sit on a chair to rest (there were several chairs along the course for this purpose) – although the test time continued to count. As soon as they felt stable, they were allowed to return to the test. The distance of each test was collected along with the gait biomechanical parameters.

Figure 1. The course of the 6-Minute Walk Test. The black arrow indicates the walking direction.

2.3.2.1. *Gait spatial and temporal data*

Gait spatial and temporal parameters were acquired during the 6MWT through plantar pressure data as follows: two pressure platforms FDM 1.5 (Zebris Medical GmbH, Weitnau-Seltmans, Germany) – each platform with 158 cm in length, 60.5 cm in width, and 2.1 cm in height. The two pressure platforms were placed, one in continuation of the other and in the middle of the first 10 m course. Thus, data were collected during the straight-line performance over the pressure platform at 100 Hz. At each pass over the pressure platform, the average values of each spatial and temporal parameter were recorded. The Zebris FDM software was used to compute the recorded data (Zebris, 2019). The following parameters were obtained: gait speed (m/s) – average gait speed during the analysed interval; cadence (steps/min) – step frequency; stride length (m) – anteroposterior distance between two heel contacts of the same foot; stride duration (s) – time span of a stride; step length (m) – anteroposterior distance between the heel contact of one foot and the heel contact of the other; step width (cm) – mediolateral distance between the right and left foot; step duration (s) – time span of a step; percentage of stance phase (%) – phase of the gait cycle in which the foot has contact with the ground (Figure 2); percent- age of loading response phase (%) – phase between the initial ground contact and contralateral toe off; percentage of the pre-swing phase (%) – phase during the gait the cycle that begins at contralateral initial contact and ends at toe off of the viewed side of the body; percentage of the swing phase (%) – phase of the gait cycle during which the foot has no contact with the ground; percentage of the double stance phase (%) – sum of the loading response phase and the pre-swing phase; foot rotation, measured in degrees [°] – angle between the longitudinal axis of the foot and the walking direction (negative values represents inward rotation and positive values represents outward rotation).

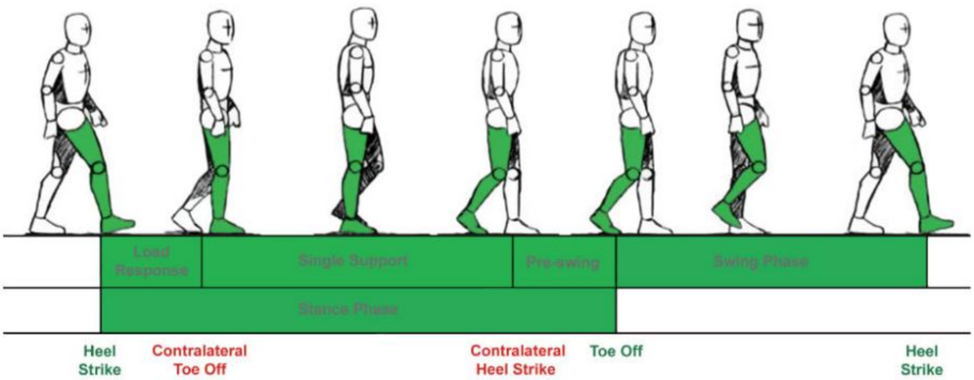

Figure 2. The gait cycle is represented by the “green” limb. In “red” are gait events of the contralateral limb.

2.3.2.2. *Angular kinematic data*

Angular kinematic parameters of the lower limbs in the sagittal plane were collected with an Xsens MTw Awinda system using 7 wireless inertial measurement units (IMU). The IMUs were attached to the segments according to: IMU1 – attached with double-sided tape on the back at the level of the sacrum with its local reference “x” pointing up- ward, “y” pointing left, and “z” pointing backward; IMU2 – attached with a neoprene velcro body strap laterally on the right thigh with its local reference “x” pointing forward, “y” pointing upward, and “z” pointing right (perpendicularly to the sagittal plane); IMU3 – attached with a neoprene velcro body strap laterally on the left thigh with its local reference “x” pointing forward, “y” pointing downward, and “z” pointing left (perpendicularly to the sagittal plane); IMU4 – attached with a neoprene velcro body strap laterally on the right shank with its local reference “x” pointing forward, “y” pointing upward, and “z” pointing right (perpendicularly to the sagittal plane); IMU5 – attached with a neoprene velcro body strap laterally on the left shank with its local reference “x” pointing forward, “y” pointing downward, and “z” pointing left (perpendicularly to the sagittal plane); IMU6 – attached with double-sided tape to the right instep with its local reference “x” pointing forward, “y” pointing left, and “z” pointing upward; IMU7 – attached with double-sided tape to the left instep with its local reference “x” pointing forward, “y” pointing left, and “z” pointing upward. Prior to the experimental task, sensor outputs were collected for five seconds while the participants were asked to stand in an a priori known pose, *i.e.*, with arms neutral beside the body. Data were collected from this position and used to apply a functional calibration procedure to determine the relative orientation of each inertial sensor regarding the related body segment (Roetenberg et al., 2013). Data were acquired with a sampling rate of 100 Hz. These data were collected at each pass over the pressure platform. Kinetikos CE-marked cloud-based platform (Kinetikos, Coimbra, Portugal) was used to reconstruct the body motion of the participants using a three-dimensional kinematic computer model of the skeletal system, including lower extremities and respective joints (Alberto et al., 2021). The coordinate system of the joint matched the International Society of Biomechanics recommendations and rotations were represented by Cardan-Euler angles, following the same recommendations (Winter, 1991). During each pass over the pressure platforms, the average values of the following angular kinematic parameters were recorded, including the angular positions of the hip, knee, and ankle at each articular transition phase, e.g., the angular position of the knee at the instant of transition between knee flection and knee extension, measured in degrees [°] and angular displacements of the hip, knee, and ankle, measured in degrees [°]. For the hip, a neutral position in relation to the pelvis was recorded as 0.0°, with positive values indicating flexion and negative values indicating extension. For the knee, a value of 0.0° was recorded for total extension, and positive values were recorded for flexion. Similarly, a neutral position for the ankle was recorded as 0.0°, with positive values indicating dorsiflexion and negative values indicating plantar flexion.

2.3.3. Data processing and statistical analysis

The 6MWT was divided into four intervals (each with 90 seconds), and only the first pass of each interval was considered for analysis. The average values of each biomechanical parameter were inserted in the Statistical Package for the Social Sciences software for Windows (version 25) in order to perform the statistical analyses. The Friedman test was used to compare the four intervals regarding the biomechanical parameters. The median age of the women was calculated, and the Mann-Whitney test was used to compare the biomechanical parameters of older women above and below the age median value. The Shapiro-Wilk test was used to test the normality of data. Due to the fact that some variables did not present a normal distribution, namely, the distance covered during the 6MWT, Spearman's rank correlation coefficient was used to study the correlation between variables. Differences were considered statistically significant for P values <0.05.

3. RESULTS

3.1. Demographic and clinical characteristics

Table 1 presents the demographic and clinical characteristics of the enrolled participants. From the median age value (71.5 years), participants were divided into two groups of 13 subjects each (above and below the age median value). No differences were found between the two groups regarding body mass, height, and body mass index; however, women below the median age value presented higher MMSE values ($p < 0.05$) and a longer distance covered during the 6MWT ($p < 0.001$) compared to women above the median age value.

Table 1. Demographic and clinical characteristics of the selected women. Distance covered during the 6MWT.

	Women below median (n=13)	Women above median (n=13)	All women (n=26)
	Mean (sd)	Mean (sd)	Mean (sd)
Age (years)	67.5 (2.0)	77.7 (5.6)	72.5 (6.6)*
Body Mass (kg)	71.9 (11.7)	68.4 (9.4)	70.2 (10.5)
Height (m)	1.53 (0.06)	1.55 (0.05)	1.54 (0.05)
Body Mass Index (Kg/m²)	30.6 (4.4)	28.6 (4.1)	29.6 (4.3)
Mini-Mental Status Examination	28.0 (1.3)	26.6 (1.7)	27.3 (1.6)Ψ
Distance Covered 6MWT (m)	412 (57)	291 (79)	351 (91)*

sd – standard deviation; Ψdifferences between groups, $p < 0.05$; *differences between groups, $p < 0.001$

3.2. Gait spatial and temporal parameters

Table 2 shows the mean and standard deviation of the gait spatial and temporal parameters as well as the comparison between 6MWT intervals. When all women were analysed as a whole, an increase in the gait speed between the 2nd and 3rd intervals was observed ($p < 0.05$). This was the result of an increase in cadence and stride length ($p < 0.05$). However, gait speed had no change between the 3rd and 4th intervals; despite this, cadence increased, and stride length decreased between these intervals ($p < 0.05$). As a consequence of the increase in gait speed along intervals, the values of the step and stride duration decreased over the test ($p < 0.05$). Moreover, the values of the stance phase, loading response phase, pre-swing phase, and double stance phase increased along the intervals; in the opposite direction, values of the swing phase decreased ($p < 0.05$).

When we separately analysed women below and women above the median age value, the behaviours of the gait spatial and temporal parameters along the intervals were similar to those observed when we analysed the group as a whole.

From the comparison between women below and women above the age median value, differences were observed regarding the gait spatial and temporal parameters. This way, gait speed, cadence, stride length, and step length were higher in women below the age median value ($p < 0.05$), while stride and step duration were naturally lower ($p < 0.05$). Women below the median age value also yielded a lower stance phase, loading response phase, pre-swing phase, and double stance phase during the first two or three intervals of the 6MWT ($p < 0.05$); during the 4th interval, no differences were observed between groups regarding these variables. In the opposite direction, women below the median age value showed a lower swing phase during the first interval of the 6MWT ($p < 0.05$). Finally, no differences were observed regarding step width and foot rotation.

The distance covered during the 6MWT was positively correlated with the following gait spatial and temporal parameters: step length ($R > 0.7$; $p < 0.001$); stride length ($R > 0.8$; $p < 0.001$); cadence ($R > 0.8$; $p < 0.001$); gait speed ($R > 0.9$; $p < 0.001$); swing phase; during the first three intervals of the 6MWT ($R > 0.5$; $p < 0.001$). On the other hand, the distance covered during the 6MWT was negatively correlated with the following gait spatial and temporal parameters: step width ($R < -0.4$; $p < 0.01$); stance phase, during the first three intervals of the 6MWT ($R < -0.4$; $p < 0.01$); loading response phase, during the first three intervals of the 6MWT ($R < -0.5$; $p < 0.001$); pre-swing phase, during the first three intervals of the 6MWT ($R < -0.6$; $p < 0.001$); double stance phase, during the first three intervals of the 6MWT ($R < -0.6$; $p < 0.001$); step time and stride time ($R < -0.7$; $p < 0.001$).

Table 2. Mean and standard deviation of the gait spatial and temporal parameters. Differences between the intervals of 6MWT.

	Women below median (n=13)				**Women above median (n=13)**				**All women (n=26)**			
Variables	**1st Interval**	**2nd Interval**	**3rd Interval**	**4th Interval**	**1st Interval**	**2nd Interval**	**3rd Interval**	**4th Interval**	**1st Interval**	**2nd Interval**	**3rd Interval**	**4th Interval**
Gait speed (m/s)	1.28 (0.17)	1.27 (0.20)ψ	1.31 (0.20)	1.33(0.21)Ψ	0.87 (0.23)λ	0.89 (0.24)*	0.94 (0.26)	0.92(0.23)Ψ	1.08 (0.29)λ	1.08(0.29)*ψ	1.13 (0.30)	1.12(0.30)Ψ
Cadence (steps/min)	130 (8)	130 (8)ψ	131 (10)+	136 (11)Ψ	108 (16)	109 (14)	111 (16)	111 (16)Ψ	119 (17)	119 (16)ψ	121 (16)+	124 (18)Ψ
Stride length (m)	1.18 (0.14)	1.17 (0.15)	1.20 (0.11)	1.17 (0.14)	0.96 (0.17)λ	0.98 (0.19)*	1.01 (0.21)	0.97(0.17)Ψ	1.07 (0.19)λ	1.07 (0.19)	1.11 (0.19)+	1.07 (0.18)
Stride duration (s)	0.92 (0.05)	0.92(0.06)*ψ	0.90 (0.08)	0.87(0.08)Ψ	1.12 (0.17)λ	1.11 (0.15)*	1.09 (0.15)	1.08(0.16)Ψ	1.02 (0.16)λ	1.02(0.15)*ψ	1.00 (0.15)	0.98(0.17)Ψ
Step length - L (m)	0.58 (0.09)	0.58 (0.10)	0.60 (0.07)	0.57 (0.09)	0.48 (0.09)	0.49 (0.11)	0.50 (0.11)	0.48 (0.08)	0.53 (0.10)	0.54 (0.11)	0.55 (0.10)	0.53 (0.09)
Step length - R (m)	0.60 (0.06)	0.59 (0.06)	0.60 (0.05)	0.60 (0.06)	0.48 (0.09)λ	0.49 (0.08)	0.51 (0.11)	0.49 (0.10)	0.54 (0.09)	0.54 (0.09)	0.56 (0.09)	0.55 (0.10)
Step width (cm)	11.8 (3.6)	12.2 (4.0)	12.4 (3.8)	12.7 (4.4)	14.3 (2.5)	13.6 (2.4)	13.6 (1.9)	13.5 (2.0)Ψ	13.1 (3.3)	12.9 (3.3)	13.0 (3.0)	13.1 (3.4)
Step duration - L (s)	0.46 (0.03)	0.46 (0.03)ψ	0.45 (0.05)	0.43(0.03)Ψ	0.57 (0.08)λ	0.56 (0.08)	0.54 (0.07)	0.54 (0.09)	0.51 (0.08)λ	0.51 (0.08)	0.50 (0.08)	0.48(0.09)Ψ
Step duration - R (s)	0.46 (0.03)	0.46 (0.04)*	0.45 (0.04)	0.44 (0.07)	0.56 (0.09)	0.56 (0.08)	0.55 (0.09)	0.54 (0.08)	0.51 (0.08)	0.51 (0.08)*	0.50 (0.09)	0.49 (0.09)
Stance phase - L (%)	63.0 (2.4)ϕλ	64.3 (2.0)ψ	65.6 (1.1)+	69.0 (2.7)Ψ	65.5 (2.5)λ	66.2 (2.8)ψ	67.3 (2.9)	68.6 (2.5)Ψ	64.3 (2.7)λ	65.2 (2.5)ψ	66.4 (2.3)+	68.8 (2.6)Ψ
Stance phase - R (%)	63.6 (2.1)λ	64.2 (2.4)ψ	65.3 (2.8)	67.6 (2.8)Ψ	67.0 (3.1)	66.5 (2.7)ψ	66.7 (3.0)	67.9 (2.4)	65.3 (3.1)	65.3 (2.8)ψ	66.0 (2.9)+	67.7 (2.5)Ψ
Loading phase - L (%)	13.2 (2.2)λ	14.1 (2.3)	14.8 (2.8)	17.4 (4.5)Ψ	16.4 (3.3)	16.2 (3.1)ψ	17.0 (2.4)	18.1 (2.8)Ψ	14.8 (3.2)λ	15.2 (2.9)ψ	15.9 (2.8)	17.7 (3.7)Ψ
Loading phase - R (%)	13.0 (1.8)ϕλ	14.0 (2.0)ψ	15.0 (2.4)	17.8 (5.6)Ψ	16.0 (1.9)	16.0 (2.6)ψ	17.0 (2.7)	18.2 (3.0)Ψ	14.5 (2.4)λ	15.0 (2.5)ψ	16.0 (2.7)	18.0 (4.4)Ψ
Pre-swing phase - L (%)	12.9 (1.9)λ	14.0 (1.9)	15.8 (2.6)	18.7 (5.9)Ψ	15.7 (2.1)	16.0 (2.5)ψ	16.6 (2.7)	17.6 (2.9)Ψ	14.3 (2.4)λ	15.0 (2.4)ψ	16.2 (2.6)	18.1 (4.6)Ψ
Pre-swing phase - R (%)	13.2 (2.0)λ	14.1 (2.3)ψ	15.2 (3.5)	17.8 (4.7)Ψ	16.2 (3.2)	16.4 (2.7)	16.8 (2.7)	17.8 (3.0)Ψ	14.7 (3.0)λ	15.3 (2.7)ψ	16.0 (3.2)	17.8 (3.8)Ψ
Swing phase - L (%)	37.0 (2.4)ϕλ	35.7 (2.0)ψ	34.4 (1.1)+	31.0 (2.7)Ψ	34.5 (2.5)λ	33.9 (2.8)ψ	32.7 (2.9)	31.4 (2.5)Ψ	35.7 (2.7)λ	34.8 (2.5)ψ	33.6 (2.3)+	31.2 (2.6)Ψ
Swing phase - R (%)	36.4 (2.1)λ	35.8 (2.4)ψ	34.7 (2.8)	32.4 (2.8)Ψ	33.0 (3.1)	33.5 (2.7)ψ	33.3 (3.0)	32.1 (2.4)	34.7 (3.1)	34.7 (2.8)ψ	34.0 (2.9)+	32.3 (2.5)Ψ
Double-stand (%)	26.5 (3.8)ϕλ	28.5 (3.7)ψ	31.0 (4.0)	36.5 (4.1)Ψ	32.3 (4.8)	32.7 (4.7)*ψ	33.9 (4.5)	36.4 (3.5)Ψ	29.4 (5.2)λ	30.6 (4.7)*ψ	32.5 (4.4)+	36.5 (3.7)Ψ
Foot rotation - L (°)	7.3 (5.6)	7.1 (5.4)	8.6 (5.2)	8.0 (4.9)	6.1 (6.0)	6.6 (6.2)	6.5 (5.8)	6.0 (5.3)	6.7 (5.7)	6.9 (5.7)	7.6 (5.5)	7.0 (5.1)
Foot rotation - R (°)	7.0 (5.3)	8.1 (4.4)	7.8 (5.2)	8.7 (5.4)	10.1 (4.6)	9.4 (4.7)	9.2 (5.3)	9.5 (4.7)	8.5 (5.1)	8.7 (4.5)	8.5 (5.2)	9.1 (5.0)

L – left; R – right; ϕ difference between interval 1 and 2, $p < 0.05$ (all groups); λ difference between interval 1 and 3, $p < 0.05$ (all groups); Ψ difference between interval 1 and 4, $p < 0.05$ (all groups); * difference between interval 2 and 3, $p < 0.05$ (all groups); ψ difference between interval 2 and 4, $p < 0.05$ (all groups); + difference between interval 3 and 4, $p < 0.05$ (all groups); in red the differences between groups above and below median ($p<0.05$).

Age presented positive correlations with step and stride time ($R > 0.5$; $p < 0.01$); stance phase, loading response phase, and double stance phase during the first three intervals of the 6MWT ($R > 0.4$; $p < 0.05$); pre-swing phase, during the first two intervals of the 6MWT ($R > 0.4$; $p < 0.05$). On the other hand, it showed negative correlations with the distance covered during the 6MWT ($R < -0.7$; $p < 0.001$), step length, stride length ($R < -0.5$; $p < 0.05$), swing phase during the first three intervals of the 6MWT ($R < -0.4$; $p < 0.05$), cadence and gait speed ($R < -0.6$; $p < 0.001$).

3.3. Angular kinematics of the lower limb joints

Figures (3 and 4) present examples of the lower limb kinematics during each 6MWT interval of a woman below the median age value and a woman above the median age value, respectively. The determination of the mean and standard deviation curves was done according to Winter (1991):

$$x = \frac{1}{N}\sum_{i=1}^{N} x_i \qquad\qquad \sigma = \frac{1}{N}\sum_{i=1}^{N} \sigma_i$$

where N is the number in intervals over the stride, x_i is the mean value of the variable at the ith interval, and σ_i is the standard deviation of the variable about x_i.

Tables 3-5 show the mean and standard deviation of the angular positions and displacements of the lower limb joints. When all women were analysed as a whole, some angular displacements of the ankle and hip became larger along the intervals ($p < 0.05$): the angular displacements of the hip became larger along the test regarding the first two displacements; the angular displacements of the ankle became larger along the test regarding the 2nd and 3rd displacements. Regarding the angular position, no changing trend was observed throughout the test. Analysing each group separately, women above the median age value also yielded larger angular displacements of the hip and ankle along the test (first two displacements). In contrast, women below the median age value presented no changes throughout the test.

The comparison between women below and women above the median age value yielded some differences regarding the angular kinematics of the lower limb joints. In this way, women below the age median value showed lower values of the angular positions of the ankle at the 1st position and 1st transition ($p < 0.05$); higher values of the 4th displacement of the ankle; higher values of the angular positions of the knee at the 1st, 2nd, and 3rd transition ($p < 0.05$); higher values of the 1st and 2nd displacement of the knee ($p < 0.05$); and higher values of the 2nd displacement of the hip ($p < 0.05$).

The distance covered during the 6MWT was positively correlated with the angular position of the hip: 1st position and 2nd transition ($R > 0.4$; $p < 0.05$). It was also positively correlated with all angular positions of the knee ($R > 0.4$; $p < 0.05$). Regarding the angular position of the ankle, it was positively correlated with the 1st position ($R > 0.4$; $p < 0.05$); on the other hand, the 3rd transition of the ankle ($R > -0.4$; $p < 0.05$) was negatively correlated with the distance covered during the 6MWT. The distance covered during the 6MWT was positively correlated with the 2nd angular displacement of the hip ($R > 0.6$; $p < 0.001$) and negatively correlated with the 1st angular displacement of the hip ($R < -0.5$; $p < 0.001$). Regarding the knee, the distance covered during the 6MWT was positively correlated with the 3rd angular displacement ($R > 0.5$; $p < 0.01$) and negatively correlated with the 2nd angular displacement ($R < -0.5$; $p < 0.01$). Regarding the ankle, it was only positively correlated with the 4th angular displacement ($R > 0.4$; $p < 0.05$).

Gait speed was positively correlated with the 2nd angular displacement of the hip ($R > 0.6$; $p < 0.01$) and negatively correlated with the 1st angular displacement of the hip ($R < -0.6$; $p < 0.01$). Gait speed presented correlations with angular displacements of the knee, positive correlation regarding 1st and 3rd angular displacements ($R > 0.5$; $p < 0.01$), and negative correlation regarding 2nd and 4th angular displacements ($R < -0.4$; $p < 0.05$). Regarding the ankle, gait speed was positively correlated with the 4th angular displacement ($R > 0.5$; $p < 0.01$) and negatively correlated with the 2nd and 3rd angular displacement ($R < -0.5$; $p < 0.01$).

Age presented no correlation with the angular position of the hip; however, it showed some correlations with the 1st ($R > 0.4$; $p < 0.05$) and 2nd angular displacements of the hip ($R < -0.4$; $p < 0.05$). Regarding the knee, negative correlations were found concerning angular position ($R < -0.4$; $p < 0.05$), but no correlations with angular displacements were found. Age also presented negative correlations with the 1st and 2nd angular positions of the ankle ($R < -0.4$; $p < 0.05$).

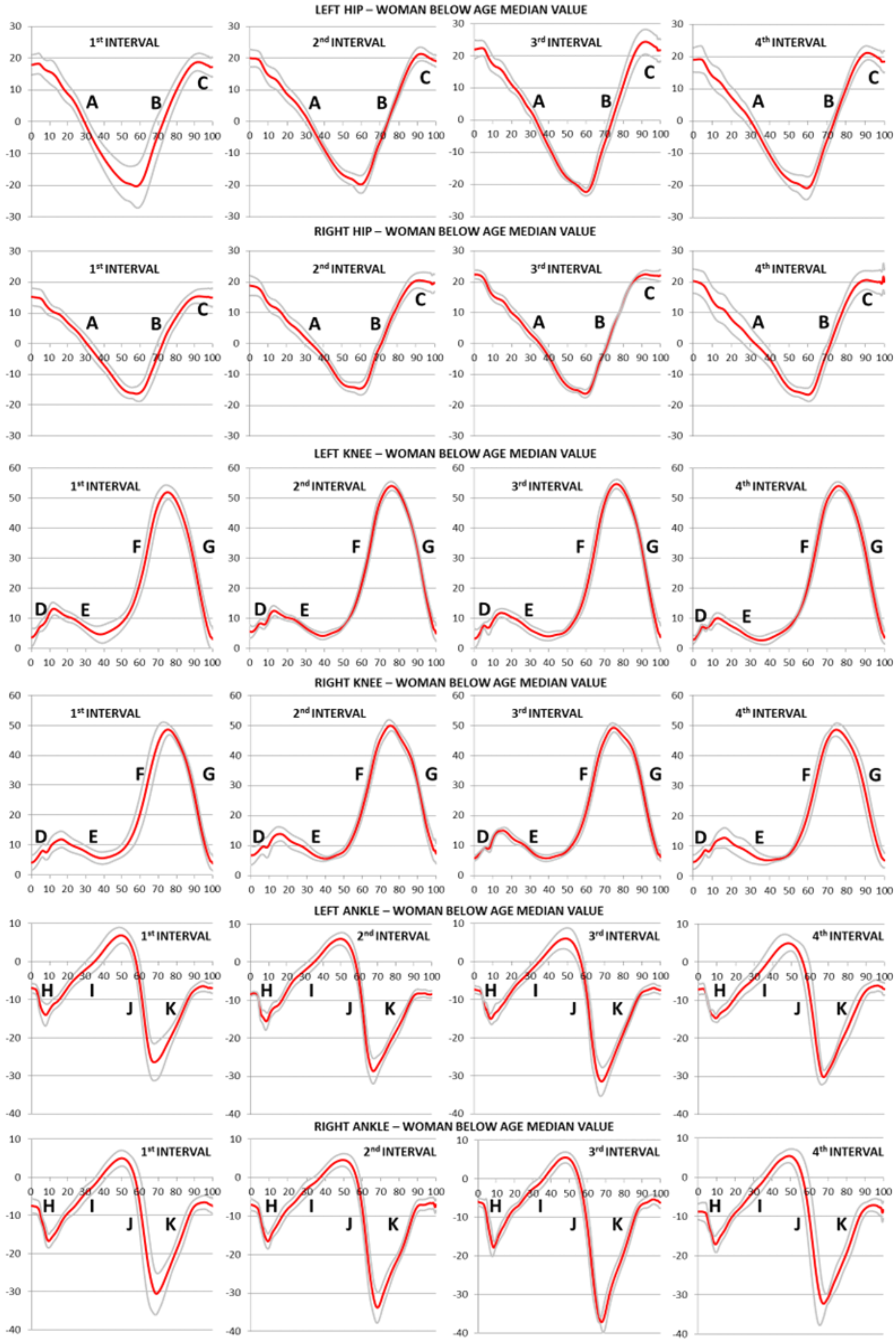

Figure 3. Lower limb kinematics of a woman below median age value. Mean (red) and standard deviation (grey) of each 6MWT interval. **A** – 1st hip displacement (from first angle position to maximum extension); **B** – 2nd hip displacement (from maximum extension to maximum flexion); **C** – 3rd hip displacement (from maximum flexion to the last angle position); **D** – 1st knee displacement (from first angle position to first flexion peak); **E** – 2nd knee displacement (from first flexion peak to the next lowest angle value); **F** – 3rd knee displacement (from the previous lowest angle value to the next flexion peak); **G** – 4th knee displacement (from the second flexion peak to the last angle position); **H** – 1st ankle displacement (from first angle position to first plantar-flexion peak); **I** – 2nd ankle displacement (from first plantar-flexion peak to dorsiflexion peak); **J** – 3rd ankle displacement (from dorsiflexion peak to second plantar-flexion peak); **K** – 4th ankle displacement (from second plantar-flexion peak to last angle position).

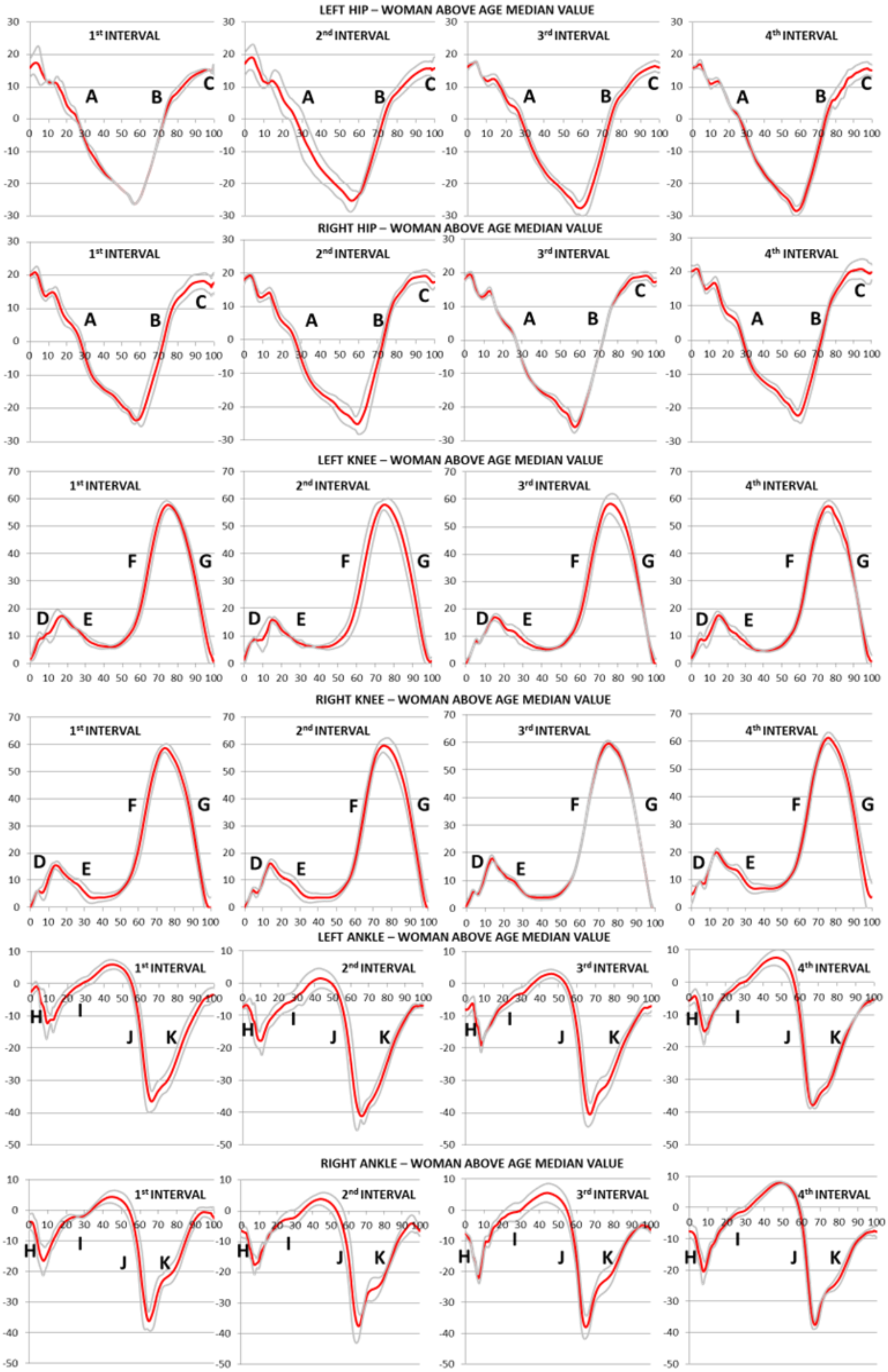

Figure 4. Lower limb kinematics of a woman above median age value. Mean (red) and standard deviation (grey) of each 6MWT interval. **A** – 1st hip displacement (from first angle position to maximum extension); **B** – 2nd hip displacement (from maximum extension to maximum flexion); **C** – 3rd hip displacement (from maximum flexion to the last angle position); **D** – 1st knee displacement (from first angle position to first flexion peak); **E** – 2nd knee displacement (from first flexion peak to the next lowest angle value); **F** – 3rd knee displacement (from the previous lowest angle value to the next flexion peak); **G** – 4th knee displacement (from the second flexion peak to the last angle position); **H** – 1st ankle displacement (from first angle position to first plantar-flexion peak); **I** – 2nd ankle displacement (from first plantar-flexion peak to dorsiflexion peak); **J** – 3rd ankle displacement (from dorsiflexion peak to second plantar-flexion peak); **K** – 4th ankle displacement (from second plantar-flexion peak to last angle position).

Table 3. Mean and standard deviation of the angular positions and angular displacements of the Ankle. Differences between the intervals of 6MWT.

Variables	Women below median (n=13)				Women above median (n=13)				All women (n=26)			
	1st Interval	2nd Interval	3rd Interval	4th Interval	1st Interval	2nd Interval	3rd Interval	4th Interval	1st Interval	2nd Interval	3rd Interval	4th Interval
L Ankle angle - first position (°)	7.8 (7.2)	6.8 (5.1)	6.8 (5.8)	5.3 (4.4)	10.6 (3.7)	11.8 (3.9)	11.6 (3.9)	12.2(5.1)Ψ	9.2 (5.8)	9.3 (5.2)	9.2 (5.4)	8.8 (5.8)
R Ankle angle - first position (°)	8.8 (6.5)ϕ	-10.1 (5.4)	-9.5 (5.2)	-8.8 (3.6)	-11.3 (4.5)	-11.4 (4.6)	-11.2 (4.4)	-11.2 (4.6)	-10.1 (5.6)	-10.7 (4.9)	-10.4 (4.8)	-10.0 (4.2)
L Ankle angle - 1st transition (°)	14.0 (6.2)	-13.1 (5.3)	-13.6 (5.2)	-12.7 (4.6)	-16.3 (4.0)	-17.8 (4.4)	-17.8 (3.2)	-18.2(4.3)Ψ	-15.1 (5.2)	-15.4 (5.3)	-15.7 (4.8)	-15.5 (5.2)
R Ankle angle - 1st transition (°)	14.9 (6.4)	-16.0 (5.7)	-16.0 (6.4)	-15.9 (3.9)	-17.2 (3.0)	-17.4 (3.7)	-17.8 (4.9)	-17.5(4.6)	-16.1 (5.0)	-16.7 (4.7)	-16.9 (5.6)	-16.7 (4.3)
L Ankle angle - 2nd transition (°)	7.5 (3.5)	7.9 (4.1)	8.6 (4.6)	9.3 (3.4)Ψ	7.7 (3.0)	7.2 (3.9)	6.6 (3.5)	6.7 (3.8)	7.6 (3.2)	7.5 (4.0)	7.6 (4.1)	8.0 (3.8)
R Ankle angle - 2nd transition (°)	7.5 (4.5)λ	7.7 (4.8)	8.0 (4.9)	8.5 (4.7)	7.8 (4.5)	8.1 (3.8)	8.1 (2.9)	8.5 (3.3)	7.7 (4.4)λ	7.9 (4.2)	8.1 (4.0)	8.5 (4.0)
L Ankle angle - 3rd transition (°)	-30.2 (8.4)	-29.2 (10.5)	-31-3 (9.0)	-30.5 (8.6)	-26.4 (4.7)λ	-27.2 (5.1)	-28.8 (4.3)+	-27.1 (5.3)	-28.3 (6.9)λ	-28.2 (8.2)	-30.1 (7.0)+	-28.8 (7.2)
R Ankle angle - 3rd transition (°)	-29.2 (8.2)	-30.0 (9.2)	-30.3 (7.8)	-30.5 (8.2)	-24.0 (6.2)	-24.4 (6.3)	-26.4 (6.4)	-24.9 (6.5)	-26.6 (7.6)	-27.2 (8.2)	-28.4 (7.3)	-27.7 (7.8)
L Ankle - 1st displacement (°)	-6.3 (3.0)	-6.3 (3.1)ψ	-6.8 (2.4)	-7.4 (2.4)Ψ	-5.7 (2.2)	-6.0 (2.4)	-6.2 (2.7)	-6.0 (2.4)	-6.0 (2.1)	-6.2 (2.7)	-6.5 (2.5)	-6.7 (2.4)Ψ
R Ankle - 1st displacement (°)	-6.1 (2.9)	-6.0 (3.1)	-6.4 (3.0)	-7.1 (3.2)	-5.9 (3.2)	-6.0 (3.0)	-6.6 (3.3)	-6.3 (2.5)	-6.0 (3.0)λ	-6.0 (3.0)	-6.5 (3.1)	-6.7 (2.9)
L Ankle – 2nd displacement (°)	21.5 (6.3)λ	21.1 (6.6)ψ	22.2 (5.4)	22.0 (4.5)Ψ	23.9 (3.4)	24.9 (3.4)	24.4 (3.0)	24.9 (3.9)Ψ	22.7 (5.1)λ	23.0 (5.5)ψ	23.3 (4.4)	23.5 (4.3)Ψ
R Ankle – 2nd displacement (°)	22.5 (4.6)	23.7 (4.2)	24.0 (4.8)	24.3 (4.1)Ψ	25.0 (4.2)	25.5 (4.9)	25.9 (5.1)	26.0 (5.4)	23.7 (4.5)	24.6 (4.6)	25.0 (5.0)	25.2 (4.7)Ψ
L Ankle - 3rd displacement (°)	-37.7 (7.4)	-37.1 (10.2)	-39.9 (8.5)	-39.8(8.6)Ψ	-34.1 (3.8)	-34.4 (5.1)	-35.5 (5.4)	-33.9 (4.6)	-35.9 (6.1)	-35.7 (8.0)	-37.7 (7.3)	-36.8 (7.4)
R Ankle - 3rd displacement (°)	-36.8 (5.1)λ	-37.7 (6.6)	-38.4 (5.2)	-39.0(7.5)Ψ	-31.8 (5.7)λ	-32.5 (6.5)ψ	-34.5 (6.8)	-33.4(7.2)Ψ	-34.3 (5.9)λ	-35.1(7.0)*ψ	-36.4 (6.2)	-36.2(7.7)Ψ
L Ankle - 4th displacement (°)	22.6 (7.9)	21.7 (9.8)	24.5 (8.5)	25.3 (9.0)	15.4 (4.9)	15.7 (5.2)	17.1 (6.5)	15.3 (5.9)	19.0 (7.4)	18.7(8.3)	20.8 (8.3)+	20.3 (9.0)
R Ankle - 4th displacement (°)	20.8 (8.1)	19.9 (8.8)	20.9 (7.6)	22.1 (8.5)	12.9 (7.0)	13.3 (7.7)	15.5 (6.9)	13.9 (6.9)	16.8 (8.5)	16.6 (8.8)	18.2 (6.7)	18.0 (8.6)

L – left; R – right; ϕ difference between interval 1 and 2, $p < 0.05$ (all groups); λ difference between interval 1 and 3, $p < 0.05$ (all groups); Ψ difference between interval 1 and 4, $p < 0.05$ (all groups); * difference between interval 2 and 3, $p < 0.05$ (all groups); ψ difference between interval 2 and 4, $p < 0.05$ (all groups); + difference between interval 3 and 4, $p < 0.05$ (all groups); in red the differences between groups above and below median ($p<0.05$).

Table 4. Mean and standard deviation of the angular positions and angular displacements of the knee. Differences between the intervals of 6MWT.

Variables	Women below median (n=13)				Women above median (n=13)				All women (n=26)			
	1st Interval	**2nd Interval**	**3rd Interval**	**4th Interval**	**1st Interval**	**2nd Interval**	**3rd Interval**	**4th Interval**	**1st Interval**	**2nd Interval**	**3rd Interval**	**4th Interval**
L Knee angle - first position (°)	4.1 (7.4)λ	4.1 (5.9)	2.3 (5.6)	2.0 (7.0)	1.7 (3.8)	1.9 (4.5)	1.8 (5.4)	2.8 (4.7)	2.9 (5.9)λ	3.0 (5.2)*	2.0 (5.4)	2.4 (5.9)
R Knee angle - first position (°)	4.0 (7.3)	3.9 (8.3)	2.6 (7.7)	0.6 (6.9)	0.0 (5.3)	-0.5 (5.4)	-0.2 (5.2)	0.0 (5.7)	2.0 (6.6)	1.7 (7.2)	1.2 (6.6)	0.3 (6.2)Ψ
L Knee angle - 1st transition (°)	17.7 (4.9)	17.6 (4.7)	17.4 (5.2)	16.4 (4.7)	11.5 (5.1)	12.2 (5.0)*	12.3 (6.7)	12.8 (5.4)	14.6 (5.9)	14.9 (5.5)	14.8 (6.4)	14.6 (5.3)
R Knee angle - 1st transition (°)	18.0 (6.7)	16.9 (7.3)	16.3 (6.8)	15.4 (6.2)	10.1 (4.6)	10.4 (4.0)*	11.3 (4.2)	11.2 (4.6)	14.1 (6.9)	13.7 (6.7)	13.8 (6.1)	13.3 (5.8)
L Knee angle - 2nd transition (°)	6.3 (4.9)	6.1 (4.9)ψ	5.1 (4.2)+	3.9 (5.5)Ψ	3.8 (3.5)	3.7 (3.9)	3.7 (3.3)	3.8 (3.1)	5.0 (4.4)	4.9 (4.5)	4.4 (3.8)	3.8 (4.4)Ψ
R Knee angle - 2nd transition (°)	6.7 (5.6)	5.6 (5.4)	6.1 (6.7)	3.8 (6.2)Ψ	2.0 (3.2)	1.7 (2.9)	2.4 (3.2)	2.7 (3.4)	4.4 (5.1)	3.6 (4.7)	4.2 (5.5)	3.3 (4.9)
L Knee angle - 3rd transition (°)	53.3 (7.1)	52.2 (7.5)	54.0 (6.6)	51.8 (7.8)	46.9(6.0)ϕλ	48.9 (7.1)	49.8 (7.4)	50.0 (7.4)Ψ	50.1(7.2)ϕλ	50.6 (7.3)	51.9 (7.2)	50.9 (7.5)
R Knee angle - 3rd transition (°)	52.7 (7.4)	52.7 (8.2)	52.7 (8.3)	51.4 (8.0)	46.6 (5.3)	47.0 (5.1)	47.1 (5.7)	47.7 (6.2)	49.7 (7.1)	49.8 (7.3)	49.9 (7.6)	49.6 (7.3)
L Knee - 1st displacement (°)	13.6 (4.8)	13.5 (4.9)*	15.1 (4.1)	14.4 (4.5)	9.7 (3.1)	10.4 (3.6)	10.5 (3.7)	10.0 (3.4)	11.7 (4.4)	11.9 (4.5)	12.8 (4.5)	12.2 (4.5)
R Knee - 1st displacement (°)	14.0 (4.0)	13.0 (4.0)ψ	13.7 (3.9)	14.8 (2.9)	10.2 (2.9)λ	11.0 (3.3)	11.5 (3.9)	11.2 (4.2)Ψ	12.1 (3.9)	12.0 (3.7)	12.6 (4.0)	13.0 (4.0)Ψ
L Knee – 2nd displacement (°)	-11.4 (5.0)	-11.4 (5.6)	-12.3 (4.8)	-12.5(4.9)Ψ	-7.7 (5.7)	-8.5 (5.7)	-8.5 (6.6)	-9.1 (6.0)Ψ	-9.6 (5.6)	-10.0 (5.8)ψ	-10.4 (6.0)	-10.8(5.7)Ψ
R Knee – 2nd displacement (°)	-11.3 (5.2)	-11.3 (5.0)	-10.2 (6.8)	-11.5 (5.4)	-8.1 (4.3)ϕλ	-8.8 (4.3)	-8.9 (4.5)	-8.5 (4.7)	-9.7 (5.0)ϕλ	-10.0 (4.8)	-9.5 (5.7)	-10.0 (5.2)
L Knee - 3rd displacement (°)	47.3 (7.5)	46.1 (9.1)	48.9 (7.1)	47.9 (9.3)	43.2(7.9)ϕλ	45.2 (8.8)	46.0 (8.2)	46.2 (8.2)Ψ	45.1(7.8)ϕλ	45.6 (8.8)	47.5 (7.7)	47.1 (8.6)Ψ
R Knee - 3rd displacement (°)	46.0 (7.3)λ	47.1 (7.7)	46.6 (9.0)	47.6 (7.4)	44.6 (6.2)	45.3 (5.4)	44.7 (5.3)	45.0 (5.6)	45.3 (6.7)	46.2 (6.6)	45.7 (7.3)	46.3 (6.6)
L Knee - 4th displacement (°)	-49.0 (9.0)	-46.7 (13.9)	-51.2 (8.4)	-49.7 (9.6)	-45.3 (5.1)λ	-47.1 (6.5)	-48.2 (6.3)	-47.7 (6.5)	-47.1 (7.4)λ	-46.9 (10.6)	-49.7 (7.4)	-48.7 (8.1)
R Knee - 4th displacement (°)	-48.7 (7.9)	-48.7 (9.3)	-49.6 (8.1)	-50.6 (6.7)	-46.7 (5.6)λ	-47.3 (5.3)	-47.5 (4.8)	-47.6 (5.5)	-47.7 (6.8)λ	-48.0 (7.4)	-48.6 (6.6)	-49.1(6.2)Ψ

L – left; R – right; ϕ difference between interval 1 and 2, $p < 0.05$ (all groups); λ difference between interval 1 and 3, $p < 0.05$ (all groups); Ψ difference between interval 1 and 4, $p < 0.05$ (all groups); * difference between interval 2 and 3, $p < 0.05$ (all groups); ψ difference between interval 2 and 4, $p < 0.05$ (all groups); + difference between interval 3 and 4, $p < 0.05$ (all groups); in red the differences between groups above and below median ($p<0.05$).

Table 5. Mean and standard deviation of the angular positions and angular displacements of the hip. Differences between the intervals of 6MWT.

Variables	Women below median (n=13)				Women above median (n=13)				All women (n=26)			
	1st Interval	2nd Interval	3rd Interval	4th Interval	1st Interval	2nd Interval	3rd Interval	4th Interval	1st Interval	2nd Interval	3rd Interval	4th Interval
L Hip angle - first position (°)	25.3 (8.9)	24.5 (8.8)	24.2 (8.4)	24.2 (9.4)Ψ	21.9 (7.5)	22.3 (7.9)ψ	23.8 (8.3)	24.4 (8.0)Ψ	23.6 (8.3)	23.4 (8.2)	24.0 (8.2)	24.3 (8.5)
R Hip angle - first position (°)	24.8 (7.9)	25.3 (8.8)ψ	24.6 (8.6)	23.3 (7.0)	21.5 (6.9)λ	21.3 (6.8)*	23.0 (7.2)	22.2 (7.9)	23.1 (7.4)	23.3 (8.0)	23.8 (7.8)+	22.8 (7.3)
L Hip angle - 1st transition (°)	-14.4 (7.8)	-13.4(9.1)*ψ	-15.7 (8.0)	-16.3(9.0)Ψ	-12.2 (4.8)	-12.5 (5.2)	-12.8 (7.2)	-12.0 (7.0)	-13.3 (6.5)λ	-12.9(7.3)*ψ	-14.2 (7.6)	-14.2 (8.2)
R Hip angle - 1st transition (°)	-13.5 (5.5)	-13.7 (5.9)	-15.2 (6.8)	-15.0 (6.1)	-11.9 (4.4)	-12.4 (5.4)	-12.1 (6.5)	-12.4 (6.6)	-12.7 (4.9)	-13.0 (5.6)	-13.6 (6.7)	-13.7 (6.3)
L Hip angle - 2nd transition (°)	27.2 (9.6)ϕλ	24.5 (10.2)	26.0 (9.3)	25.7 (9.8)Ψ	22.7 (7.2)	23.4 (7.5)	24.0 (8.9)	25.1 (8.4)	25.0 (8.6)	24.0 (8.8)	25.0 (9.0)	25.4 (8.9)
R Hip angle - 2nd transition (°)	25.8 (7.8)ϕ	26.6 (8.4)ψ	26.2 (9.3)	24.8 (7.2)	22.1 (7.4)	22.2 (6.8)	23.6 (6.8)	23.5 (8.1)	24.0 (7.7)	24.4 (7.8)	24.9 (8.1)	24.2 (7.6)
L Hip - 1st displacement (°)	-39.7 (7.6)	-37.9 (8.0)	-39.9 (7.1)	-40.5 (7.3)	-34.1 (8.7)λ	-34.8(9.3)*ψ	-36.6 (10.2)	-36.5(8.9)Ψ	-36.9 (8.5)	-36.4(8.7)*ψ	-38.3 (8.7)	-38.5(8.2)Ψ
R Hip - 1st displacement (°)	-38.3 (7.1)	-38.9 (7.3)	-39.8 (7.0)	-38.4 (6.7)	-33.4 (5.7)	-33.6 (5.9)	-35.1 (5.7)	-34.6 (5.2)	-35.9 (6.8)λ	-36.3 (7.1)	-37.4 (6.7)	-36.5 (6.2)
L Hip - 2nd displacement (°)	41.5 (6.8)	37.9 (10.6)	41.8 (6.5)	41.9 (6.5)	35.0 (8.7)λ	35.9 (9.2)	36.8 (10.5)	37.1 (9.2)Ψ	38.3 (8.3)	36.9 (9.8)*ψ	39.3 (8.9)	39.5 (8.2)Ψ
R Hip - 2nd displacement (°)	39.4 (6.3)λ	40.2 (6.8)	41.4 (7.1)+	39.9 (6.7)	34.1 (6.2)	34.6 (5.9)	35.7 (5.5)	35.9 (5.4)	36.7 (6.7)λ	37.4 (6.9)	38.5 (6.9)	37.9 (6.3)Ψ
L Hip - 3rd displacement (°)	-2.3 (1.7)	-0.7 (5.6)	-2.1 (1.8)	-2.1 (1.6)	-1.3 (1.3)	-1.3 (0.8)	-0.5 (2.0)	-1.0 (0.7)	-1.8 (1.6)	-1.0 (3.9)	-1.3 (2.0)	-1.6 (1.3)
R Hip - 3rd displacement (°)	-1.7 (1.4)	-1.7 (1.4)	-1.8 (1.3)	-1.9 (1.2)	-1.0 (0.9)	-1.0 (0.9)	-1.2 (1.1)	-1.1 (0.9)	-1.3 (1.2)	-1.4 (1.2)	-1.5 (1.2)	-1.5 (1.1)

L – left; R – right; ϕ difference between interval 1 and 2, $p < 0.05$ (all groups); λ difference between interval 1 and 3, $p < 0.05$ (all groups); Ψ difference between interval 1 and 4, $p < 0.05$ (all groups); * difference between interval 2 and 3, $p < 0.05$ (all groups); ψ difference between interval 2 and 4, $p < 0.05$ (all groups); + difference between interval 3 and 4, $p < 0.05$ (all groups); in red the differences between groups above and below median ($p<0.05$).

4. DISCUSSION

According to our literature review, there is limited research on the characteristics of older adults' gait biomechanical parameters over long-distance walking. Thus, this study was designed to evaluate gait characteristics in older women over the 6MWT regarding gait spatial and temporal parameters as well as angular kinematics of the lower limb joints. Our data showed changes in gait spatial and temporal parameters along the 6MWT, *i.e.*, an increased gait speed as a result of an increased cadence and stride length. Moreover, changes along the 6MWT in other gait spatial and temporal parameters were also observed, *i.e.*, an increase in the stance phase, loading response phase, pre-swing phase, and double stance phase, along with a decrease in the swing phase, were observed along the test. Furthermore, the angular displacements of the hip and ankle became larger along the test.

Previous studies found an increase in gait speed along long-distance walking in the elderly (Elhadi et al., 2017; Wong et al., 2020). Despite that, the motivation to achieve a better result during the 6MWT may be an explanation for the increase in gait speed observed during our tests. However, the increase in gait speed occurred until the 3rd interval of the test, after which there was a tendency to reduce it, namely, in women above the median age value. This may reflect the onset of fatigue, which seems more marked in older women. However, the present study did not control parameters related to fatigue, making it impossible to reach a conclusion on this issue.

In spite of the increase in gait speed during the first three intervals of the 6MWT, the stance phase, the loading response phase, the pre-swing phase, and the double stance phase became larger along the test. According to a previous study (Maki, 1997), increased stance and double stance phases were associated with a cautious gait. Therefore, we can speculate that older women can increase their gait speed above their natural speed; however, their gaits become more cautious in order to yield a more stable pattern.

The increases in angular displacements of the lower limb joints, i.e., hip and ankle, follow the increase in gait speed. On the other hand, the correlations observed between gait speed and the angular displacements of the lower limb joints also pointed to a close relationship between them. This is not surprising because, according to a previous systematic review (Fukuchi et al., 2019), gait speed affects the joint kinematics of different populations, namely, older adults.

Another aim of the present study was to analyse the effect of age. For this purpose, a comparison between the groups of older women above and below the median age value was carried out. The behaviours of the gait spatial and temporal parameters along the intervals were similar between these groups. Nonetheless, women below the age median value showed higher gait speed, cadence, stride length, and step length. These women also yielded lower stance phase, loading response phase, pre-swing phase, and double stance phase.

Moreover, the correlations found between age and the gait spatial and temporal parameters also supported the relationship between these parameters and aging. Therefore, these data pointed to a lower functional capacity and a more cautious gait as age advances, as pointed out in a previous systematic review (Herssens et al., 2018). On the other hand, other systematic reviews (Boyer et al., 2017) supported moderate standardized effects of age for changes in lower limb kinematics (Boyer et al., 2017; Zhong et al., 2021). Our data corroborated these findings: women above medium age value exhibited shorter angular displacements of the lower limb joints during gait. Therefore, these data strengthen the need to improve joint mobility and motor control of hip, knee, and ankle in older women. This can be achieved through exercise programs, which should also promote the functional capacity and confidence of older women by improving their gait spatial and temporal parameters (Aleixo et al., 2022, 2024).

According to a previous systematic review (Barbieri et al., 2013), few studies have addressed the effects of fatigue on gait spatial and temporal parameters. The same review pointed out that young adults reduced gait speed and stride/step length and increased stride time with fatigue; older adults also increased step width with fatigue. In our study, the aforementioned gait spatial and temporal parameters did not show the described behaviours along the test. Accordingly, the test time seemed to be insufficient to induce fatigue in older adults and, consequently, to study the effects of fatigue on gait. Thus, longer protocols must be used, and the collection of other fatigue-related parameters must also be recommended.

Furthermore, in order to avoid biases related to gait speed, the assessed subjects should be asked to perform the respective test at a natural gait speed. Finally, in order to establish gait normality parameters in older women, a larger study with a similar methodology should be developed. Further, the methodology should consider the conclusion of this study, the sample should be increased, and subjects should be from different geographic areas. Other parameters should also be analysed, namely, parameters related to slip fall, e.g., heel anteroposterior velocity at heel strike (Aleixo & Abrantes, 2015), parameters related to trip falls, e.g., minimum toe clearance variability (Silva et al., 2024), and parameters related to joint stability, e.g., dynamic joint stiffness (Aleixo et al., 2021).

The main limitation of the study was the fact that the selection of participants was based only on subjects belonging to just one portuguese town, therefore limiting the generalis-ability of the results. Furthermore, the sample size can also be considered small.

Wearable inertial systems are able to evaluate gait kinematics (Picerno, 2017). Consistent with our data and the development of our study, it was possible to recognize the potential of inertial sensors in gait assessment, particularly in the gait of older adults. Compared with three-dimensional motion analysis systems, i.e., the gold standard equipment regarding kinematics assessment, inertial sensors are less time-consuming during the subject preparation before assessment. Furthermore, they can be easily used outside the laboratory and are less expensive.

5. CONCLUSIONS

Older women in the current sample yielded changes in gait spatial and temporal parameters along the 6MWT, *e.g.*, there was an increase in gait speed, stance phase, and double stance phase. Moreover, the angular displacements of the hip, knee, and ankle also became larger along the 6MWT. In our study, older women (compared to younger ones) yielded lower gait speed, cadence, stride length, and step length, along with higher stance and double stance phases and shorter angular displacements of the hip, knee, and ankle. Further, these data underline the need to improve joint mobility and motor control of the lower limb joints in older women. This can be achieved through exercise programs, which should also promote their functional capacity and confidence through the improvement of gait spatial and temporal parameters.

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CAPÍTULO IV

ESTUDO III

EFFECTS OF A 12-WEEK PROPRIOCEPTIVE AND STRENGTH EXERCISE PROGRAM TO PREVENT FALLS IN THE ELDERLY.

EFEITOS DE UM PROGRAMA DE EXERCÍCIOS PROPRIOCETIVOS E DE FORÇA DE 12 SEMANAS PARA PREVENIR QUEDAS EM IDOSOS

(Journal of Bodywork and Movement Therapies, 2025 Dec:45:656-666,
https://doi.org/10.1016/j.jbmt.2025.10.003)

ESTUDO III: Efeitos de um programa de exercícios propriocetivos e de força de 12 semanas para prevenir quedas em idosos.

O terceiro artigo que forma parte deste estudo "**Effects of a 12-week proprioceptive and strength exercise program to prevent falls in the elderly**" foi publicado na revista *"Journal of Bodywork and Movement Therapies"*.

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ABSTRACT

Background: Older fallers exhibited alterations in gait biomechanical parameters. Guidelines for an exercise program to prevent falls were presented elsewhere, which focused its methodology in improving the gait biomechanical parameters related to falls. This research assessed the effects of a 12-week proprioceptive and strength exercise program on older adults' gait biomechanics, as well as on tests assessing functional capacity and fear of falling (Six-Minute Walk Test, 6MWT; Timed Up and Go test, TUG; Falls Efficacy Scale-International, FES-I).

Methods: A Non-randomized, single-group pre-post design (participants served as their own controls). Thirty-six older adults were selected (30 females; 70.2 ± 6.3 years). Assessments were performed at baseline, pre-intervention, and post-intervention. Gait kinematics of the lower limbs as well as spatial and temporal parameters were recorded using pressure platforms and inertial sensors during the 6MWT. The distance covered during the 6MWT was also measured. Participants also performed the TUG and answered the FES-I. Intervention comprised a 12-week proprioceptive and strength exercise program, with three 3 sessions/week (45 min).

Results: Sixteen elderly participants (13 females; 68.0 ± 4.6 years) completed the three assessment points and intervention. Gait speed, cadence, and the distance covered during the 6MWT improved after the exercise program, while step time, TUG time, and fear of falling presented a reduction after the exercise program ($p < 0.05$). Knee and ankle kinematics also presented changes ($p < 0.05$).

Conclusions: The structured and supervised 12-week exercise program effectively enhanced functional capacity and gait biomechanical parameters related to falls, while also reducing the fear of falling among older adults.

Trial registration: EudraCT No. 2021-004912-25.

Keywords: proprioceptive and strength exercise; fall prevention; functional mobility; elderly; gait biomechanics.

1. INTRODUCTION

Falls are a major public health problem in older adults (WHO, 2021). One-third of older adults over 65 years fall every year (Gillespie et al., 2012; Sherrington et al., 2019). Falls in this population can cause important physical and psychological harm (James et al., 2020). Furthermore, the financial pressure on households, communities, and society resulting from falls should not be overlooked; for example, the estimated medical costs attributable to fatal and nonfatal falls in the United States reached $50 billion in 2015 (Florence et al., 2018). This way, further research on fall prevention strategies is critical (James et al., 2020).

Preventive strategies that reduce falls in older adults could lead to a substantial reduction in healthcare spending (Florence et al., 2018). The preventive strategies that have been evaluated in previous research included exercise programs aimed at improving strength or balance, educational initiatives, medication management, and changes to the environment (Gillespie et al., 2009). In this sense, exercise programs are an important preventive strategy regarding falls in older adults. A Cochrane systematic review reported strong evidence concerning the efficacy of exercise programs in preventing falls in older adults, namely exercises programs targeting postural stability, functional exercises, and strength exercises (Sherrington et al., 2019).

Gait is a common daily living activity in older adults and a considerable number of falls in these subjects occur while walking. Tripping and slipping appear as the most prevalent causes (Berg et al., 1997; Lehtola et al., 2006). According to a recent systematic review (Silva et al., 2024, 2025), falls history was associated with some spatial and temporal parameters, namely gait speed, stride/step length, and double stance phase. Moreover, it was also pointed that fallers yielded higher variability of the spatial and temporal parameters and minimum toe clearance (the last one is a gait biomechanical parameter related to trip falls). Due to the scarcity of research, this systematic review was unable to produce major conclusions regarding parameters related to slipping falls; nonetheless, the heel anteroposterior velocity at heel strike has been associated with slips in previous research (Aleixo & Abrantes, 2015). Finally, differences in lower-limb joint angular kinematics were observed between fallers and non-fallers, with fallers exhibiting reduced ankle and hip range of motion (Kemoun et al., 2002).

Evidence indicates that exercise programs have demonstrated effectiveness in enhancing the gait biomechanical parameters mentioned in the previous paragraph (Aleixo et al., 2016, 2022; Persch et al., 2009; Shin & An, 2014; Teixeira-Salmela et al., 2001). While previous studies have investigated proprioceptive and strength exercises independently, evidence on their combined effects on biomechanical gait parameters and fall risk remains limited. This way, a recent manuscript presented guidelines for a proprioceptive and functional strength exercise program to prevent falls in older adults, which was developed with the aim of improving the gait biomechanical parameters related to falls (Aleixo & Abrantes, 2024). Moreover, this is the first fall prevention exercise program in which the prescribed exercises were specifically designed based on gait biomechanical parameters associated with falls, thereby representing a novel contribution to the literature. However, the effects of this exercise program have not been evaluated. This way, it was important to develop research that can test this exercise program (Aleixo & Abrantes, 2024).

According to Storm et al (2020), the 6-min walk test (6MWT) was considered valuable for evaluating the gait biomechanical parameters. Gait analysis during the 6MWT using wearable inertial sensors has been successfully performed and demonstrated to be technically feasible (Storm et al., 2020). Thus, several studies used wearable inertial sensors to analyse the older adults' gait during the 6MWT (Drover et al., 2017; Galán-Mercant et al., 2019; Grimpampi et al., 2015; Howcroft et al., 2017; Waugh et al., 2019).

During their professional practice, healthcare professionals do not always have at their disposal the necessary equipment to evaluate the gait biomechanical parameters mentioned above. In this sense, other tools have gained expression when it comes to assessing functional capacity and fear of falling in older adults. Therefore, the 6MWT is a test that measures functional capacity, and its utility was subsequently extended beyond the cardiopulmonary domain to encompass individuals with various conditions and disorders, including older adults (Ubuane et al., 2018).

The Timed Up and Go test (TUG) also evaluated functional capacity during a task comprising walking and the sit-to-stand movement (Podsiadlo & Richardson, 1991), i.e., daily living tasks in which frequently falls occur (Lehtola et al., 2006). Additionally, the TUG is an assessment that reflects the level of some capabilities such as strength, postural stability, and body mobility (Barry et al., 2014).

The Falls Efficacy Scale-International (FES-I) is a highly reliable tool for measuring fear of falling in older adults, being used in both research and clinical practice (Figueiredo & Santos, 2017). Fear of falling is a common consequence of falls and a determinant for the occurrence of new falls (Delbaere et al., 2010; Friedman et al., 2002; Tinetti et al., 1990). The FES-I has excellent psychometric properties and assesses the subjects' concerns regarding basic daily activities, both physical and social (Yardley et al., 2005).

Proprioceptive and strength exercises play a key role in fall prevention (Sherrington et al., 2019). As previously noted, evidence on the effects of combined proprioceptive and strength interventions on gait biomechanics in older adults remains limited. Moreover, the fall prevention exercise program proposed by Aleixo & Abrantes (2024), which integrates these combined exercises, warrants evaluation. Therefore, this study evaluated the effects of a 12-week proprioceptive and strength exercise program (Aleixo & Abrantes, 2024) on gait biomechanics as well as on functional capacity and fear of falling in older adults, assessed through the 6MWT, TUG, and FES-I. It was hypothesized that the program would yield significant improvements in these outcomes.

2. METHODS

2.1. Study design and timeline

The present research was prepared following the Consort guidelines with an adaptation to non-randomized clinical trials (Reeves & Gaus, 2004; Schulz et al., 2010). Accordingly, a non-randomized, single-group pre–post design was employed, with participants serving as their own controls. According to Fig. 1, the selected subjects: 1) were first assessed on July 22, 2021 (baseline), and did not receive any intervention during the subsequent 12-week period; 2) were reassessed after this subsequent 12-week period on October 21, 2021 (pre-intervention), and received the intervention (12-week exercise program); 3) were reassessed after intervention on January 20, 2022 (post-intervention). Thus, participants were evaluated at three points, i.e., baseline, pre-intervention, and post-intervention). In summary, the research lasted 24 weeks, from July 2021 to January of 2022, i.e., during COVID-19 pandemic.

2.2. Sample size calculation

The sample size estimation was determined a priori using G*Power software (version 3.1.9.7). Our sample size was calculated based on a Wilcoxon signed-rank test, assuming an effect size of 0.5 with an alpha level of 0.05 and 80% power. According to this calculation, 35 were the number of subjects to achieve in the sample.

2.3. Subject selection

Posters and flyers were handed out across the community of Marrazes, Leiria, Portugal, with the support of the parish council and town sports club (Sport Clube Leiria Marrazes). Subjects aged 65 years or over were selected. The exclusion criteria were: a) any rheumatic or neurologic disease; b) heart disease, chronic obstructive pulmonary disease, or cancer; c) the need for some device to assist during walking – e.g., cane or walker; d) cognitive impairment, i.e., Mini-Mental Status Examination score <26 (I. Santana et al., 2016); e) participation in any physical exercise program in the previous 3 months before baseline assessment. All subjects reviewed and signed an informed consent statement before participating in the research.

As aforementioned, this research was conducted during the COVID-19 pandemic. Unfortunately, the number of covid-19 cases increased during the period corresponding to the intervention phase. As a result, some subjects presented health-related concerns that prevented them from continuing their participation in the intervention. In addition, 10 subjects were users of a day centre and were particularly affected by mobility restrictions and safety measures, i.e., the institution made it impossible for them to participate in the intervention. These questions limited the number of subjects included in analysis.

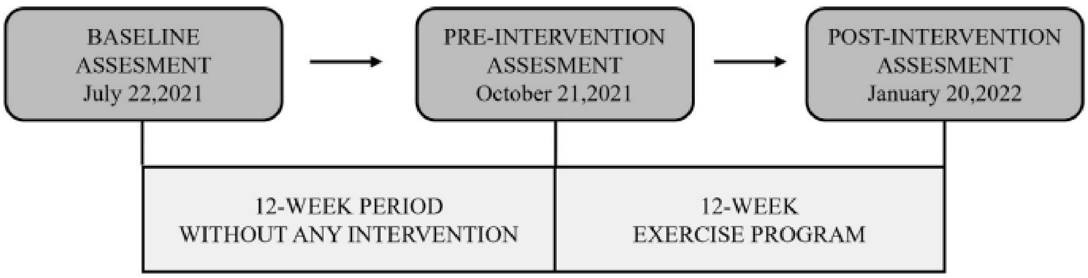

Fig 1. Assessment points and durations between them.

2.4. Data collection session

Data collection sessions had the following structure: 1) completion of a form to collect demographic and clinical data; 2) completion of the Mini-Mental Status Examination; 3) completion of the FES-I; 4) collection of anthropometrics measurements (height and body mass), according to Norton (2018); height measurements were taken using a stadiometer and body mass using an electrical impedance scale (Tanita BC-602); 5) TUG test; 6) 6MWT. During the 6MWT, the gait biomechanical parameters were collected (in addition to the distance covered during the test). All data collection sessions were overseen by the same investigators, who possessed extensive experience with procedures.

2.5. Mini-Mental Status Examination

To assess cognitive impairment, the Portuguese version of the Mini-Mental Status Examination (MMSE) was administered (Santana et al., 2016). The MMSE consists of 30 questions that assess six cognitive domains: temporal and spatial orientation, retention, attention and calculation, recall, language, and constructive ability. Each correct answer gets 1 point; the maximum score is 30 (Santana et al., 2016).

2.6. FES-I

The FES-I is an adapted version of the Tinneti Falls Efficacy Scale (Tinetti et al., 1990), which aims to evaluate fear of falling. In this study, the Portuguese version of the FES-I was used (Figueiredo & Santos, 2017). The FES-I is a 16-item questionnaire that evaluate the concerns about falling across different activities. The answers vary between: "not all concerned" (1 point); "somewhat concerned" (2 points); "fairly concerned" (3 points); and "very concerned" (4 points). Total score is reached by adding the points in the various questions, which range from 16 to 64. A higher score reflects an increased level of fear of falling (Figueiredo & Santos, 2017).

2.7. TUG

The TUG was performed following the protocol outlined by Almeida et al. (2017). Initially, one researcher explained the TUG test instructions, while another researcher ensured the subject's safety by supervising the task. Each subject completed one TUG trial, when the subject showed signs of not understanding the instructions, a second demonstration was provided, and a second trial was allowed. The first researcher scored the performance using a stopwatch (Almeida et al., 2017).

2.8. 6MWT

The 6MWT was performed on a 30 m flat course with a rectangular shape (10 m x 5 m). To optimize the measurement of the distance covered by each subject, the course was marked with cones in each corner and with tape every 1 m. Subjects were instructed to walk as fast as possible to complete the 6 min of the test. Moreover, they were also informed that, if they felt fatigued during the test, they could rest on one of the chairs provided along the course; when they felt capable again, they were instructed to return to the test. The distance covered by each subject was recorded.

2.9. Assessment and processing of the gait biomechanical data

During the 6MWT, the gait spatial and temporal parameters were collected using two pressure platforms FDM 1.5 (Zebris Medical GmbH, Weitnau-Seltmans, Germany); each platform had the following dimensions: 158 cm in length, 60.5 cm in width, and 2.1 cm in height. As can be seen in Fig. 2, the platforms were positioned in the middle of the first 10-m segment of the course. Spatial and temporal data were collected at each pass over the pressure platforms (100 Hz). The Zebris FDM software (Zebris, 2019) was used to collect and compute the average value of the following parameters: gait speed (m/s), cadence (steps/min), stride length (m), stride time (s), step length (m), step width (cm), step time (s). Moreover, the following gait phases were also computed as defined elsewhere (Silva et al., 2024, 2025): stance phase (%), loading response phase (%), pre-swing phase (%), swing phase (%), and double stance phase (%).

The Xsens MTw Awinda system, with 7 wireless IMUs, was used to capture the angular kinematic data of the lower limbs. The position of each wireless IMU and the calibration of the system are described in a previous study (Silva et al., 2024, 2025). The placement of each IMU was consistently performed by the same researcher, who had extensive experience with this procedure. Data were collected at 100 Hz. The Kinetikos CE-marked cloud-based (Kinetikos, Coimbra, Portugal) allowed the reconstruction of the body kinematic model that includes both lower extremities segments and joints, namely hip, knee, and ankle (Alberto et al., 2021). At each pass over the pressure platforms, the average value of the following angular kinematic parameters was computed: angular positions of the hip, knee, and ankle at each articular transition phase [°]; angular displacements of the hip, knee, and ankle [°]. A neutral position of the thigh regarding the pelvis means 0.0°; a positive value means hip flexion and a negative value means hip extension. A total extension of the knee means 0.0°; a positive value means knee flexion. Regarding the values of the ankle, a neutral position of the foot means 0.0°; a positive value means dorsiflexion and a negative value means plantar flexion.

The analysis of the gait biomechanical parameters was performed for the four 90-s intervals of the 6MWT. This way, only the first pass over the platforms of each interval was considered for analysis.

Fig. 2. The course of the 6-Minute Walk Test. The black arrow marks the gait direction.

2.10. Intervention

The proposed exercise program comprises proprioceptive and functional strength exercises (Aleixo & Abrantes, 2024), the type of exercises that best prevent falls (Sherrington et al., 2019). Proprioceptive exercises aim to improve the communication between the central nervous system and muscles, i.e., they are distinct in their greater ability to activate and enhance proprioception and somatosensory function (Gollhofer, 2008). On the other hand, functional strength exercises aim to improve the strength used to perform daily living activities (J. C. Santana, 2016), focusing on improving the quality of movement (Liao et al., 2019; Pacheco et al., 2013). Thus, both proprioceptive and functional exercises are essential for achieving better movement quality and postural stability. According to the authors of the exercise program (Aleixo & Abrantes, 2024), these exercises were specifically prescribed for the improvement of the four movement pillars, i.e., locomotion, level changes of the centre of mass, pulling and pushing with the upper limbs, and rotations (J. C. Santana, 2016); although emphasis should be placed on the locomotion pillar.

The parameters of the exercise program were defined as follow: 12 weeks; 3 sessions/week (Monday, Wednesday, and Friday); 45 min/session. Each session was structured as followed: a) 5-min warm-up with active stretching exercises; b) 20-min with 9 proprioceptive exercises focused on the locomotion pillar and gait biomechanical parameters associated with falls; c) 15-min with 4 functional strength exercises focusing on the other three pillars (pull and push with the upper body, changes in the centre of mass, and rotations exercises); d) 5-min cool-down with static stretching exercises. Intensity and progression of the exercises were adjusted according to their complexity and the individual ability of each subject to perform the exercise. Therefore, exercise complexity gradually increased over the 12-week program as subjects performed them easily. Exercises can be seen at http://elderly.falls.ulusofona.pt/ .

The exercise programs were conducted in the exercise room of Sport Clube Leiria Marrazes, Portugal. The program was always conducted by the same researcher (physiotherapist with more than 15 years of experience in health and clinical exercises) with all subjects. Each training session was organized into groups up to five subjects.

2.11. Adherence rate of the program

Adherence to the program was monitored throughout its duration. Adherence rate was calculated as following: (number of training sessions performed/36 sessions)*100.

Subjects who missed more than 9 sessions, corresponding to an attendance rate below 75%, were not included in the statistical analysis. The following criteria were also defined for the subjects discontinuing the exercise program: a) any type of pain or injury that limits the execution of the exercises; b) any type of pain or injury that intensifies with the performance of the exercises. In this sense, an individual record was used, which was completed at each session by the researcher. This individual record documented attendance also included a space to note any occurrences.

2.12. Statistical analyses

Statistical analysis was performed using the IBM SPSS Statistics, version 30.0 (IBM Corp., Armonk, NY, USA). A two-tailed Wilcoxon signed-rank test was conducted to assess differences in the variables across the three measurement time points: baseline, pre-intervention, and post-intervention. Confidence intervals were estimated using the Hodges–Lehmann estimator and effect sizes were calculated using Rosenthal's r, providing robust nonparametric measures of both central tendency and the magnitude of the observed effects. Conversely, to evaluate differences in gait biomechanical parameters across the four intervals of the 6MWT, the Friedman test was employed. Effect size for the overall Friedman test was estimated using Kendall's W. Statistical significance will be defined for p values < 0.05.

2.13. Ethical considerations and trial registration

This research was approved by the Ethical Committee of the Faculdade de Educação Física e Desporto – Universidade Lusófona, Lisboa, Portugal (Ref. No. J1621A) and registered on the European Union Drug Regulating Authorities Clinical Trials Database - EudraCT (Ref. No. 2021-004912-25). The experimental procedures were performed in accordance with the Declaration of Helsinki (WMA, 2013).

3. RESULTS

3.1. Participant characteristics

As can be seen in fig. 3, 36 subjects were selected to participate in the present study (age: 70.2 ± 6.3 years; 30 females; height: 161.0 ± 4.4 cm; body mass: 72.5 ± 11.9 kg; body mass index: 29.7 ± 4.5 kg/m^2). They were all evaluated at baseline assessment. However, before the pre-intervention assessment, 10 subjects withdrew from the study because Covid-19 numbers were growing, and they were concerned about their health. After the beginning of the exercise program, with Covid-19 numbers rising, other 10 subjects withdrew from the study because the day centre, to which they belonged restricted their continuation in the exercise program. This way, the final sample consisted of 16 subjects.

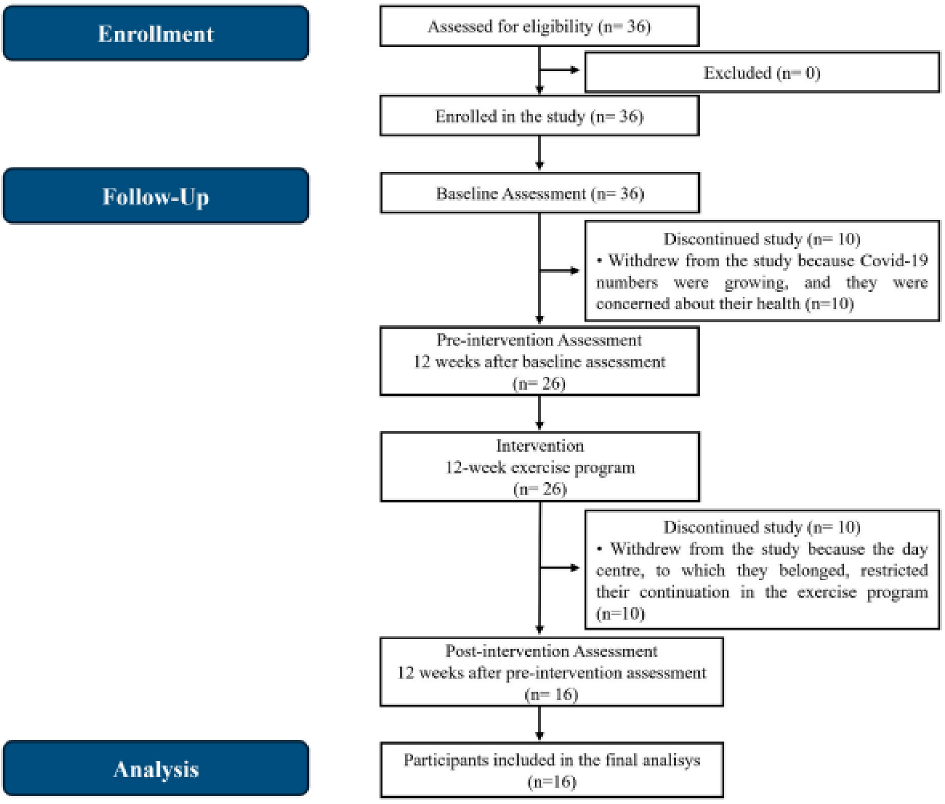

Fig. 3. Flowchart of subjects through the trial (according to the CONSORT guidelines).

The 16 subjects presented the following characteristics at baseline: 68.0 ± 4.6 years; 13 females (81.2 %); height: 160.0 ± 0.1 cm; body mass: 75.6 ± 13.5 kg; body mass index: 29.7 ± 4.5 kg/m^2. (Table 1)

3.2. Adherence rate to exercise program

The adherence rate to the 12-week exercise program, comprising 36 sessions, was 95.3%. All subjects in the exercise program attended at least 88.9%, with individual adherence rates ranging from 88.9 to 100%. No adverse events were recorded during the exercise program period.

3.3. FES-I, TUG, and 6MWT

Table 1 and Fig. 4 present the results of the FES-I, TUG, and 6MWT at baseline, pre-, and post-intervention. A decrease in FES-I values was only observed between baseline and post-intervention (p = 0.049, r = 0.49, 95 % CI [− 6.0, 0.0]). A decrease in TUG time was observed between baseline and postintervention (p = 0.002, r = 0.78, 95 % CI -1.4, − 0.5]) and between pre- and post-intervention (p = 0.007, r = 0.67, 95 % CI [− 2.6, − 0.9]); no differences were found between baseline and pre-intervention. The distance covered during the 6MWT increased between baseline and pre-intervention ($p = 0.002$, $r = 0.78$, 95 % CI [20.5, 65.5]) and between pre- and post-intervention ($p < 0.001$, $r = 0.88$, 95 % CI [47.0, 85.0]); a tendency toward an increase in the distance covered during the 6MWT was observed between pre- and post-intervention ($p = 0.070$, $r = 0.45$, 95 % CI [−1.5, 50.0]).

Table 1 Data of the FES-I, TUG, 6MWT, body mass, and body mass index at baseline, pre-intervention, and post-intervention.

Variables	Baseline mean (sd)	Pre- intervention mean (sd)	Post-intervention mean (sd)
FES-I score (16-64)	24.4 (7.7)	22.3 (3.5)	21.3 (8.4) **
TUG (s)	9.5 (4.5)	9.5 (2.4)***	8.2 (3.5)**
6MWT (m)	411.2 (82.3)*	453.7 (85.5)	480.1 (74.1)**
Body Mass (kg)	75.6 (13.5)	75.8 (13.1)	76.5 (13.9)
Body Mass Index (Kg/m²)	29.7 (4.5)	29.8 (4.4)	30.0 (4.5)

*difference between baseline and pre-intervention ($p < 0.01$); **difference between baseline and post-intervention ($p < 0.05$); ***difference between pre-intervention and post-intervention ($p < 0.01$).

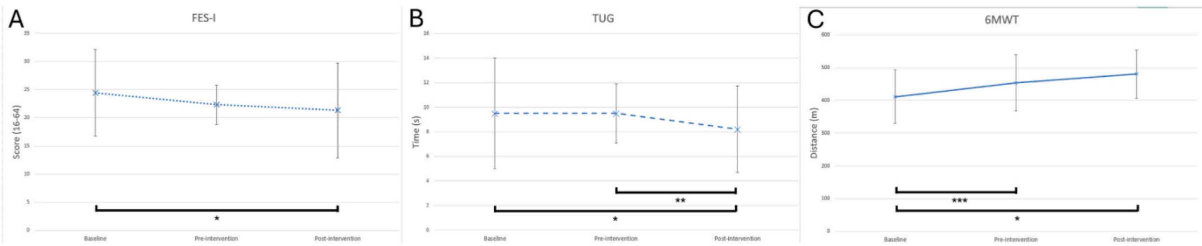

Fig. 4. Progression of the FES-I, TUG, and 6MWT over the three assessment time points. A – FES-I; B – TUG; C – 6MWT; *difference between baseline and postintervention ($p < 0.05$); **differences between pre-intervention and post-intervention ($p < 0.01$); ***difference between baseline and pre-intervention ($p < 0.01$).

3.4. Gait spatial and temporal parameters

Table 2 presents the results of the gait spatial and temporal parameters, as well as the comparisons between baseline, pre-, and postintervention. An increase in gait speed between baseline and postintervention (first-interval of the 6MWT – $p = 0.002$, $r = 0.76$, 95 % CI [0.05, 0.24]; second-interval of the 6MWT – $p = 0.013$, $r = 0.62$, 95 % CI [0.04, 0.25]; third-interval of the 6MWT – $p = 0.004$, $r = 0.72$, 95 % CI [0.06, 0.27]; fourth-interval of the 6MWT – $p = 0.017$, $r = 0.59$, 95 % CI [0.04, 0.24]), as well as between pre- and post-intervention was observed (first-interval of the 6MWT – $p = 0.039$, $r = 0.52$, 95 % CI [0.01, 0.17]; third-interval of the 6MWT – $p = 0.063$, $r = 0.47$, 95 % CI [0.00, 0.18]; fourth-interval of the 6MWT – $p = 0.017$, $r = 0.56$, 95 % CI [0.03, 0.18]). Also, a tendency toward an increase in the gait speed was observed between the baseline and pre-intervention. This was associated with an increase in cadence observed along the study, i.e., between baseline and post-intervention (first-interval of the 6MWT – $p = 0.001$, $r = 0.81$, 95 % CI [6, 17]; second-interval of the 6MWT – $p < 0.001$, $r = 0.88$, 95 % CI [7, 18]; third-interval of the 6MWT – $p = 0.001$, $r = 0.87$, 95 % CI [8, 18]; fourth-interval of the 6MWT – $p = 0.001$, $r = 0.84$, 95 % CI [6, 15]). Moreover, a tendency toward an increase in cadence was verified between baseline and pre-intervention. As a result of the increase in gait speed, it was also observed a reduction of the step time along the study, i.e., between baseline and post-intervention (first-interval of the 6MWT – $p = 0.005$, $r = 0.71$, 95 % CI [− 0.05, − 0.01]; second-interval of the 6MWT – $p = 0.013$, $r = 0.62$, 95 % CI [− 0.07, − 0.01]; third-interval of the 6MWT – $p = 0.008$, $r = 0.66$, 95 % CI [− 0.07, − 0.02]; fourth-interval of the 6MWT – $p = 0.016$, $r = 0.60$, 95 % CI [− 0.07, − 0.01]). The other gait spatial and temporal parameters presented no differences between baseline and post-intervention. An increase in gait speed across the defined 6MWT intervals was observed at baseline (χ^2 (3) = 9.83, $p = 0.020$, Kendall's W = 0.21) and post-intervention evaluations (χ^2 (3) = 13.65, $p = 0.003$, Kendall's W = 0.28).

Table 2 Data of the gait spatial and temporal parameters. Differences between baseline, pre, and post-intervention.

Variables	Baseline (n=16)				Pre-intervention (n=16)				Post-intervention (n=16)			
	1st Interval	2nd Interval	3rd Interval	4th Interval	1st Interval	2nd Interval	3rd Interval	4th Interval	1st Interval	2nd Interval	3rd Interval	4th Interval
Gait speed (m/s)	1.27 (0.24)	1.26 (0.28)	1.31 (0.29)	1.37 (0.32)	1.33(0.25)***	1.35 (0.27)	1.38(0.25)***	1.39(0.28)***	1.42 (0.25)**	1.40 (0.27) **	1.47 (0.28)**	1.49 (0.30)**
Cadence (steps/min)	125 (11)	126 (12)*	128 (13)*	131 (16)	130 (12)***	131 (13)***	135 (13)***	136 (14)***	137 (12)**	138 (12)**	141 (14)**	143 (12)**
Stride length (m)	1.21 (0.19)	1.20 (0.21)	1.22 (0.19)	1.24 (0.22)	1.23 (0.21)	1.24 (0.21)	1.22 (0.19)	1.23 (0.21)	1.25 (0.22)	1.22 (0.21)	1.25 (0.19)	1.25 (0.22)
Stride time (s)	0.95 (0.10)	0.96 (0.11)*	0.90 (0.16)	0.89 (0.17)	0.92(0.09)***	0.92(0.11)***	0.88(0.10)***	0.87(0.11)***	0.88 (0.08)**	0.87 (0.08)**	0.84 (0.09)**	0.83 (0.08)**
Step length - L (m)	0.61 (0.10)	0.60 (0.12)	0.61 (0.09)	0.61 (0.11)	0.61 (0.10)	0.62 (0.09)	0.61 (0.10)	0.61 (0.10)	0.63 (0.11)	0.60 (0.10)	0.63 (0.09)	0.63 (0.11)
Step length - R (m)	0.60 (0.11)	0.59 (0.10)*	0.61 (0.11)	0.63 (0.12)	0.62 (0.11)	0.63 (0.12)	0.61 (0.10)	0.61 (0.12)	0.62 (0.12)	0.62 (0.12)	0.62 (0.10)	0.62 (0.12)
Step width (cm)	13.1 (4.0)	12.7 (3.7)	13.4 (3.5)	13.4 (4.2)	13.6 (3.4)	13.3 (3.4)	13.3 (3.4)	13.4 (3.6)	13.6 (3.4)	13.8 (3.1) **	13.4 (2.9)	12.9 (3.1)
Step time - L (s)	0.48 (0.06)	0.48 (0.06)	0.47 (0.07)	0.45 (0.07)	0.47(0.05)***	0.46 (0.05)	0.45 (0.06)	0.44 (0.06)	0.44 (0.05)**	0.44 (0.05) **	0.42 (0.06)**	0.41 (0.06) **
Step time - R (s)	0.47 (0.05)	0.47 (0.05)	0.47(0.06)*	0.46 (0.09)	0.46(0.04)***	0.46(0.06)***	0.43 (0.04)	0.43 (0.07)	0.44 (0.04)**	0.43 (0.04)**	0.42 (0.05)**	0.42 (0.05)**
Stance phase - L (%)	62.4 (2.2)	63.6 (2.1)*	65.9 (1.4)	68.2 (2.7)	62.3 (2.0)	64.7(1.5)***	65.3 (2.2)	66.9 (3.4)	61.8 (2.4)	62.9 (2.5)	65.2 (3.0)	67.3 (3.0)
Stance phase - R (%)	63.9 (2.5)	65.1 (2.5)	65.2 (3.0)	67.3 (3.0)	63.6 (2.6)	64.7 (2.8)	66.9 (3.1)	68.2 (2.6)	62.7 (2.7)	65.3 (2.7)	67.1 (1.8)	68.3 (3.5)
Loading phase - L (%)	13.3 (2.2)*	14.5 (2.5)	14.9 (3.1)	17.7 (4.7)	12.4 (2.4)	14.3 (3.0)	16.2 (3.4)	17.6 (4.8)	12.0 (2.2) **	14.0 (2.6)	16.5 (3.6)	19.6 (5.8)
Loading phase - R (%)	12.8 (2.2)	13.7 (2.1)	15.6 (3.3)	16.8 (5.9)	12.7 (2.2)	14.6 (2.7)	15.8 (3.8)	17.0 (4.7)	12.1 (1.9)	13.3 (2.9)	14.9 (3.5)	15.7 (3.9)
Pre-swing phase - L (%)	12.6 (1.9)	13.5 (1.9)	15.9 (3.4)	17.4 (6.1)	12.7 (1.8)	14.7 (2.9)	15.9 (4.0)	17.4 (5.6)	12.0 (1.8)	13.5 (3.3)	148 (3.8)	16.0 (4.3)
Pre-swing phase - R (%)	13.1 (2.1)	14.5 (2.4)	14.9 (3.5)	17.7 (4.7)	12.6 (2.4)	14.3 (3.0)	16.5 (3.8)	18.2 (5.6)	12.0 (2.0) **	14.0 (2.3)	17.0 (4.2)	19.2 (5.8)
Swing phase - L (%)	37.6 (2.2)	36.5 (2.1)*	34.1 (1.4)	31.8 (2.7)	37.7 (2.0)	35. (1.5)***	34.7 (2.2)	33.1 (3.4)	38.2 (2.4)	37.1 (2.5)	34.8 (3.0)	32.7 (3.0)
Swing phase - R (%)	36.1 (2.5)	34.9 (2.5)	34.8 (3.0)	32.7 (3.0)	36.4 (2.6)	35.3 (2.8)	33.1 (3.1)	31.8 (2.6)	37.3 (2.7)	34.7 (2.7)	32.9 (1.8)	31.7 (3.5)
Double-stand (%)	26.0 (4.1)	28.4 (3.4)	30.9 (3.9)	35.2 (3.9)	25.4 (3.8)***	29.2 (3.1)	32.7 (3.8)	35.5 (3.7)	24.1 (3.3) **	27.8 (4.3)	32.2 (3.2)	35.7 (3.5)

L – left; R – right; *difference between baseline and pre-intervention ($p < 0.05$); **difference between baseline and post-intervention ($p < 0.05$); ***difference between pre- and post-intervention ($p < 0.05$).

3.5. Angular kinematics of the lower limb joints

Tables 3–5 presents the results of the angular positions and displacements of the lower limb joints, including the comparisons between baseline, pre-, and post-intervention. Differences between baseline and post-intervention were observed regarding some knee and ankle displacements ($p < 0.05$). Concerning hip, no differences were found.

4. DISCURSSION

The present study evaluated the effects of a 12-week proprioceptive and strength exercise program (specifically design to prevent falls) on gait biomechanics as well as on functional capacity and fear of falling in older adults, assessed through the 6MWT, TUG, and FES-I. In the present cohort of community-dwelling older adults, participation in the exercise program was associated with significant improvements in functional capacity, as evidenced by increased gait speed, enhanced TUG performance, and greater 6-min walk distance from baseline to postintervention. Alongside the improvement in functional capacity, a decrease in the fear of falling was also observed.

Previous studies have reported that exercise programs can lead to significant improvements in older adults' gait speed (Aleixo et al., 2016, 2022; Persch et al., 2009; Shin & An, 2014). Thus, the findings of this study align with those of previous research. The increase in gait speed after the 12-week exercise program was accompanied by changes in other biomechanical gait parameters (i.e., cadence, step time, and lower limb joint kinematics). This is in line with what is described in a previous systematic review that studied the effects of different gait speeds on gait biomechanics of healthy participants (Fukuchi et al., 2019). On the other hand, gait speed is dependent on cadence and step length (Fukuchi et al., 2019). In our study, the observed increase in gait speed was supported by a higher cadence, suggesting an improvement in functional capacity following the exercise program. On the other hand, according to a previous systematic review (Silva et al., 2024, 2025), older adults fallers tend to yield lower gait speed, indicating that this parameter could distinguish fallers from non-fallers. This way, the improvement in gait speed as result of the exercise program seems to indicate its ability to improve parameters associated with fall risks in older adults. Moreover, the characteristics of the exercise program are in line with the characteristics defined in literature regarding fall prevention exercise programs (Sherrington et al., 2019). Nonetheless, the suggestion that this program can prevent falls should be evaluate in longitudinal studies that also assess fall incidence.

Table 3 Data of the angular positions and displacements of the ankle. Differences between baseline, pre-, and post-intervention.

Variables	Baseline (n=16)				Pre-intervention (n=16)				Post-intervention (n=16)			
	1st Interval	2ndInterval	3rd Interval	4th Interval	1st Interval	2nd Interval	3rdInterval	4thInterval	1stInterval	2ndInterval	3rdInterval	4th Interval
L Ankle angle - first position (°)	-8.3 (7.5)	-6.7 (5.9)	-6.7 (6.8)	-5.8 (6.0)	-7.8 (7.3)	-7.6 (8.0)	-8.2 (8.3)	-7.6 (6.6)	-9.6 (7.9)	-8.2 (8.8)	-7.0 (7.5)	-7.4 (8.1)
R Ankle angle - first position (°)	-8.6 (7.7)	-9.8 (7.0)	-9.4 (6.4)	-9.0 (5.6)	-9.5 (9.7)	-10.4 (8.9)	-9.4 (9.1)	-9.1 (9.5)	-9.0 (7.9)	-8.2 (8.0)	-7.3 (7.3)	-8.1 (7.8)
L Ankle angle - 1st transition (°)	-13.5 (6.2)	-12.9 (4.9)	-13.3 (5.4)	-13.0 (5.0)	-13.7 (6.2)	-13.5 (6.9)	-14.1 (6.3)	-13.6 (5.0)	-14.7 (7.0)	-14.3 (6.8)	-13.3 (5.8)	-13.9 (6.7)
R Ankle angle - 1st transition (°)	-14.4 (6.3)	-15.6 (6.2)	-15.3 (5.3)	-15.7 (4.5)	-15.2 (8.1)	-16.0 (6.5)	-15.4 (6.9)	-15.0 (6.9)	-14.6 (6.3)	-14.5 (6.1)	-13.7 (5.6)	-14.3 (6.3)
L Ankle angle - 2nd transition (°)	6.8 (3.3)	8.7 (3.7)	8.6 (4.1)	8.9 (3.2)	7.0 (2.8)	7.9 (3.9)	7.9 (2.9)	8.2 (3.2)	4.6 (3.7)**	6.2 (3.6) **	6.5 (3.5)	7.3 (4.0)
R Ankle angle - 2nd transition (°)	8.4 (3.5)	7.7 (3.1)	7.9 (3.1)	7.6 (3.5)	8.1 (3.3)	6.8 (3.3)	7.9 (4.3)	8.3 (3.8)	6.2 (4.1)	6.0 (4.0)	6.7 (5.0)	6.5 (4.8)
L Ankle angle - 3rd transition (°)	-27.4 (9.6)	-28.4 (8.9)	-29.7 (8.7)	-29.9 (7.8)	-27.4 (7.9)	-26.5 (9.8)	-26.8 (8.6)	-27.3 (8.9)	-25.5 (7.6)	-24.8 (7.2)	-25.6 (7.5)	-25.6 (7.6)
R Ankle angle - 3rd transition (°)	-29.3 (7.1)*	-30.7 (8.1)	-31.2 (7.0)*	-32.6 (7.1)*	-26.0 (7.3)	-27.6 (6.8)	-27.2(7.0)	-27.9 (7.4)	-27.3 (6.1)	-26.5 (6.4)	-27.7 (7.6)	-28.7 (7.7)
L Ankle angle - 4th transition (°)	-9.6 (8.0)	-6.8 (5.6)	-7.0 (7.8)	-5.8 (5.9)	-7.8 (8.5)	-7.3 (8.5)	-8.0 (8.1)	-7.5 (7.5)	-9.4 (6.7)	-7.9 (9.0)	-6.8 (7.2)	-6.9 (7.8)
R Ankle angle - 4thtransition (°)	-8.5 (7.4)	-10.0 (6.8)	-9.4 (6.0)	-8.7 (5.5)	-9.4 (9.3)	-10.1 (8.8)	-9.3 (9.3)	-9.4 (9.3)	-9.0 (7.6)	-8.1 (7.2)	-7.8 (7.6)	-7.9 (7.6)
L Ankle - 1st displacement (°)	-5.5 (2.7)	-6.3 (2.9)	-6.6 (3.0)	-7.2 (2.6)	-5.9 (3.4)	-5.9 (3.4)	-5.9 (3.8)	-6.0 (3.8)	-5.1 (3.3)	-5.9 (3.0)	-6.3 (3.2)	-6.5 (3.2)
R Ankle - 1st displacement (°)	-5.9 (2.7)	-5.8 (2.7)	-5.9 (2.6)	-6.7 (2.5)	-5.7 (3.0)	-5.6 (3.4)	-5.9 (3.3)	-5.9 (3.8)	-5.7 (2.4)	-6.2 (2.5)	-6.4 (2.4)	-6.2 (2.4)
L Ankle – 2nd displacement (°)	21.4 (5.4)	21.8 (4.8)	21.8 (4.5)	21.9 (4.1)	20.7 (5.2)***	21.4 (5.0)	22.0(5.1)***	21.8 (4.8)	19.2 (5.7)**	20.6 (5.7)	19.8 (5.1)**	21.2 (5.7)
R Ankle – 2nd displacement (°)	22.8 (4.8)	23.3 (5.0)	23.2 (5.2)	23.3 (5.1)	23.3 (6.6)	22.8 (5.3)***	23.2(4.5)***	23.3(4.6)***	20.8 (4.9)**	20.5 (5.0)**	20.4 (4.4)**	20.8 (4.9)**
L Ankle - 3rd displacement (°)	-37.0 (7.8)	-37.7 (8.2)*	-38.3 (8.8)*	-38.8 (8.5)*	-34.4 (7.2)***	-34.4 (8.4)	-34.7 (8.4)	-35.5 (9.2)	-30.1 (5.9)**	-30.1 (5.4)**	-32.1 (6.8)**	-32.8 (5.7)**
R Ankle - 3rd displacement (°)	-37.6 (6.4)*	-38.4 (7.2)*	-39.1 (6.5)*	-40.2 (7.0)	-34.1 (6.2)	-34.5 (7.3)	-35.1 (7.3)	-36.2 (7.2)	-33.5 (5.1)	-32.5 (5.6)**	-34.3 (6.5)**	-35.2 (6.8)**
L Ankle - 4th displacement (°)	21.1 (8.9)	22.4 (8.9)	22.7 (10.2)*	24.0 (10.1)	19.7 (11.9)	19.2 (13.1)	18.8 (12.2)	19.8 (11.9)	16.0 (8.7)	15.6 (7.9)**	18.8 (9.2)	18.6 (9.2)
R Ankle - 4th displacement (°)	20.8 (8.8)	20.7 (8.7)	21.7 (9.0)*	23.8 (8.4)*	16.7 (11.5)	17.6 (12.0)	17.9 (11.6)	18.4 (11.8)	18.3 (6.4)	18.4 (5.9)	19.9 (7.2)	20.7 (8.1)

L – left; R – right; *difference between baseline and pre-intervention ($p < 0.05$); **difference between baseline and post-intervention ($p < 0.05$); ** *difference between pre- and post-intervention ($p < 0.05$).

Table 4 Data of the angular positions and displacements of the knee. Differences between baseline, pre-, and post-intervention.

Variables	Baseline (n=16)				Pre-intervention (n=16)				Post-intervention (n=16)			
	1stInterval	2ndInterval	3rd Interval	4thInterval	1stInterval	2ndInterval	3rdInterval	4thInterval	1stInterval	2ndInterval	3rdInterval	4thInterval
L Knee angle - first position (°)	4.1 (7.2)	3.1 (5.6)	2.0 (5.2)	2.5 (6.6)	2.1 (6.2)	1.1 (5.6)	0.8 (6.5)	0.3 (5.6)***	2.1 (4.4)	3.1 (3.6)	3.5 (4.7)	3.3 (4.5)
R Knee angle - first position (°)	2.9 (6.1)	2.4 (6.8)	2.1 (5.0)	-0.5 (4.9)	0.9 (5.2)	0.8 (5.5)	0.3 (4.7)	0.9 (5.3)	1.8 (3.4)	2.3 (4.2)	2.3 (4.1)	1.9 (4.4)
L Knee angle - 1st transition (°)	16.6 (5.2)	16.7 (5.6)	16.4 (5.8)	16.6 (4.9)	17.2 (4.7)	15.7 (5.7)	15.8 (5.4)	16.2 (6.3)	17.9 (7.1)	17.9 (6.1)	17.5 (6.0)	17.3 (6.3)
R Knee angle - 1st transition (°)	16.0 (6.6)	15.5 (6.8)	14.5 (6.2)	14.2 (5.5)	16.2 (6.7)	15.8 (6.8)	16.3 (7.4)	16.6 (7.3)	15.9 (6.5)	15.8 (6.9)	15.9 (6.7)	15.7 (6.7)
L Knee angle - 2nd transition (°)	5.8 (6.0)	4.3 (5.2)	4.2 (5.8)	3.5 (5.1)	4.6 (4.7)	2.4 (4.7)	2.0 (4.6)	1.9 (3.9)	3.3 (4.3)	2.9 (3.9)	3.3 (4.5)	2.9 (4.2)
R Knee angle - 2nd transition (°)	5.0 (4.7)*	3.7 (4.1)	3.9 (5.0)	2.1 (3.6)	2.9 (4.7)	2.7 (4.4)	2.6 (4.9)	3.0 (4.7)	3.2 (.3.6)	2.3 (3.6)	1.9 (3.9)	2.2 (4.2)
L Knee angle - 3rd transition (°)	51.9 (8.6)	52.9 (6.7)	52.5 (8.2)	52.1 (8.7)	53.8 (7.0)	52.6 (6.8)	52.4 (6.9)	51.7 (7.5)	52.8 (9.8)	52.8 (9.3)	52.5 (8.8)	52.6 (9.2)
R Knee angle - 3rd transition (°)	51.7 (7.1)	52.3 (7.2)	51.0 (7.5)	50.7 (6.9)*	53.8 (6.7)	53.3 (7.3)	53.9 (6.3)	54.1 (7.5)	52.1 (10.0)	51.9 (9.6)	52.0 (9.8)	52.5 (10.4)
L Knee angle - 4th transition (°)	5.9 (11.4)	3.4 (6.7)	2.3 (5.0)	2.5 (6.4)	2.0 (5.9)	0.9 (5.5)	0.4 (5.7)***	0.3 (5.5)***	1.7 (5.0)	3.0 (3.8)	3.5 (4.8)	3.4 (4.4)
R Knee angle - 4th transition (°)	2.7 (6.0)	2.3 (6.5)	1.8 (5.3)	-0.4 (4.6)	0.9 (5.9)	0.7 (5.4)	0.2 (4.5)	0.8 (5.3)	2.0 (3.5)	2.6 (4.0)	2.3 (4.0)	2.1 (4.3)
L Knee - 1st displacement (°)	13.3 (5.1)	13.8 (5.4)	14.4 (4.8)	14.0 (5.9)	15.1 (5.4)	14.7 (5.0)	15.0 (5.4)	15.9 (6.4)***	15.8 (7.1)**	14.6 (6.4)	14.1 (5.6)	14.0 (5.4)
R Knee - 1st displacement (°)	13.1 (4.3)*	13.1 (4.5)	12.4 (3.9)*	14.7 (4.4)	15.3 (5.0)	15.1 (4.4)	16.0 (4.9)	15.7 (5.1)	14.1 (5.5)	13.5 (5.3)	13.6 (5.2)	13.8 (5.0)
L Knee – 2nd displacement (°)	-11.9 (5.8)	-12.8 (6.7)	-12.2 (7.4)	-13.1 (6.2)	-12.7 (6.4)	-13.4 (5.6)	-13.8 (5.6)	-14.3 (7.0)	-14.7 (6.1)	-14.8 (6.1)	-14.2 (6.0)	-14.5 (6.3)
R Knee – 2nd displacement (°)	-11.0 (5.5)*	-11.9 (6.0)	-10.6 (7.0)*	-12.1 (6.2)	-13.4 (5.9)	-13.1 (5.6)	-13.7 (6.5)	-13.6 (6.9)	-12.8 (4.7)	-13.5 (5.3)	-14.1 (5.5)**	-13.5 (5.2)
L Knee - 3rd displacement (°)	48.3 (8.2)*	49.4 (8.1)	48.3 (8.5)	48.7 (9.5)	49.3 (8.6)	50.3 (8.2)	50.5 (8.2)	49.8 (8.3)	49.6 (9.0)	49.8 (9.8)	49.2 (9.4)	49.7 (9.6)
R Knee - 3rd displacement (°)	46.7 (7.1)	48.6 (7.8)	47.1 (8.4)*	48.6 (7.4)*	50.9 (6.3)	50.6 (5.8)	51.3 (6.0)	51.1 (7.1)	48.9 (8.1)	49.6 (8.6)	50.1 (8.7)	50.3 (8.9)
L Knee - 4th displacement (°)	-49.5 (8.8)	-50.8 (8.0)	-50.2 (8.4)	-49.6 (9.3)	-51.9 (8.3)	-51.8 (8.2)	-52.1 (8.7)***	-51.4 (8.6)	-51.1 (10.9)	-49.8 (9.8)	-49.0 (9.6)	-49.2 (9.3)
R Knee - 4th displacement (°)	-49.1 (7.6)*	-49.9 (8.6)	-49.2 (6.6)*	-51.0 (6.8)	-52.9 (6.0)	-52.6 (5.9)	-53.7 (5.4)	-53.3 (6.2)	-50.1 (9.2)	-49.2 (7.7)	-49.7 (7.8)	-50.4 (8.4)

L – left; R – right; *difference between baseline and pre-intervention ($p < 0.05$); **difference between baseline and post-intervention ($p < 0.05$); ***difference between pre- and post-intervention ($p < 0.05$).

Table 5 Data of the angular positions and displacements of the hip. Differences between baseline, pre-, and post-intervention.

Variables	Baseline (n=16)				Pre-intervention (n=16)				Post-intervention (n=16)			
	1st Interval	2nd Interval	3rd Interval	4th Interval	1stInterval	2ndInterval	3rdInterval	4thInterval	1stInterval	2ndInterval	3rdInterval	4th Interval
L Hip angle - first position (°)	27.7 (7.9)	26.7 (7.8)	26.7 (7.5)	27.6 (7.8)	26.4 (8.6)	25.7 (8.4)	25.1 (8.2)	24.0 (8.1)	27.2 (6.3)	26.6 (6.1)	26.4 (5.8)	25.8 (6.4)
R Hip angle - first position (°)	26.3 (8.3)	26.6 (9.2)	26.7 (8.5)	25.7 (8.0)	25.1 (9.0)	25.3 (9.4)	24.4 (9.4)	24.9 (9.7)	26.6 (5.4)	26.6 (5.6)	26.4 (5.4)	25.9 (5.5)
L Hip angle - 1st transition (°)	-10.1 (8.7)	-12.2 (5.7)	-12.9 (6.7)	-13.2 (7.1)	-14.2 (6.5)	-14.8 (6.3)	-16.2 (6.7)	-17.2 (6.6)	-13.2 (3.8)	-13.8 (5.3)	-14.9 (5.4)	-15.4 (5.4)
R Hip angle - 1st transition (°)	-12.4 (3.8)	-12.5 (4.0)	-12.8 (5.2)	-13.5 (5.2)	-14.5 (5.3)	-14.5 (5.6)	-15.8 (6.6)	-15.7 (6.5)	-13.2 (3.2)	-14.2 (4.1)	-14.4 (6.6)	-15.3 (5.0)
L Hip angle - 2nd transition (°)	27.5 (10.0)	27.7 (8.6)	28.4 (8.3)	28.5 (8.0)	27.0 (8.6)	26.2 (8.2)	25.8 (7.9)	25.1 (8.4)	28.0 (6.1)	27.4 (5.9)	26.9 (5.3)	26.4 (5.8)
R Hip angle - 2nd transition (°)	26.9 (8.3)	27.6 (9.0)	28.0 (9.0)	27.0 (7.7)	25.7 (8.7)	26.1 (9.4)	25.3 (9.3)	25.5 (9.8)	27.2 (5.2)	27.1 (5.4)	26.9 (5.0)	26.5 (5.2)
L Hip angle - 3rd transition (°)	27.0 (7.5)	26.2 (7.5)	26.4 (7.6)	26.5 (7.4)	25.4 (8.0)	24.7 (7.5)	24.0 (7.4)	23.3 (8.0)	26.7 (6.1)	26.0 (5.9)	25.7 (5.5)	25.1 (6.1)
R Hip angle - 3rd transition (°)	25.4 (8.1)	26.2 (8.8)	26.3 (8.6)	25.3 (7.5)	24.4 (8.5)	24.8 (9.1)	23.6 (9.0)	24.1 (9.4)	25.8 (5.2)	25.9 (5.4)	25.6 (4.7)	25.3 (5.1)
L Hip - 1st displacement (°)	-39.3 (8.5)	-39.6 (8.8)	-39.6 (8.5)	-40.7 (8.6)	-40.7 (8.5)	-40.5 (7.6)	-41.2 (8.1)	-41.3 (7.6)	-40.4 (8.0)	-40.0 (8.8)	-41.4 (8.4)	-41.2 (8.5)
R Hip - 1st displacement (°)	-38.7 (7.5)	-39.1 (9.0)	-39.5 (8.6)	-39.3 (9.0)	-39.6 (8.4)	-39.8 (8.6)	-40.2 (8.7)	-40.5 (9.4)	-39.8 (5.5)	-40.8 (6.2)	-40.8 (6.0)	-41.2 (6.7)
L Hip - 2nd displacement (°)	40.8 (8.3)	41.1 (8.7)	41.3 (8.3)	41.7 (8.3)	41.3 (7.8)	41.0 (7.5)	42.0 (7.5)	42.3 (7.9)	41.2 (7.8)	40.7 (8.9)	41.9 (8.4)	41.8 (8.4)
R Hip - 2nd displacement (°)	39.3 (7.3)	40.2 (8.7)	40.7 (8.7)	40.5 (8.6)	40.2 (7.6)	40.7 (7.9)	41.0 (7.9)	41.2 (8.7)	40.3 (4.9)	41.3 (6.2)	41.4 (6.2)	41.8 (6.4)
L Hip - 3rd displacement (°)	-2.0 (1.5)	-2.0 (1.9)	-2.0 (1.9)	-2.0 (2.0)	-1.6 (1.9)	-1.4(1.5)	-1.8 (2.0)	-1.8 (1.8)	-1.3 (1.8)	-1.4 (1.6)	-1.2 (1.3)	-1.2 (1.4)
R Hip - 3rd displacement (°)	-1.5 (1.1)	-1.5 (1.2)	-1.7 (1.1)	-1.7 (1.1)	-1.4 (1.6)	-1.3 (1.7)	-1.6 (1.7)	-1.4 (1.7)	-1.4 (1.0)	-1.2 (1.1)	-1.4 (1.5)	-1.2 (1.2)

L – left; R – right.

In the present study, gait speed increased throughout the 6MWT. This is consistent with findings from a previous study (Silva et al., 2024, 2025). As noted in that study, this increase may be attributed to participants' motivation to optimize their performance during the test.

It was hypothesized that the exercise program would lead to significant improvements in gait biomechanical parameters associated with falls. While meaningful gains were observed in functional capacity and fear of falling, certain gait parameters – such as step length, stride length, and stance phase – did not show significant improvement. This lack of change warrants transparent acknowledgment, as it may indicate that the program's benefits are more pronounced for overall functional performance and psychological outcomes rather than specific spatial and temporal gait characteristics. These findings highlight potential limitations in the scope of the intervention and underscore the need for further research to refine training strategies that more directly target the biomechanical aspects of gait.

As aforementioned, data indicated a decrease in fear of falling following the intervention. Fear of falling in older adults has been extensively studied, with robust evidence supporting the effectiveness of exercise-based interventions. This way, a previous systematic review concluded that exercise programs incorporating strength, balance, and functional exercises effectively reduce fear of falling in older adults living independently in the community (Kumar et al., 2016). Additionally, a recent systematic review (Savvakis et al., 2024), focused on frail and pre-frail older adults, highlighted the benefits of strength, balance, and functional exercises to decrease the fear of falling. On the other hand, there is a recognized relationship between gait speed and the fear of falling, which is often a consequence of prior falls (Ayoubi et al., 2014; Maki, 1997; Tinetti et al., 1990; Uemura et al., 2012). This suggests the fear of falling may adversely affect gait dynamics in older adults, influencing not only gait speed but also stride length and double support phase (Maki, 1997). Moreover, a previous systematic review pointed out that the stride length and double stance phase can differentiate fallers from non-fallers (Silva et al., 2024, 2025). However, the present study did not observed changes in these gait spatial and temporal parameters as a result of the exercise program. Finally, the observed reduction in FES-I scores may not only reflect physiological improvements but also the influence of psychological and social factors. Social interaction, supervised exercise, and the group dynamics inherent to the program could have played a critical role, particularly given the context of pandemic-related isolation. Prior evidence suggests that the benefits of exercise interventions extend beyond physical function, with psychological effects constituting an important mechanism for reducing fall risk among older adults (Yang et al., 2022). While fear of falling may not always be immediately problematic, it can escalate into anxiety, perpetuating a cycle of inactivity, physical decline, reduced quality of life, and heightened fall risk (Jørstad et al., 2005). Future research should aim to disentangle the relative contributions of physiological and psychosocial pathways in order to more fully understand and optimize intervention strategies.

The better performance in 6MWT and TUG yielded by the older adults after the exercise program is clinically significant, as this performance reflects improved gait speed and postural stability during change directions and rise from a seated position – essential skills for daily activities and fall prevention (Barry et al., 2014; Lehtola et al., 2006). In addition to being validated outcomes of functional capacity in older adults, the observed improvements can also be related to potential real-world impacts, such as enhanced mobility, confidence, or autonomy (Almeida et al., 2017; Ubuane et al., 2018). On the other hand, the better performance in TUG is consistent with findings from previous studies that implemented exercise programs (Krebs et al., 2007; Sadeghi et al., 2021). Krebs et al. (2007) compared functional training with traditional strength training, finding that both approaches enhanced TUG performance in older adults. Similarly, Sadeghi et al. (2021) further observed that exercise programs integrating balance and strength exercises led to significant improvements in TUG performance among older adults. Accordingly, these findings suggest that structured and supervised interventions incorporating strength and functional exercises enhance TUG performance.

The adherence rate to the exercise program was remarkably high, suggesting that the program was well accepted by the participants. The adaptation of exercise intensity and progression according to the complexity and individual capacity of each subject may have been a contributing factor. Another important factor that may have contributed to the positive outcomes was the organization of the program into small groups. This approach facilitated the implementation of the program, allowing for more individualized attention from the physiotherapist, which likely optimized the correction of movements and the adaptation of exercises to the specific needs of each participant. Additionally, the small-group dynamic likely fostered a more supportive and motivating environment, enhancing adherence and acceptance of the program among participants. On the other hand, the absence of adverse events during the program reinforces the safety of the protocol, indicating that the strategies for adjustment and gradual progression were effective in minimizing risks and ensuring the safe execution of exercises. Exercise programs with regular monitoring and individualized adaptation are more effective in reducing falls and promoting safety in older adults (Bento et al., 2010). In summary, the high adherence rate and absence of adverse events provide strong evidence for the feasibility and acceptability of the intervention, highlighting that the program is not only safe and well-tolerated, but also highly suitable for widespread implementation in community settings.

This study was conducted during the dynamic period of the COVID19 pandemic, when fluctuations between social restrictions and relaxations could have influenced both physical activity and psychological status. Thus, COVID-19 could be considered a possible confounding factor. The improvement in gait speed and 6MWT performance between baseline and pre-intervention may have reflected an increase in individuals' physical activity levels because of the relaxation of social restrictions. Moreover, it reinforces the notion that regular physical activity, even at moderate levels, can be beneficial, particularly for vulnerable populations. On the other hand, the period between pre- and post-intervention presented renewed social restrictions because of COVID-19, limiting physical activity beyond the program. Even so, improvements in gait speed, 6MWT, and TUG performances were observed after intervention, reinforcing the ability of the exercise program to improve functional capacity in this sample of community-dwelling older adults.

This study presented several strengths. First, the use of objective gait analysis technologies (pressure platforms and IMUs) provided rigorous biomechanical data that complemented functional assessments (TUG and 6MWT), reducing reliance on subjective or timing-based measures. Second, the multidimensional design, integrating gait biomechanics, functional capacity, and psychological outcomes, offered a more comprehensive evaluation of fall risk changes. Third, conducting the trial in a community-dwelling sample enhanced ecological validity and supports the applicability of findings to real-world exercise programs. Fourth, the intervention was conducted in accordance with a low cost and pre-validated exercise protocol (Aleixo & Abrantes, 2024), publicly accessible at http://elderly.falls.ulusofona.pt/, thereby strengthening methodological transparency and reproducibility. Moreover, this trial constitutes the first empirical evaluation of the Aleixo & Abrantes (2024) program, highlighting its innovative character and its potential for future adaptation and broader application. Finally, the inclusion of older adults with higher body mass index values (~30 kg/m^2), a group at elevated fall risk but often underrepresented in exercise trials, strengthens the population-specific relevance.

This study is subject to several limitations that warrant consideration, including the small sample size that limited the statistical power of the analyses. Indeed, of the 36 participants initially recruited, only 16 completed the intervention, yielding an attrition rate of over 50 %. Such high dropout reduces statistical power, may limit sample representativeness, and could compromise internal validity. Moreover, the use of a non-randomized design without a control group significantly limits internal validity, as group equivalence cannot be assumed without random allocation. Accordingly, the potential influence of unmeasured confounding variables and selection bias cannot be excluded. Furthermore, while the intervention demonstrated improvements in functional parameters, fall prevention potential was inferred rather than directly measured, as no fall incidence tracking or follow-up was performed. This way, the Fall Risk Questionnaire could be a valuable tool to achieve this goal (Monteiro et al., 2023). Moreover, the present study analysed the impact of an exercise program with only 12 weeks of duration, leaving the long-term retention of benefits and sustainability of effects uncertain. Also, participants were recruited through convenience sampling in a single community, which may have introduced sampling bias and further limits external validity. Finally, the participant profile, characterized by a predominance of women and a mean body mass index within the overweight-to-obese range, restricts the generalizability of the results to broader or more heterogeneous older adult populations. Future studies should employ randomized controlled designs with a matched comparison group, incorporate longer follow-up periods with fall incidence monitoring, and recruit more diverse cohorts to strengthen both internal and external validity.

5. CONCLUSIONS

Despite the acknowledged limitations, this study provides evidence that the structured and supervised 12-week exercise program positively improved gait biomechanics and functional capacity in this sample of community-dwelling older adults. The exercise program was associated with increased gait speed and cadence, along with better performance in functional tests such as the TUG and 6MWT. It also appeared to reduce fear of falling, highlighting potential psychosocial benefits. The high adherence and no adverse events indicate that the intervention was safe, well-tolerated, and feasible for community implementation. Further research employing larger cohorts and randomized controlled designs is warranted to validate these findings and elucidate the respective contributions of physiological and psychological mechanisms underlying the effects of the exercise program.

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CAPÍTULO V

DISCUSSÃO DOS RESULTADOS

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Esta tese teve como objetivos abordar três lacunas identificadas na literatura científica: (1) a ausência de uma revisão sistemática que sintetizasse os parâmetros biomecânicos da marcha associados a quedas em idosos; (2) a escassez de investigação sobre alterações biomecânicas ao longo da marcha de longa duração; e (3) a falta de evidência quanto à eficácia de programas de exercício na modificação de parâmetros biomecânicos da marcha associados às quedas. Os três objetivos desta tese foram alcançados através da consecução de três artigos.

O primeiro artigo teve como objetivo principal identificar e descrever os parâmetros biomecânicos da marcha associados a quedas na população idosa através de uma revisão sistemática. Segundo os resultados obtidos, os parâmetros espaço-temporais foram os mais analisados na comparação entre idosos com e sem historial de quedas, destacando-se a velocidade da marcha como o parâmetro mais consistente. Como referido por vários autores (Maki, 1997; Ayoubi et al., 2014; Uemura et al., 2012), a velocidade da marcha mostrou-se significativamente reduzida nos idosos com historial de quedas, sugerindo que este pode ser um parâmetro biomecânico relevante para diferenciar idosos com e sem historial de quedas, e por via disso, um parâmetro associado às quedas. No que diz respeito aos fatores subjacentes à redução da velocidade da marcha, os dados compilados nesta revisão sistemática apontam para duas possíveis explicações. Por um lado, como demonstrado nos estudos incluídos, a diminuição da capacidade funcional pode contribuir para esta redução. Por outro lado, o medo de cair também parece desempenhar um papel igualmente importante (Maki, 1997; Ayoubi et al., 2014; Uemura et al., 2012).

Além da velocidade da marcha, a revisão sistemática realizada aponta para que outros parâmetros espaço-temporais também mostrem capacidade diferenciadora, nomeadamente o comprimento do passo e a fase de duplo apoio. De acordo com a literatura (Fukuchi et al., 2019), a velocidade da marcha está dependente da cadência e do comprimento do passo. Assim, os dados apresentados pela revisão sistemática apontam para que a redução no comprimento do passo tem um contributo mais significativo do que a cadência para a diminuição da velocidade observada nos idosos com historial de quedas. Desta forma, os dados indicam que o medo de voltar a cair influencia a marcha do idoso, em especial a velocidade da marcha, tal como é defendido na literatura (Maki, 1997), em que o comprimento da passada/passo e a duração da fase de apoio duplo estão relacionados com o medo de cair.

No que concerne aos parâmetros relacionados com o tropeçar, os resultados foram mais contraditórios. Os dados desta revisão sistemática não confirmaram a capacidade da *minimum toe clearance* para diferenciar, consistentemente, idosos com e sem historial de quedas. Contudo, como mencionado numa revisão sistemática anterior (Barrett et al., 2010) e na realizada no âmbito desta tese (primeiro artigo), a variabilidade da *minimum toe clearance*, avaliada através de medidas lineares e não-lineares, mostrou-se promissora como indicador de risco de queda. Esta observação é particularmente relevante, uma vez que, como referido pela literatura (Aleixo et al., 2019; Bhudarally et al., 2020; Moosabhoy et al., 2006), a *minimum toe clearance* é sensível às posições angulares das articulações do membro inferior em fase aérea, especialmente do tornozelo e anca.

Quanto à cinemática articular, os resultados sugerem diferenças significativas entre os idosos com e sem historial de quedas ao nível da anca e tornozelo, mas não ao nível do joelho. Esta distinção é importante do ponto de vista clínico, pois, como proposto na literatura (Aleixo et al., 2022; Aleixo & Abrantes, 2024), programas de exercícios propriocetivos e de força funcional que visem especificamente estas articulações podem ser particularmente eficazes na melhoria do controlo motor e, consequentemente, na redução do risco de quedas.

No âmbito das quedas causadas por escorregar, os dados disponíveis são escassos e inconsistentes. Embora alguns estudos (Aleixo & Abrantes, 2015; Baba et al., 2023; Chiba et al., 2005) tenham identificado a velocidade do calcanhar e o ângulo do pé no contacto com o solo como parâmetros relevantes, os resultados desta revisão sistemática não confirmaram estas associações de forma consistente. Da mesma forma, a literatura sobre estabilidade postural durante a marcha apresentou-se limitada e os resultados contraditórios.

Uma das principais limitações identificadas nesta revisão sistemática prende-se com a qualidade metodológica dos estudos incluídos. Como referido nos resultados, a maioria dos estudos foram classificados como fracos na sua avaliação global, particularmente no que diz respeito ao viés de seleção e ao desenho do estudo. Além disso, a heterogeneidade na definição de queda e a utilização de diferentes metodologias de avaliação, incluindo a marcha em tapete rolante (Schmitt et al., 2021), também limitaram a comparação dos resultados. Por outro lado, a escassez de dados em alguns parâmetros, como a atividade muscular e a estabilidade articular, aponta para a necessidade de investigação futura nestes tópicos.

Do ponto de vista clínico, os resultados da presente revisão sistemática (primeiro artigo) sublinham a importância de monitorizar parâmetros específicos da marcha, como a velocidade da marcha, o comprimento do passo e a fase de duplo apoio, nomeadamente na avaliação do risco de quedas em idosos. Por outro lado, estes resultados também sugerem que intervenções direcionadas para a melhoria do controlo motor e da confiança na marcha podem ser particularmente eficazes na prevenção de quedas nos idosos.

De acordo com a presente revisão sistemática (primeiro artigo) existia uma escassez de investigação sobre as alterações biomecânicas da marcha nos idosos ao longo da marcha de longa distância. Assim, o segundo artigo teve como objetivo descrever as características da marcha em mulheres idosas, de uma comunidade específica em Portugal, durante o 6MWT. O estudo focou-se na análise dos parâmetros espaço-temporais da marcha (parâmetros associados às quedas com base na revisão sistemática realizada – primeiro artigo), bem como na cinemática angular das articulações dos membros inferiores, com o objetivo de compreender como é que esses parâmetros se comportavam ao longo de uma marcha de longa duração. Por outro lado, neste artigo também se comparou dois grupos de mulheres idosas (≥75 anos e <75 anos). Os resultados demonstraram que as participantes aumentaram a velocidade da marcha ao longo do teste, um fenómeno atribuível ao incremento da cadência e do comprimento da passada. No entanto, este aumento ocorreu apenas até ao terceiro intervalo do teste, seguindo-se uma tendência de redução, particularmente nas mulheres mais idosas (≥75 anos). Para além disso, os dados obtidos no terceiro artigo também corroboram estes resultados. Este padrão sugere o possível aparecimento de fadiga, embora o estudo não tenha controlado parâmetros diretamente relacionados com este fenómeno, o que limitou a capacidade de tirar conclusões definitivas. Por outro lado, não foram encontradas alterações nos parâmetros espaço-temporais compatíveis com os efeitos da fadiga reportados noutras investigações (Barbieri et al., 2013), o que sugere que a duração do 6MWT pode não ser suficiente para induzir fadiga em idosos. Assim, futuros estudos deverão considerar protocolos mais longos e incluir medições adicionais relacionadas com a fadiga.

Curiosamente, apesar do aumento inicial da velocidade, verificou-se também uma fase de apoio e de duplo apoio mais prolongadas. Segundo um estudo prévio (Maki, 1997), o aumento destas fases está associado a uma marcha mais cautelosa, o que sugere que, embora mulheres idosas consigam aumentar a velocidade, adotam estratégias de prevenção para garantir segurança durante a marcha.

Ainda no segundo artigo, no que diz respeito à cinemática articular, foi observado um aumento dos deslocamentos angulares da anca e do tornozelo em resposta ao incremento da velocidade da marcha. Estas alterações estão em linha com revisões sistemáticas anteriores (Fukuchi et al., 2019), que indicam que a velocidade da marcha influencia diretamente a cinemática articular em idosos. Além disso, ao comparar mulheres mais velhas (≥75 anos) e mulheres mais jovens (<75 anos), verificou-se igualmente que as participantes mais jovens apresentaram maior velocidade, cadência, comprimento da passada e menor duração das fases de apoio, reforçando a noção de que o envelhecimento está associado a uma redução da capacidade funcional e a uma marcha mais conservadora, tal como destacado na literatura (Herssens et al., 2018).

Uma das limitações do segundo artigo prendeu-se com o facto de a amostra ser constituída apenas por residentes de uma única cidade portuguesa, o que comprometeu a generalização dos resultados. Além disso, o reduzido tamanho da amostra e a ausência de controlo da velocidade natural de marcha podem ter também introduzido enviesamentos. Por fim, o estudo consubstanciou o potencial dos sistemas inerciais na avaliação da marcha, uma vez que estes dispositivos permitem análises cinemáticas fora do laboratório, com menor custo e maior praticabilidade comparativamente aos sistemas tridimensionais de análise de movimento.

O terceiro artigo avaliou o impacto de um programa de exercícios de 12 semanas, especificamente desenhado para a prevenção de quedas, em parâmetros biomecânicos da marcha associados às quedas, capacidade funcional e no medo de cair em idosos. Os resultados demonstraram que o programa de exercícios teve um impacto significativamente positivo na capacidade funcional, refletido em melhorias na velocidade da marcha, nos desempenhos no *Timed Up and Go test* e no 6MWT, bem como uma redução no medo de cair (FES-I).

De acordo com a revisão sistemática realizada (primeiro artigo), os idosos com historial de quedas tendem a apresentar uma menor velocidade da marcha, sugerindo que este parâmetro pode ser um parâmetro diferenciador entre idosos com e sem historial de quedas. Assim, o aumento da velocidade da marcha observado no terceiro artigo parece indicar que o programa de exercícios pode ter um efeito protetor contra as quedas; para além disso, as características desse programa estão alinhadas com as recomendações de Sherrington et al (2019) para programas de prevenção de quedas. No entanto, a confirmação desta hipótese exigiria estudos longitudinais que avaliem diretamente a incidência de quedas após a intervenção.

Os resultados obtidos no terceiro artigo estão em concordância com investigações anteriores (Aleixo et al., 2016, 2022; Persch et al., 2009; Shin & An 2014), as quais também reportaram melhorias na velocidade da marcha após programas de exercício em idosos. Além disso, o aumento da velocidade da marcha no presente estudo foi acompanhado por alterações noutros parâmetros biomecânicos, como a cadência, o tempo de passo e a cinemática articular dos membros inferiores, corroborando as conclusões de uma revisão sistemática anterior (Fukuchi et al., 2019), que destacou a relação entre a velocidade da marcha e outros parâmetros biomecânicos.

No que diz respeito ao medo de cair, o terceiro estudo verificou uma redução significativa após a intervenção, um resultado consistente com a literatura. Uma revisão sistemática anterior (Kumar et al., 2016) concluiu que os programas de exercício que combinam exercícios de força, funcionais, e de estabilidade postural são eficazes na redução do medo de cair. Da mesma forma, Savvakis et al. (2024) destacaram os benefícios deste tipo de intervenção em idosos frágeis e pré-frágeis. Existe ainda uma relação bem estabelecida entre a velocidade da marcha e o medo de cair, frequentemente associado a quedas anteriores (Ayoubi et al., 2014; Maki 1997; Tinetti et al., 1990; Uemura et al., 2012). Contudo, o presente estudo não observou alterações significativas no comprimento do passo ou na fase de duplo apoio como resultado do programa de exercícios, parâmetros que, segundo a revisão sistemática realizada durante esta tese (primeiro artigo), podem diferenciar idosos com e sem historial de quedas. Este facto sugere que o impacto do programa de exercício no medo de cair pode estar mais relacionado com fatores psicológicos e de confiança do que com alterações específicas na biomecânica da marcha, tal como proposto por Yang et al. (2022).

A elevada taxa de adesão ao programa de exercício sugere que a intervenção foi bem aceite pelos participantes. Fatores como a adaptação individualizada da intensidade e progressão dos exercícios, bem como a organização em pequenos grupos, facilitaram a implementação do programa, permitindo um acompanhamento mais personalizado por parte do investigador que aplicou o respetivo programa. Esta abordagem não só otimizou a correção de movimentos, como também criou um ambiente mais motivador e seguro, contribuindo para a adesão e eficácia da intervenção. A ausência de eventos adversos reforça ainda a segurança do protocolo, corroborando a importância de programas supervisionados e adaptados para minimizar os riscos nos idosos (Bento et al., 2010).

Embora este terceiro estudo tenha fornecido contribuições relevantes para a área, importa reconhecer algumas limitações que devem ser consideradas. Em primeiro lugar, a utilização de uma amostra reduzida e a ausência de randomização podem comprometer a robustez estatística dos resultados e limitar a sua generalização. Adicionalmente, seria pertinente avaliar os efeitos a longo prazo da intervenção proposta, bem como a sua relação direta com a incidência de quedas, dado que este aspeto não foi analisado no presente trabalho. Futuras investigações deverão ainda integrar análises mais aprofundadas da atividade muscular e da estabilidade articular, de modo a permitir uma compreensão mais generalizada dos mecanismos subjacentes às quedas nesta população.

Finalmente, importa salientar que os resultados deste compêndio de artigos proporcionaram evidências científicas robustas sobre a relação entre parâmetros biomecânicos da marcha e as quedas em idosos, destacando-se parâmetros como a velocidade da marcha, o comprimento do passo, a fase de duplo apoio e a variabilidade da *minimum toe clearance* como indicadores de risco. Adicionalmente, também demonstrou que um programa de exercícios propriocetivos e de força pode melhorar a capacidade funcional e parâmetros biomecânicos associados às quedas, e reduzir o medo de cair, reforçando o papel crucial da atividade física estruturada na promoção do envelhecimento ativo e seguro. Assim, os resultados aqui apresentados têm implicações clínicas relevantes, sublinhando a necessidade da integração de avaliações biomecânicas e intervenções personalizadas em programas de prevenção de quedas.

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CAPÍTULO VI

CONCLUSÃO

CONCLUSÃO

Com base nos resultados alcançados nos diferentes artigos que integram a presente tese de doutoramento, destacam-se as seguintes conclusões:

- Os resultados da revisão sistemática evidenciaram que a velocidade da marcha, o comprimento da passada/passo e a fase de duplo apoio são parâmetros biomecânicos críticos na distinção entre idosos com e sem historial de quedas, devendo, por isso, ser prioritariamente considerados pelos profissionais de saúde na avaliação clínica e no desenvolvimento de intervenções preventivas de quedas. Além disso, os idosos com historial de quedas apresentam também uma maior variabilidade na marcha, sendo a variabilidade da *minimum foot/toe clearance* um parâmetro particularmente relevante devido à sua associação com o tropeçar, um mecanismo comum de quedas nos idosos.
- Mulheres idosas apresentaram alterações nos parâmetros espaço-temporais e cinemáticos da marcha ao longo da marcha de longa duração (6MWT), caracterizadas por um aumento progressivo da velocidade da marcha, do tempo de fase de apoio e da fase de apoio duplo. Paralelamente, observou-se um aumento dos deslocamentos angulares das articulações da anca, joelho e tornozelo durante a realização do teste.
- Quando comparadas, as mulheres idosas mais velhas (≥75 anos) apresentaram valores significativamente inferiores em parâmetros biomecânicos da marcha, nomeadamente na velocidade da marcha, cadência, comprimento do passo e comprimento da passada, acompanhados por fases de apoio e duplo apoio mais prolongadas, e deslocamentos angulares articulares mais reduzidos.
- O programa de exercícios de 12 semanas, combinando exercícios propriocetivos e de força, apresentou efeitos sobre a capacidade funcional dos idosos. Como demonstram os resultados, a implementação do programa resultou em melhorias significativas em diversos parâmetros biomecânicos da marcha, nomeadamente no aumento da cadência e velocidade da marcha, nas alterações na cinemática do joelho e do tornozelo, bem como na melhoria do desempenho em testes funcionais, como é o caso do 6MWT.

Em síntese, este trabalho forneceu evidências científicas robustas que suportam a implementação de programas de exercício em idosos, destacando-se como um contributo relevante para a promoção do envelhecimento ativo e seguro. Os resultados obtidos não apenas validam a eficácia da intervenção proposta, como também abrem caminho para novas investigações que possam aprofundar a relação entre parâmetros biomecânicos, medo de cair e estratégias de prevenção de quedas personalizadas, contribuindo assim para o avanço do conhecimento nesta área.

ANEXOS

ANEXO 1 – PARECER DE APROVAÇÃO DO COMITÊ DE ÉTICA

UNIVERSIDADE LUSÓFONA
| Faculdade de Educação Física e Desporto

Comissão de Ética da Faculdade de Educação Física e Desporto -ULHT

Parecer J1621A

A Comissão de Ética da Faculdade de Educação Física e Desporto – ULHT, em reunião de 16 de Junho de 2021, analisou o projeto de Doutoramento em Educação Física e Desporto – Ramo Atividade Física e Saúde, de Jullyanne Rodrigues de Moura Silva, subordinado ao tema *Vitalidade: Programa de Exercícios Físicos para a Prevenção de Quedas em Idosos,* tendo decidido emitir parecer positivo sem recomendações.

O Diretor da Comissão de Ética da FEFD – ULHT

Faculdade de Educação Física e Desporto UNIVERSIDADE LUSÓFONA

(José Gregório Viegas Brás)

ANEXO 2 – FOLHETO UTILIZADO PARA RECRUTAMENTO DE PARTICIPANTES

ANEXO 3 – CONSENTIMENTO DE INFORMADO

CONSENTIMENTO DE INFORMADO LIVRE E ESCLARECIDO PARA INVESTIGAÇÃO CIÊNTIFICA EM SERES HUMANOS

Titulo do Projeto ou estudo:

VITALIDADE: Programa de Exercícios Físicos, Baseado no Estudo da Biomecânica da Marcha para Diminuição do Risco de Quedas nos Idosos

Title: VITALITY: Physical Exercise Program, Based on Gait Biomechanics to Reducing the Risk of Falls in Elderly

Investigadores responsável pelo Projeto:

Jullyanne Rodrigues de Moura silva

Prof. Doutor Pedro Aleixo

Prof. Doutor Tiago Atalaia

Instituição de Acolhimento:

CICANT – Centro de Investigação em Comunicação Aplicada, Cultura e Novas Tecnologias. Campo Grande, 376, 1749-024 Lisboa, Portugal

Faculdade de Educação Física e Desporto – Universidade Lusófona de Humanidades e Tecnologias

Este documento, designado **Consentimento, Informado, Livre e Esclarecido**, contém informações importantes em relação ao estudo para qual foi abordado(a), bem como o que esperar se decidir participar do estudo. Leia atentamente toda a informação aqui contida. Deve se sentir inteiramente livre para colocar qualquer questão, assim como para discutir com terceiros (familiars / e ou Amigos) a decisão da sua participação neste estudo. Deve solicitar todas as informações que achar importantes e todos os esclarecimentos aos investigadores deste estudo.

Informação Geral
Gostariámos de o convidar a participar num estudo Científico realizado na área da Atividade fisica e saúde. Este estudo pretende investigar os efeitos de um programa de exercícios fisicos nos parâmetros biomecânicos da marcha associados às quedas de idosos, A participação neste estudo significa que as informações e dados sobre si será recolhida e analizada juntamente com informações de outras pessoas. A sua participação é fundamental.

Qual o objetivo do estudo?
O Objetivo do estudo é analisar os efeitos de um programa de exercício de prevenção de quedas (exercícios propriocetivos e de força) em parâmetros biomecânicos da marcha de idosos. Para tal, desenvolvemos o programa "VITALIDADE: Programa de Exercícios Físicos, Baseado no Estudo da Biomecânica da Marcha para Diminuição do Risco de Quedas nos Idosos".
O que é o programa VITALIDADE e o que é esperado da minha participação?
O Programa VITALIDADE é um programa de exercícios contém exercícios propriocetivos e de força, que está estruturado com uma duração de 12 semanas, 3 vezes por semana com a duração de 45 minutos cada sessão de exercícios físicos. A sua participação também consiste no preenchimento de um conjunto de testes e questionários que servirão para avaliarmos a força dos membros inferiores (***30 seconds sit-to-stand***), o equilíbrio e controlo motor (***TUG/ TimedUp&Go***) o medo de cair (***falls efficacy scale-international-FES I***) e os parâmetros biomecânicos da sua marcha, através de uma **plataforma de força**. Estes testes e questionários serão aplicados em 4 momentos (3 meses antes do início do programa de exercícios(t0), no início do programa de exercícios(t1), no final do programa de exercícios(t2) e 6 meses depois do final do programa de exercicios físicos(t3)). Também é esperado que durante a sua participação no programa de exercícios que seja pontual e assíduo.
A minha participação é voluntaria? Quais os meus direitos?
A sua participação é voluntária e você pode recusar-se a participar neste estudo ou pode desistir a qualquer momento, sem ter qualquer tipo de consequência para si.

Quem devo contactar em caso de dúvidas, preocupação ou urgência?
Se tiver alguma dúvida, preocupação ou urgência, pode contactar Jullyanne silva, fica ao seu dispor para qualquer esclarecimento que nos queira solicitar ou fornecer: 919662476. Fisio.jullyannesilva@gmail.com

Eu ____, declaro que autorizo que os meus dados, sejam utilizados na elaboração deste estudo cientifico, Toda a informação será tratada confidencialmente, omitindo todos os meus dados pessoais – nome, morada, número de telefone ou qualquer outro tipo de informação que possa permitir a minha identificação. Declaro que li e/ou foi-me lido este documento e o entendi, formulei todas as dúvidas que eventualmente possa ter tido sobre o estudo em questão, as quais foram esclarecidas pelos investigadores. É de minha livre vontade que aceito participar neste estudo, submetendo-me às suas regras de orientação. Tenho disponibilidade para pertencer a este estudo durante um período de 3 meses, participando no preenchimento dos questionários e nas 3 avaliações requeridas. Fui também informado que sou livre de recusar a utilização dos meus dados clinicos neste estudo, bem como o direito de desistir deste em qualquer fase, sem ser prejudicado. Foi-me explicado que a minha participação não irá privar-me de receber todos os cuidados de saúde necessários à minha condição.

Data: _________________________

Assinatura do utente ou responsável legal: __________________________

Assinatura do investigador: _______________________________________

ANEXO 4 – AUTORIZAÇÃO DE RECOLHA DE IMAGENS

PEDIDO DE AUTORIZAÇÃO PARA RECOLHA DE IMAGENS

Exmo. (a)Sr.(ª)

Eu, Jullyanne Rodrigues de Moura Silva, aluna do Doutoramento em Educação Física e Desporto na Universidade Lusófona de Humanidades e Tecnologias, no âmbito do Projeto "VITALIDADE: Programa de Exercícios Físicos para a Prevenção de Quedas em Idosos", solicito a sua autorização para a recolha de imagem (fotografia e vídeo) durante o decorrer do projeto nas avaliações e no programa de exercícios. As imagens e vídeos realizados servirão unicamente para fins científicos e académicos estando a identidade e privacidade assegurada.

Saudáveis Saudações

Leiria __________ de Julho de 2021

Jullyanne Rodrigues de Moura Silva

Eu, ____, li e compreendi este documento.

☐ Autorizo a recolha de fotos/vídeos

☐ Não autorizo a recolha de fotos/videos

Assinatura do Participante

____

ANEXO 5 – FORMULÁRIO DE CARACTERIZAÇÃO DOS PARTICIPANTES

Caracterização do Participante

Dados Pessoais:

Data: ___/___/___

Nome: ____

Género: M ( ) F ( ) Estado Civil: ______________________________

Idade: ______________________ Data de nascimento: ___/___/___

Morada: ____

Código Postal: _____ - _____ Localidade: _________________________________

Telemóvel/Telefone: ____

Com quem vive? Sozinho( ) Família( )Quem?___________________________

Trabalha atualmente? Sim( ) Não( ) Aposentado( ) Baixa médica( )

Se SIM, qual o teu trabalho? ____

Hobbies ou ocupação? ____

Características Antropométricas:

Peso: _______ Kg Altura: ______ cm IMC: _______________________

Medicação:

Está a tomar alguma medicação? SIM ( ) NÃO ( )

Se SIM, que medicação está a tomar e qual o objetivo?

Medicamento: ____

Medicamento: ____

Medicamento: ____

Medicamento: ____

Universidade Lusófona de Humanidades e Tecnologias - Faculdade de Educação Física e Desporto

Condições de saúde (não controladas/instáveis)

	Sim	Não	Quais?
Múltiplas quedas sem causas determinadas			
Hipotensão postural sintomática associada a sintomas de pré-síncope			
Hipertensão arterial não controlada (ex: Pressão arterial sistólica >170mmHg e/ou Pressão arterial diastólica > 100mmHg			
Acidente vascular encefálico, acidente isquémico transitório, enfarte do miocárdio ou angina instável nos últimos 6 meses			
Arritmia não controlada (Taquicardia>100bpm, Bradicardia <60bpm)			
Cardiomiopatia			
Estenose aórtica			
Perda de consciência súbita inexplicada			
asma severa ou Doença Pulmonar Obstrutiva Crônica,			
Episódio recente de queda com lesão resultante, sem posterior observação médica			
Doença sistêmica aguda e progressiva (ex.: cancro)			
Doença infeciosa aguda (ex.: pneumonia, infeção urinária) ou sinais/sintomas que conduzam a suspeita da mesma (ex.: febre, delirium)			
Artroplastia da anca ou joelho nos 3 meses anteriores,			
Incapacidade para manutenção da postura na posição de sentado			
Disfunção vestibular muito severa (ou aguda)			
Défice cognitivo que impeça a pessoa de seguir as instruções verbais em segurança,			
Participação em qualquer programa de exercício físico nos últimos 3 meses.			

ANEXO 6 – HORÁRIO DAS CLASSES DE EXERCÍCIOS

UNIVERSIDADE LUSÓFONA

fefd faculdade de educação física e desporto

Vitalidade: Programa de Exercícios físicos para prevenção de Quedas nos idosos

Horário

Hora	Participante	Participante	Participante	Participante	Participante	Participante
Grupo A 8:00 – 8:45						
Grupo B 9:00 – 9:45						
Grupo C 10:00 – 10:45						
Grupo D 11:00 – 11:45						
Grupo D 15:00 – 15:45						
Grupo E 16:00 – 16:45						
Grupo F 17:00 – 17:45						

*segunda-feira/quarta-feira/sexta-feira

ANEXO 6 – REGISTO DE ASSIDUIDADE AO PROGRAMA DE EXERCÍCIOS

UNIVERSIDADE LUSÓFONA

fefd faculdade de educação física e desporto

VITALIDADE: Programa de Exercícios Físicos para a Prevenção de Quedas em Idosos

Registo de assiduidade dos participantes

Mês: OUTUBRO 2021

Nomes	25	27	29	Total
Nº de participantes por dia				

Legenda: Presença = (P) Falta = (F)

Registo de assiduidade dos participantes

Mês: NOVEMBRO 2021

NOMES	2	3	5	8	10	12	15	17	19	22	24	26	29	30	TOTAL
Nº de participantes por dia															

Legenda: Presença (P); Falta (F)

UNIVERSIDADE LUSÓFONA

fefd faculdade de educação física e desporto

Registo de assiduidade dos participantes

Mês: DEZEMBRO 2021

Nomes	3	6	7	10	13	15	17	20	22	23	27	29	30	Total
Nº de participantes por dia														

Legenda: Presença (P); Falta (F)

UNIVERSIDADE LUSÓFONA

fefd faculdade de educação física e desporto

VITALIDADE: Programa de Exercícios Físicos para a Prevenção de Quedas em Idosos

Registo de assiduidade dos participantes

Mês: JANEIRO 2022

Nomes	**3**	**5**	**7**	**10**	**12**	**14**	**total**

Legenda: Presença (P); Falta (F).

ANEXO 8 – PARECER DE APROVAÇÃO DO REGISTRO E APROVAÇÃO DA REVISÃO SISTEMÁTICA (PROPERO)

NIHR | National Institute for Health and Care Research

PROSPERO
International prospective register of systematic reviews

GAIT BIOMECHANICS PARAMETERS RELATED TO THE RISK OF FALLS: SYSTEMATIC REVIEW.

Jullyanne Silva, Pedro Aleixo, Tiago Atalaia, João Abrantes

To enable PROSPERO to focus on COVID-19 submissions, this registration record has undergone basic automated checks for eligibility and is published exactly as submitted. PROSPERO has never provided peer review, and usual checking by the PROSPERO team does not endorse content. Therefore, automatically published records should be treated as any other PROSPERO registration. Further detail is provided here.

Citation
Jullyanne Silva, Pedro Aleixo, Tiago Atalaia, João Abrantes. GAIT BIOMECHANICS PARAMETERS RELATED TO THE RISK OF FALLS: SYSTEMATIC REVIEW.. PROSPERO 2024 Available from https://www.crd.york.ac.uk/PROSPERO/view/CRD42021271511

REVIEW TITLE AND BASIC DETAILS

Review title
GAIT BIOMECHANICS PARAMETERS RELATED TO THE RISK OF FALLS: SYSTEMATIC REVIEW.

Original language title
English

Review objectives
The aim of this study was to conduct a systematic review to identify and describe gait biomechanical parameters signed to be related to the risk of fall in healthy elderly populations

Keywords
Fall, Gait, kinematics, kinetics

SEARCHING AND SCREENING

Searches
Systematic Review was conducted independently by 2 researchers (PA and JS), using the following protocol: (1) a comprehensive search of articles was made on MEDLINE Complete,

Cochrane, EMBASE, PEDro, ScienceDirect, and CINAHL Complete for articles published until July 06th, 2021[1] , using the following search sentence - ((gait)) AND ((fall*)) AND ((elder*) OR (old*) OR (senior*)) AND ((kinematic*) OR (kinetic*) OR (biomechanic*) OR (electromyogra*) OR (emg) OR motion analys*) OR (plantar pressure)); (2) Hand search from relevant reports; (3) exclusion of duplicate reports – Mendeley was used to manage all references, removing duplicates; (4) selection of reports by title and abstract; (5) screening of reports by analyzing the complete text. In the fourth and fifth points of the protocol, a third reviewer (TA) would be consulted if there were any differences between the two reviewers.

Study design

The present study included observational studies, according to the following inclusion criteria: (1) articles that associate gait biomechanical parameters to falls

ELIGIBILITY CRITERIA

Condition or domain being studied

Gait is associated with an important risk factor of falls. It is important to find differences of quantitative gait variables between fallers. Our study analyzed the published literature on the biomechanical gait parameters associated with the risk of falls. A comprehensive search of studies published in peer-review articles (July 06, 2021) was conducted on electronic databases (e.g., PubMed). Studies analyzing the relation between biomechanical parameters from gait with the risk of falls were included.

Population

Elderly, considered the WHO definition for elderly, i.e., subjects aged 60 or over (WHO, 2017).

Intervention(s) or exposure(s)

Reports comparing elderly fallers to non-fallers on data from gait biomechanical analyses;
Reports comparing elderly with high fall risk to elderly with low fall risk on data from gait biomechanical analyses;

Reports comparing gait biomechanical analyses without occurrence of falls to gait biomechanical analyses with occurrence of falls, in elderly. In the scope of this study, data from biomechanical gait analyses included spatiotemporal, kinematic, kinetic, electromyographic, and plantar pressure data.

Comparator(s) or control(s)

Elderly fallers e non-fallers

Context

The present study included observational studies, according to the following inclusion criteria: (1) reports comparing elderly fallers to non-fallers on data from gait biomechanical analyses; (2) reports comparing elderly with high fall risk to elderly with low fall risk on data from gait biomechanical analyses; (3) reports comparing gait biomechanical analyses without occurrence of falls to gait biomechanical analyses with occurrence of falls, in elderly. In the scope of this study, data from biomechanical gait analyses included spatiotemporal, kinematic, kinetic, electromyographic, and plantar pressure data. It was also considered the WHO definition for elderly, i.e., subjects aged 60 or over (WHO, 2017). The following exclusion criteria were also defined: (1) reports assessing subjects under 60 years (or the mean age of the subjects less one standard deviation was lower than 60 years); (2) reports assessing subjects: that use any walking aid, with neurological or osteoarticular disease (e.g., stroke, Parkinson's disease, polyneuropathy, osteoarthritis, or rheumatoid arthritis), with dementia, or amputees. No restrictions were imposed regarding language or publication date.

OUTCOMES TO BE ANALYSED

Main outcomes

Gait spatio-temporal parameters and its variability

Additional outcomes

Gait kinematic and kinetic parameters

DATA COLLECTION PROCESS

Data extraction (selection and coding)

Data will be extracted by one reviewer (JS) using a pre-defined form: (1) authors and year of publication; (2) study design, inclusion and exclusion criteria, definition of fall or high risk for falling; (3) sample characteristics (sample size and sociodemographic data – age, gender, type of population); (4) gait assessment – including gait biomechanical parameters assessed; (5) results (gait biomechanical parameters related or not related to falls – a statistically significant difference were identified when a p<0.05 was achieved). All information was cross-checked by a second reviewer (PA). After this process, a single reviewer independently synthesized data: on the one hand, the selected reports were grouped according to the three inclusion criteria defined earlier; on the other hand, data of each gait biomechanical parameter collected in the different reports were also grouped and synthesized.

Risk of bias (quality) assessment

To assess the methodological quality of the studies, the Quality Assessment Tool for Quantitative Studies was used, which was developed by Effective Public Health Practice Project (Effective Public Health Practice Project, 2003). This assessment focused on 6 domains: (1) selection bias; (2) study design; (3) confounders; (4) blinding (5) data collection method; and (6) withdrawals e dropouts. Each domain was evaluated with the following classification: "1" corresponds to a strong report in that domain; "2" corresponds to a reasonable report in that domain; "3" corresponds to a weak report in that domain. The reports that met the inclusion criteria were assessed independently for their methodological quality by the 2 researchers. Any disagreements were resolved with a consensus discussion between them. If disagreements remained after discussions between both reviewers, a third reviewer was consulted.

PLANNED DATA SYNTHESIS

Strategy for data synthesis

Data was extracted by one reviewer (JS) using a pre-defined form: (1) authors and year of publication; (2) study design, inclusion and exclusion criteria, definition of fall or high risk for falling; (3) sample characteristics (sample size and sociodemographic data – age, gender, type of population); (4) gait assessment – including gait biomechanical parameters assessed; (5)

results (gait biomechanical parameters related or not related to falls – a statistically significant difference were identified when a p<0.05 was achieved).

Analysis of subgroups or subsets

Kinetcs and kinematics

REVIEW AFFILIATION, FUNDING AND PEER REVIEW

Review team members

- Mrs Jullyanne Silva, Faculdade de Educacao Fisica e Desporto
- Professor Pedro Aleixo, MovLaB\/CIDEFES\/Universidade Lusófona - Lisboa
- Professor Tiago Atalaia, MovLaB\/CICANT\/Universidade Lusófona; Escola Superior de Saúde da Cruz Vermelha Portuguesa - Lisboa
- Professor João Abrantes, MovLab\/CICANT\/Universidade Lusófona - Lisboa

Review affiliation

CIDEFES/Universidade Lusófona/Faculdade de Educacao Fisica e Desporto

Funding source

CIDEFES - The CIDEFES is a newly created research center from the Faculdade de Educação Física e Desporto, of the Lusophone University.

Behavior is our common language; hence CIDEFES members contribute to studying behavior from different perspectives \u2013 Sport, Physical Education, or Exercise and Health \u2013 creating an innovative and integrative research effort.<\/div>

Named contact

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TIMELINE OF THE REVIEW

Review timeline

Start date: 06 July 2021. End date: 10 October 2021

Date of first submission to PROSPERO

24 August 2021

Date of registration in PROSPERO

29 September 2021

CURRENT REVIEW STAGE

Publication of review results

The intention is to publish the review once completed.The review will be published in English

Stage of the review at this submission

Review stage	Started	Completed
Pilot work	✓	
Formal searching/study identification	✓	✓
Screening search results against inclusion criteria		
Data extraction or receipt of IP		
Risk of bias/quality assessment		
Data synthesis		

Review status
The review is currently planned or ongoing.

ADDITIONAL INFORMATION

PROSPERO version history

- Version 1.1 published on 29 Sep 2021
- Version 1.0 published on 29 Sep 2021

Review conflict of interest
None known

Country
Portugal

Medical Subject Headings
Accidental Falls; Biomechanical Phenomena; Humans

Details of any existing review of the same topic by the same authors
Aleixo, P., Atalaia, T. & Abrantes, J. (2021). Dynamic joint stiffness: a critical review.
Aleixo, P., Tavares, C., Vaz Patto, J. & Abrantes, J. (2017). Segurança eficácia dos exercícios propriocetivos em doentes com artrite reumatóide (revisão sistemática).
Baptista, I.; Abrantes, J.; Atalaia, T. Vertical Jump Test Assessment in Non-Athlete Adults: Systematic Review.

Disclaimer

Any enquiries about the record should be referred to the named review contact

ANEXO 9 – PARECER DE APROVAÇÃO DO REGISTRO DO ESTUDO (EUdraCT)

Validate Application Results

EudraCT Number:	2021-004912-25
Sponsor's Protocol Code Number:	CT101COFAC
National Competent Authority:	Portugal - INFARMED
Validation Date and Time:	2021-12-02 13:17:48 CET

The Clinical Trial (EEA CTA) has passed all validation rules.

XML File Identifier: noxNZcsETx4DXxGLFhxstG/WGvY=

1

ANEXO 10 – PARECER DE APROVAÇÃO DA UTILIZAÇÃO DA FES-I

Email – jullyanne silva – Outlook - Google Chrome

outlook.live.com/mail/deeplink?popoutv2=1&version=20210517003.09

Responder | Excluir | Lixo Eletrônico | Bloquear

Re: Pedido de autorização para utilização da escala

DF

Daniela Figueiredo <daniela.figueiredo@ua.pt>
Sáb, 22/05/2021 07:42
Para: Você

FES-I_vPortuguesa.pdf
172 KB

Bom dia, Jullyanne.

Agradeço o contacto.
Envio a versão Portuguesa da FES-I em anexo, autorizando a sua utilização.

Votos de muitos sucessos para o seu trabalho de investigação.

Com os melhores cumprimentos,
Daniela Figueiredo

ANEXO 11 – ESCALA DE EFICÁCIA NAS QUEDAS – INTERNACIONAL (FES-I)

Escala de Eficácia nas Quedas – Internacional
(Versão Portuguesa)

Este instrumento deverá ser citado do seguinte modo: Figueiredo, D. & Santos, S. (2017). Cross-cultural validation of the Falls Efficacy Scale-International (FES-I) in Portuguese community-dwelling older adults. *Archives of Gerontology and Geriatrics*, 68: 168-173.

Gostaríamos de lhe fazer algumas questões acerca da sua preocupação com a possibilidade de cair. Por favor, responda pensando como desempenha normalmente as atividades abaixo listadas. Se atualmente não realiza alguma atividade (e.g., se alguém faz as compras por si), responda considerando o seu grau de preocupação em cair caso tivesse de a desempenhar. Para cada uma das seguintes atividades, marque com uma cruz a resposta que mais se aproxima da sua opinião.

	Nada preocupado(a) 1	Um pouco preocupado(a) 2	Moderadamente preocupado(a) 3	Muito preocupado(a) 4
1.Limpar a casa (e.g., varrer, aspirar ou limpar o pó)	1 ☐	2 ☐	3 ☐	4 ☐
2. Vestir-se ou despir-se	1 ☐	2 ☐	3 ☐	4 ☐
3. Preparar refeições simples	1 ☐	2 ☐	3 ☐	4 ☐
4. Tomar um banho ou um duche	1 ☐	2 ☐	3 ☐	4 ☐
5. Ir às compras	1 ☐	2 ☐	3 ☐	4 ☐
6. Sentar ou levantar de uma cadeira	1 ☐	2 ☐	3 ☐	4 ☐
7. Subir ou descer escadas	1 ☐	2 ☐	3 ☐	4 ☐
8. Caminhar pelo bairro	1 ☐	2 ☐	3 ☐	4 ☐
9. Alcançar algo acima da cabeça ou no chão	1 ☐	2 ☐	3 ☐	4 ☐
10. Ir atender o telefone antes de deixar de tocar	1 ☐	2 ☐	3 ☐	4 ☐
11. Andar sobre uma superfície escorregadia (e.g., molhada ou com gelo)	1 ☐	2 ☐	3 ☐	4 ☐
12. Visitar um amigo ou um familiar	1 ☐	2 ☐	3 ☐	4 ☐
13. Andar num local com muita gente	1 ☐	2 ☐	3 ☐	4 ☐
14. Andar sobre uma superfície irregular (e.g., solo rochoso; pavimento em mau estado)	1 ☐	2 ☐	3 ☐	4 ☐
15. Subir ou descer uma ladeira	1 ☐	2 ☐	3 ☐	4 ☐
16. Sair para um evento social (e.g., ato religioso, encontro de família, ou encontro no clube)	1 ☐	2 ☐	3 ☐	4 ☐

ANEXO 12 – QUESTIONÁRIO MINI MENTAL (MMSE)

Mini Mental State Examination (MMSE)

1. Orientação (1 ponto por cada resposta correcta)

Em que ano estamos? _____
Em que mês estamos? _____
Em que dia do mês estamos? _____
Em que dia da semana estamos? _____
Em que estação do ano estamos? _____

Nota:____

Em que país estamos? _____
Em que distrito vive? _____
Em que terra vive? _____
Em que casa estamos? _____
Em que andar estamos? _____

Nota:____

2. Retenção (contar 1 ponto por cada palavra correctamente repetida)

"Vou dizer três palavras; queria que as repetisse, mas só depois de eu as dizer todas; procure ficar a sabê-las de cor".
Pêra _____
Gato _____
Bola _____

Nota:____

3. Atenção e Cálculo (1 ponto por cada resposta correcta. Se der uma errada mas depois continuar a subtrair bem, consideram-se as seguintes como correctas. Parar ao fim de 5 respostas)

"Agora peço-lhe que me diga quantos são 30 menos 3 e depois ao número encontrado volta a tirar 3 e repete assim até eu lhe dizer para parar".
27_ 24_ 21 _ 18_ 15_

Nota:____

4. Evocação (1 ponto por cada resposta correcta.)

"Veja se consegue dizer as três palavras que pedi há pouco para decorar".
Pêra ______
Gato ______
Bola ______

Nota:____

5. Linguagem (1 ponto por cada resposta correcta)

a. "Como se chama isto? Mostrar os objectos:
Relógio ____
Lápis______

Nota:____

b. "Repita a frase que eu vou dizer: O RATO ROEU A ROLHA"

Nota:____

c. "Quando eu lhe der esta folha de papel, pegue nela com a mão direita, dobre-a ao meio e ponha sobre a mesa"; dar a folha segurando com as duas mãos.

Pega com a mão direita____

Dobra ao meio ____

Coloca onde deve____

Nota:____

d. "Leia o que está neste cartão e faça o que lá diz". Mostrar um cartão com a frase bem legível, "FECHE OS OLHOS"; sendo analfabeto lê-se a frase.

Fechou os olhos____

Nota:____

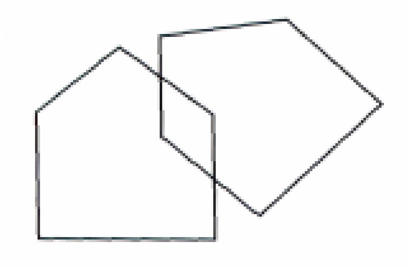
e. "Escreva uma frase inteira aqui". Deve ter sujeito e verbo e fazer sentido; os erros gramaticais não prejudicam a pontuação.

Frase:

Nota:____

6. Habilidade Construtiva (1 ponto pela cópia correcta.)

Deve copiar um desenho. Dois pentágonos parcialmente sobrepostos; cada um deve ficar com 5 lados, dois dos quais intersectados. Não valorizar tremor ou rotação.



Cópia:

Nota:____

TOTAL(Máximo 30 pontos):____

<u>**Considera-se com defeito cognitivo**</u>:	• analfabetos ≤ 15 pontos • 1 a 11 anos de escolaridade ≤ 22 • com escolaridade superior a 11 anos ≤ 27

"A ciência nunca resolve um problema sem criar outros dez"

George Bernard Shaw