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Estratégias de movimento durante a marcha com obstáculos e treinamento de equilíbrio HiBalance em pessoas com doença de Parkinson

Porto Alegre

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Estratégias de movimento durante a marcha com obstáculos e treinamento de equilíbrio HiBalance em pessoas com doença de Parkinson

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Dedicatória

A todos aqueles que colocaram a mão em mim e me impulsionaram neste novo desafio da minha vida, dando-me uma parte de si para tornar esta conquista possível…. à minha família pelo amor, tempo, paciência e empatia... aos meus amigos pela energia... aos meus colegas pelo apoio... aos meus professores pela dedicação... a todos, dedico este pequeno momento chamado... felicidade.

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Epígrafe

Temos um cérebro por uma razão e apenas uma razão: para produzir movimentos adaptativos e complexos. O movimento é a única maneira de afetarmos o mundo ao nosso redor.

Daniel Wolpert (médico, neurocientista e engenheiro britânico)

RESUMO

O objetivo desta tese foi: Objetivo 1, um primeiro estudo comparou os parâmetros espaço-temporais da marcha entre indivíduos com e sem DP ao atravessar obstáculos. Objetivo 2, um segundo estudo descreveu detalhadamente uma intervenção *HiBalance* de três meses sobre parâmetros espaço-temporais da marcha com obstáculos e fatores de risco para quedas em pessoas com DP para um futuro ensaio clínico randomizado. Método 1: Foi realizada uma revisão sistemática com meta-análise. Foram pesquisadas seis bases de dados até setembro de 2023. Foram selecionados estudos que avaliaram parâmetros de marcha de pessoas com e sem DP ao caminhar sobre obstáculos. Dois investigadores independentes avaliaram a elegibilidade e extraíram parâmetros de marcha ao cruzar obstáculos. O risco de viés e a heterogeneidade foram avaliados e um modelo de efeitos aleatórios foi aplicado para determinar os tamanhos dos efeitos. Método 2: Foi desenvolvido um protocolo para um ensaio clínico randomizado. Quarenta pessoas com diagnóstico de DP idiopática serão distribuídas aleatoriamente em dois grupos: *HiBalance* (n=20) ou treinamento de marcha (n=20). As intervenções serão realizadas duas vezes por semana durante três meses, com sessões de 50 minutos. As avaliações serão realizadas antes, depois e no acompanhamento de seis meses. Os resultados primários incluirão parâmetros espaço-temporais de marcha ao cruzar o obstáculo. Os resultados secundários incluirão variáveis relacionadas ao risco de queda (ou seja, equilíbrio postural, força muscular, potência muscular e medo de cair). Resultados 1: Vinte e cinco estudos foram incluídos na revisão e 17 na metanálise. A metanálise mostrou que pessoas com DP apresentam passo após cruzar o obstáculo mais curto que pessoas sem a doença, ampliam sua base de apoio e reduzem a velocidade de marcha ao cruzar o obstáculo. Resultados 2: Nossa hipótese é que o treinamento de três meses com este protocolo *HiBalance* será mais eficaz do que o treinamento de marcha na melhoria das estratégias de movimento durante a travessia de obstáculos (ou seja, aumentando a velocidade de travessia de obstáculos e o comprimento do passo) e reduzirá a largura do passo e a variabilidade de altura). Além disso, o protocolo *HiBalance* será mais eficaz do que o treino de marcha na melhoria do equilíbrio, força e potência dos músculos dos membros inferiores e na redução do medo de cair. Conclusões: Pessoas com DP adotam comportamento motor mais conservador durante a travessia de obstáculos do que aquelas sem DP.

Contudo, esta estratégia implicaria uma maior exigência de controle postural, apresentando uma situação de maior risco de tropeçar e cair. A proposta de ensaio clínico com *HiBalance* responde à necessidade de implementar intervenções específicas de equilíbrio e marcha para problemas específicos que requerem a solução da tarefa motora de ultrapassar obstáculos em pessoas com DP.

Palavras-chave: Doença de Parkinson; Análise da Marcha; marcha sobre obstáculos; Quedas; Transtornos Motores; Equilíbrio Postural.

ABSTRACT

The objective of this thesis was: Objective 1, a first study compared the spatiotemporal gait parameters between individuals with and without PD when crossing obstacles. Objective 2, a second study described in detail a three-month HiBalance intervention on spatiotemporal gait parameters with obstacles and factors the risk of falls in people with PD for a future randomized clinical trial. Method 1: A systematic review with meta-analysis was carried out. Six databases were searched until September 2023. Studies were selected that evaluated the gait parameters of people with and without PD while walking over obstacles. Two independent investigators assessed eligibility and extracted gait parameters when crossing obstacles. The risk of bias and heterogeneity were evaluated, and a random effects model was applied to determine effect sizes. Method 2: A protocol for a randomized clinical trial was developed. Forty people diagnosed with idiopathic PD will be randomly assigned to two groups: HiBalance (n=20) or gait training (n=20). The interventions will be carried out twice weekly for three months, with 50-minute sessions. Evaluations will be carried out before, after, and at a six-month follow-up. Primary outcomes will include spatiotemporal parameters during obstacle crossing. Secondary outcomes will include variables related to fall risk (i.e., postural balance, muscle strength, muscle power, and fear of falling). Results 1: Twenty-five studies were included in the review and 17 in the meta-analysis. The meta-analysis showed that people with PD have a shorter landing step after crossing an obstacle, broaden their support base, and reduce walking speed when crossing the obstacle compared to people without PD. Results 2: We hypothesize that three-month training with this HiBalance protocol will be more effective than gait training in improving movement strategies during obstacle crossing (i.e., increasing obstacle crossing speed and step length and reducing the variability of step width and height). Additionally, the HiBalance protocol will be more effective than gait training in improving balance, strength, and power of lower limb muscles, and in reducing fear of falling. Conclusions: People with PD adopt more conservative motor behavior during obstacle crossing than those without PD. However, this strategy would imply a greater requirement for postural control, presenting a situation of greater risk of tripping and falling. The clinical trial proposal with HiBalance responds to the need to implement specific balance and gait interventions for specific problems that require the solution of the motor task of crossing obstacles in people with PD.

Key words: Parkinson's Disease; Gait Analysis; Obstacle Crossing; Falls; Motor Disorders; Control Postural.

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ESTUDO 1

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LISTA DE ABREVIATURAS E SIGLAS

CS	Crossing speed
CSW	Crossing step width
ES	Effect size
FOG	Freezing of gait
GT	Gait training
HB	Highly challenging balance training
H&Y	Hoehn and Yahr stage
LFAO	Leading foot placement after the obstacle
LTC	Leading toe clearance
MoCA	Montreal cognitive assessment
MP	Muscle power
MS	Maximum strength
OC	Obstacle crossing
PD	Parkinson´s disease
RFD	Rate of force development
SMD	Standardized mean difference
TTC	Trailing toe clearance
TFBO	Trailing foot placement before the obstacle
UPDRS	Unified Parkinson's Disease Rating Scale

SUMÁRIO

1 CONTEXTUALIZAÇÃO

A doença de Parkinson (DP) é uma doença neurodegenerativa progressiva do movimento cuja prevalência aumenta em pessoas idosas (ARMSTRONG e OKUN, 2020). É uma das doenças que tem apresentado um aumento significativo nas pessoas com mais de 60 anos com uma incidência global próxima dos 2% e com pico entre os 85 e os 89 anos, apresentando um aumento de 5 a 10 vezes a partir da sexta até a nona década de vida (LEITE SILVA et al., 2023). Com o número de diagnósticos que duplicaria em mais 20 anos, apresenta um rápido aumento em relação a outras condições neurológicas (GBD 2016 PARKINSON'S DISEASE COLLABORATORS 2018). A sua prevalência mundial é de aproximadamente 200/100.000 indivíduos, aumentando mais de 35/100.000 novos casos a cada ano, mostrando uma prevalência global de mais de 6 milhões de pessoas (SIMON et al., 2020). Os homens apresentam maior proporção da doença com uma proporção de 1.4:1.0 em comparação às mulheres. Tudo isso faz da DP o segundo distúrbio neurodegenerativo mais comum e uma das principais doenças que causam incapacidade na população idosa (ERKKINEN et al., 2018).

A fisiopatologia da DP é caracterizada por inclusões semelhantes a corpos de Lewy e neurites de Lewy com uma degeneração de células produtoras de dopamina na substância negra e outras regiões do cérebro (GBD 2016 PARKINSON'S DISEASE COLLABORATORS 2018). Essa depleção de dopamina gera disfunção do sistema dos gânglios da base, que provoca as principais manifestações da doença. A maioria de suas etiologias são idiopáticas, cujas causas descritas seriam principalmente a combinação de fatores genéticos e ambientais (ARMSTRONG e OKUN, 2020). É caracterizada por uma série de disfunções motoras e não motoras. Os sintomas motores aparecem precocemente na doença e são caracterizados pela presença de tremor, rigidez, bradicinesia, instabilidade postural e comprometimento da marcha. Os sintomas não motores mais frequentes são comprometimento cognitivo, sintomas disautonômicos, distúrbios do sono, anomalias sensoriais, entre outros (HALLI-TIERNEY et al., 2020). O conjunto de sintomas (motores e não motores) que a doença apresenta provoca incapacidade progressiva com a progressão da doença, provocando uma redução das atividades funcionais, afetando fortemente a qualidade de vida e os custos de saúde das pessoas com DP e dos seus familiares (LEITE SILVA et al., 2023).

Os sintomas motores presentes na doença perturbam a capacidade da marcha e o controle postural, aumentando a carga disfuncional da doença (ZESIEWICZ, 2019). As características do comprometimento da marcha em pessoas com DP mostram alterações espaço-temporais, como diminuição da velocidade e comprimento do passo e da passada, aumento da assimetria e variabilidade dos passos e alterações nos padrões rítmicos da marcha (MIRELMAN et al., 2019). Por outro lado, a presença de instabilidade postural afeta o controle dinâmico durante a caminhada, diminuindo respostas posturais antecipatórias e compensatórias ou ajustes antes de perturbações (STEGEMÖLLER et al., 2012). Além disso, é relatado que características como maior rigidez axial (MAK et al., 2007), menor amplitude de movimento articular e presença de menor força e potência muscular dos membros inferiores em pessoas com DP (ROGERS, 1996), contribuem para uma menor capacidade de propulsão da marcha, alterando negativamente os parâmetros espaço-temporais da marcha. O distúrbio da marcha piora à medida que a doença progride, reduzindo a independência da pessoa com DP (HESS e HALLETT, 2017).

Os parâmetros de marcha alterados associados a pessoas com DP têm sido descritos como alterações contínuas no controle da marcha, classificadas em três problemas principais: marcha lenta, maior variabilidade e assimetria e mau controle postural (PETERSON e HORAK, 2016). A marcha lenta tem sido associada a fatores como hipocinesia (contribui para menor comprimento da passada), bradicinesia (contribui para maior duração da passada) e rigidez muscular (contribui para diminuição da velocidade da marcha e dificuldade de andar). A variabilidade, que é elevada tanto no sentido ântero-posterior quanto lateral em pessoas com DP, bem como uma maior assimetria observada nesta população, contribuiriam para as flutuações espaço-temporais dos passos (COLLINS e KUO, 2013). Por seu lado, a alteração do controle postural em pessoas com DP apresenta um limite de estabilidade e um controle do equilíbrio lateral mais afetado, observado desde os estágios iniciais da doença. (PETERSON e HORAK, 2016). Estas alterações no controle contínuo da marcha afetariam a capacidade de adaptação eficiente e rápida a tarefas e contextos mais desafiadores quando as pessoas com DP caminham, e poderiam estar relacionadas a um maior risco de queda.

Distúrbios da marcha e pior controle motor têm sido associados a um risco aumentado de queda (ALLEN et al., 2022). Pessoas com DP têm duas vezes mais probabilidade de cair do que pessoas sem a doença, e o maior risco está entre pessoas com deficiências neurológicas (PELICIONI et al., 2019). Quase dois terços das pessoas com DP sofrem uma queda a cada ano, a metade sofrerá uma queda dentro de 6 meses e, destas, uma proporção próxima de 50% sofrerá quedas recorrentes (COLE et al., 2011). Cerca de metade das quedas ocorrem durante tarefas dinâmicas, como caminhar. Os preditores relatados de queda incluem história de queda anterior, comprometimento do controle motor da marcha, presença de congelamento da marcha (FOG) e presença de comprometimento cognitivo e de orientação (CANNING et al., 2014). Entre os fatores de risco intrínsecos para quedas em pessoas com DP, têm sido mencionados principalmente a instabilidade postural, os distúrbios da marcha e o comprometimento cognitivo (PELICIONI et al., 2021). Fatores ambientais (extrínsecos), descritos como cenários complexos, consideram caminhar em ambientes menos estáveis, superfícies irregulares ou com níveis diferentes, estabelecendo um grande desafio para pessoas com capacidade reduzida de adaptação da marcha, o que aumenta o risco de queda e é relatado como um dos fatores que mais contribuem para o medo de cair (NILSSON et al., 2012).

O contexto de caminhar evitando obstáculos em situações da vida diária, principalmente a tarefa de ultrapassar um obstáculo, exige maior capacidade de controle da tarefa e mostra-se uma das principais causas de tropeços e quedas em pessoas com DP (PELICIONI et al., 2021). As consequências das quedas para as pessoas com DP têm sido relacionadas com as restrições na vida quotidiana, o medo de cair, os elevados níveis de estresse, o aumento do risco de fraturas e as consequências financeiras que tudo isto acarreta (WALKER et al., 2013). Foi demonstrado que pessoas com DP apresentam risco de queda apesar de estarem adequadamente medicadas (ALLEN et al., 2022), portanto, as quedas continuam a ser um problema de saúde prioritário nesta população.

Caminhar sobre obstáculos tem se mostrado uma tarefa motora de interesse quando realizada por idosos e pessoas com deficiência motora, como pessoas com DP (ALCOCK et al., 2018). A marcha com obstáculos envolve uma adaptação adequada para conseguir uma travessia bem-sucedida, superando o obstáculo. Foi

descrito que os idosos que relataram queda no último ano têm mais dificuldades em superar o obstáculo e que essas dificuldades são amplificadas nas pessoas com DP (UEMURA et al., 2011). Alguns estudos relatam que durante a marcha com obstáculos é necessário ajustar os parâmetros espaço-temporais da marcha para gerar uma estratégia segura durante a travessia (ALCOCK et al., 2018). Esses parâmetros incluem o aumento do comprimento da passada, a distância que o pé se encontra antes do obstáculo, a velocidade da caminhada, a altura do pé em relação ao obstáculo, entre outras (STEGEMÖLLER et al., 2012). Além disso, atravessar o obstáculo envolveria quatro tarefas fundamentais para superar o obstáculo: manter o equilíbrio durante a travessia, evitar tropeçar no obstáculo, evitar escorregar durante a aterrissagem e mover o corpo para frente (MOLLAEI et al., 2017).

Caminhar sobre obstáculos requer maior função cognitiva e controle do equilíbrio, cujas capacidades estão diminuídas em idosos e pessoas com DP. A superação do obstáculo tem sido relacionada à capacidade de negociação que envolve planejamento motor e capacidade visuomotora, e como tarefa dupla por envolver a capacidade de atenção e memória de trabalho (tarefa motora e cognitiva). A exigência desses recursos cognitivos afetaria significativamente o desempenho da caminhada e seria causa de maior risco de quedas em pessoas com DP (RAFFEGEAU et al., 2019). Como as pessoas com DP apresentam prejuízo na automaticidade dos movimentos em decorrência da disfunção dos gânglios da base, elas necessitam de maior controle da atenção para conseguirem realizar tarefas motoras que geralmente são executadas de forma automática em pessoas saudáveis (WU et al., 2015). No treinamento de marcha em dupla tarefa, foi observada uma melhora na automaticidade, bem como uma diminuição na variabilidade da marcha (XIAO et al., 2023). Por esta razão, o uso de tarefas duplas tem sido frequentemente incorporado no treino de marcha e equilíbrio em pessoas com DP, com o objetivo de reduzir a deterioração do equilíbrio e, portanto, a vulnerabilidade a quedas.

Em pessoas com DP têm sido relatadas estratégias durante a travessia através de parâmetros espaço-temporais da marcha como aumentar a altura do pé, reduzir a velocidade de travessia, aumentar a largura do passo, entre outras modificações interpretadas como uma forma mais conservadora ou compensatória de realizar a tarefa. Contudo, há pouca informação sobre se estas adaptações são diferentes

daquelas utilizadas em idosos e se esta estratégia conservadora exporia a pessoa com DP a um maior ou menor risco de tropeçar. Nesse sentido, tem sido discutido que os sintomas motores característicos da doença implicariam em uma hipometria da trajetória horizontal e vertical do pé durante o cruzamento e em uma menor velocidade da marcha, exigindo maior estabilidade dinâmica durante a fase unipodal do cruzamento (MOLLAEI et al., 2017). Como os sintomas motores da DP apresentam variações e limitações nessas adaptações causando maior deterioração na marcha, faz-se necessário discutir os mecanismos da estratégia para evitar o risco de tropeçar ao cruzar um obstáculo como cenário ao qual estão expostos diariamente.

A estabilidade dinâmica tem sido descrita como fator essencial durante a marcha e sua deficiência tem sido relatada como fator de risco para quedas em idosos e principalmente em pessoas com DP (ALLEN et al., 2022). Os componentes envolvidos no controle do equilíbrio têm sido bem discutidos na literatura. A capacidade de manter a verticalidade através do equilíbrio postural e, assim, controlar o equilíbrio durante o movimento dependeria de uma integração complexa de estímulos visuais, vestibulares e somatossensoriais (SCHONEBURG et al., 2013), que ponderam a informação sensorial de acordo com o objetivo da tarefa motora e as condições ambientais em que é realizada. Nesse sentido, Horak et al. (2016) afirmam que as alterações do equilíbrio e da marcha em pessoas com DP são extensas e complexas (HORAK et al., 2016). Por isso propõem um modelo sistêmico de controle motor composto por seis sistemas que interagem dinamicamente para um controle adequado do equilíbrio. Esses sistemas são: limitações biomecânicas, limites de estabilidade, ajustes posturais antecipados, respostas posturais, orientação sensorial e estabilidade da marcha. Em pessoas com DP, limitações biomecânicas, como fraqueza muscular do tornozelo ou quadril e alteração postural na flexão, limitariam a recuperação postural ou do equilíbrio. Por sua vez, ajustes posturais antecipatórios limitados causariam instabilidade durante a marcha e as respostas posturais são alteradas devido às limitações do feedback proprioceptivo apresentadas pela doença, causando respostas retardadas aos distúrbios. Limitações na integração sensorial causam instabilidade e desorientação durante a caminhada (HORAK e MACPHERSON, 2011). O equilíbrio dinâmico durante a marcha apresenta má

coordenação com alterações no apoio dos pés e no controle axial para regular o centro de massa em constante mudança durante a tarefa motora (SCHONEBURG et al., 2013). Portanto, a capacidade de adaptar rapidamente uma resposta postural durante a marcha parece ser um fator crítico no enfrentamento da marcha com obstáculos em pessoas com DP e um desafio para planos de treinamento que buscam mitigar o risco de queda.

Além de uma capacidade de equilíbrio postural alterada em pessoas com DP, tem sido relatado que a perda de força muscular nos membros inferiores é diminuída quando comparada a pessoas saudáveis, o que favoreceria o risco de queda ao caminhar (KRISTENSEN et al., 2023). A presença de uma diminuição na velocidade de geração de força muscular, expressa como potência muscular ou taxa de desenvolvimento de força (TDF), afetaria sua capacidade de resposta neuromuscular a distúrbios no corpo (PIJNAPPELS et al., 2005). Em pessoas com DP, tanto a potência muscular como a TDF mostraram uma deterioração mais significativa do que em pessoas saudáveis, e uma perda mais precoce da força muscular máxima (LOMBORG et al., 2022). Os requisitos de propulsão e controle de suporte durante a marcha exigem uma resposta muscular adequada para alcançar uma adaptação bem-sucedida da marcha em ambientes desafiadores. Embora o treinamento resistido para tratamento de sintomas motores tenha apresentado melhorias na marcha, pouco se estudou sobre o papel da potência muscular na adaptação da marcha em pessoas com DP e no risco de queda (LOMBORG et al., 2022).

Intervenções fisioterapêuticas que focam no treino de marcha, equilíbrio, força muscular, capacidade aeróbica, entre outros, têm se mostrado benéficas para o controle de diferentes alterações de sintomas motores, mitigando o agravamento da doença (RADDER et al., 2020). Os exercícios fisioterapêuticos em pessoas com DP são capazes de induzir melhorias quando comparados a nenhuma intervenção com aumentos na velocidade de caminhada de 0,04 m/s; IC95% 0,02 a 0,06, nos testes de caminhada de dois e seis minutos com aumento da distância percorrida em 13,37 m; IC95% 0,55 a 26,20, questionário de congelamento da marcha com melhora na pontuação de -1,41 pontos; IC95% −2,63 a −0,19, teste timed up and go com melhora significativa de −0,63 s; IC95% −1,05 a −0,21, teste de alcance funcional com melhora de 2,16 cm; IC95% 0,89 a 3,43, escala de equilíbrio de Berg com melhora de 3,71

pontos, IC95% 2,30 a 5,11 e melhores escores UPDRS de −5,01 pontos 95% IC −6,30 a −3,72, entre outros resultados (TOMLINSON et al., 2012; MAK e WONG-YU, 2019). Da mesma forma, foi demonstrado que o exercício físico reduz as taxas de queda em pessoas com DP leve ou moderada em 26%, reduzindo ligeiramente em 10% aquelas que sofrem uma ou mais quedas (ALLEN et al., 2022). O treinamento físico tem demonstrado ser benéfico na redução das alterações da marcha e do equilíbrio, e como a DP é de natureza progressiva e crônica, os programas de exercícios devem ser aplicados precocemente para aliviar os sintomas, prevenir quedas e progressão da doença (MAK e WONG-YU, 2019). No entanto, as terapêuticas de substituição da levodopa recebidas pelas pessoas com DP não conseguem normalizar estas alterações, mantendo o risco de queda apesar de estarem adequadamente medicadas (BLOEM et al., 1996).

Os estudos mostram que, para que os programas de exercícios sejam eficazes, eles devem ser específicos, progressivos e dificultar que as pessoas com DP se esforcem até o limite de sua capacidade (TOMLINSON et al., 2012). Apesar dos benefícios demonstrados pelo exercício físico na intervenção fisioterapêutica, os efeitos têm se mostrado de curto prazo (aproximadamente entre 3 e 6 meses), por isso ainda se discute se as características dos programas de exercícios seriam adequadas para estimular as habilidades de controle do equilíbrio e o desempenho da marcha e manter esses benefícios interrompendo ou descontinuando os exercícios (SPARROW et al., 2016; MAK e WONG-YU, 2019).

A revisão de Tomlinson et al (2012) relatou que programas de exercícios que utilizaram doses mais intensas e maiores desafios durante o treinamento de equilíbrio postural apresentaram melhores resultados no equilíbrio e na marcha, e melhores opções para mitigar o risco de queda em pessoas com DP (TOMLINSON et al., 2012). Nesse sentido, foi proposto um treinamento de equilíbrio altamente desafiador, denominado *HiBalance* (HB), voltado ao treinamento específico do equilíbrio postural e desempenho da marcha, que é criado a partir de um referencial teórico em relação aos principais subsistemas do controle postural expostos por Horak (HORAK et al., 2009). O HiBalance utiliza quatro dos seis componentes de controle do equilíbrio propostos no modelo sistêmico de controle motor e que seriam os mais afetados em pessoas com DP, tais como: integração sensorial, ajustes posturais antecipatórios, agilidade motora e limites de estabilidade (CONRADSSON et al., 2012). O HiBalance é baseado em exercícios que são planejados progressivamente para atingir os quatro

componentes principais do controle do equilíbrio postural mencionados. Adicionalmente, utiliza os princípios da aprendizagem motora, enfatizando a especificidade, a sobrecarga progressiva e a variação do exercício, incorporando cenários desafiadores através da multitarefa (LEAVY et al., 2017). A concepção dos seus exercícios procura alterar a base de apoio, aumentar a velocidade e amplitude dos movimentos, aplicar diferentes complexidades de multitarefa (cognitiva e motora) e restringir a visão para aumentar a dificuldade (CONRADSSON et al., 2012). Em pessoas com DP, o treino de HiBalance durante 10 a 12 semanas demonstrou ser mais eficaz em comparação com controles com atividade física regular ou programas regulares de exercícios em casa, na melhoria do controle do equilíbrio, da velocidade de caminhada, do comprimento do passo e das atividades de movimento (CONRADSSON et al., 2015; LEAVY et al., 2020). Além disso, o treino HiBalance pode reduzir o medo de cair (SPARROW et al., 2016).

De acordo com a contextualização apresentada, é possível descrever algumas lacunas de conhecimento sobre o tema:

- Embora a posição do pé e sua relação com o obstáculo tenham sido estudadas em idosos e em pessoas com DP, não encontramos comparações sistemáticas dos ajustes espaço-temporais da marcha de pessoas com e sem DP ao caminhar sobre obstáculos.
- Embora o equilíbrio postural e o treinamento de marcha sejam recomendados para pessoas com DP, os parâmetros espaço-temporais durante a negociação de obstáculos e sua possibilidade de adaptação têm sido pouco estudados.
- O treinamento que impõe dificuldades e desafios às pessoas com DP tem demonstrado promover o equilíbrio postural e a marcha regular, porém, pouco se investigou sobre os efeitos que poderia ter na função muscular como fator importante na adaptação da marcha e fator protetor do risco de cair.

Sendo assim, o objetivo desta tese foi explorar, em uma revisão sistemática com metanálise, as possíveis diferenças nos parâmetros espaço-temporais da marcha com obstáculos de pessoas com e sem DP e propor, em um protocolo para futuro

ensaio clínico randomizado, um treinamento utilizando o *HiBalance* para melhorar os parâmetros da marcha com obstáculos e variáveis relacionadas ao risco de quedas.

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2 OBJETIVOS

Objetivo geral:

Analisar a estratégia de adaptação à marcha sobre obstáculos e sua relação com fatores de risco para quedas e propor um ensaio clínico randomizado de treinamento padronizado de equilíbrio de alto desafio para pessoas com doença de Parkinson.

Objetivo de estudo 1: Comparar os parâmetros espaço-temporais da marcha de pessoas com e sem doença de Parkinson (DP) ao caminhar sobre obstáculos.

Objetivo de estudo 2: Descrever em detalhes uma intervenção *HiBalance* de três meses sobre os parâmetros espaço-temporais de marcha com obstáculos e fatores de risco de queda em pessoas com DP para um futuro ensaio clínico randomizado.

3 ARTIGO 1

Movement strategies during obstacle crossing in people with Parkinson's disease: a systematic review with meta-analysis

(Artigo aceito no jornal PM&R

– *Qualis A3, Fator de Impacto 2.1*)

Movement strategies during obstacle crossing in people with Parkinson's disease: a systematic review with meta-analysis

Journal:	*PM&R: The journal of injury, function and rehabilitation*
Manuscript ID	PMR-23-0358.R1
Wiley - Manuscript type:	Updated Systematic Review
Classifications:	Neurorehabilitation (including TBI, CVA, SCI)
Keywords:	Gait/Balance, Movement disorders, Neurologic Disorders
Abstract:	Objective: Obstacle walking requires adaptations in gait parameters when people need to step over obstacles. This review aims to compare the spatiotemporal gait parameters of people with and without Parkinson's disease (PD) while stepping over obstacles. Literature Survey: A systematic literature search was conducted in six databases (Pubmed, Scopus, Web of Science, EBSCO, Embase, and SciELO) from inception to September 2023. Methodology: Studies that evaluated gait parameters of people with and without PD while walking over obstacles were selected. Two independent researchers evaluated the eligibility and extracted gait parameters during obstacle crossing. The risk of bias was assessed using the Joanna Briggs Institute Critical Appraisal Checklist. Heterogeneity was assessed using I2 tests. Random effects models were determined for effect sizes as standardized mean differences (SMD). Synthesis: Twenty-five studies were included in the review and 17 in the meta-analysis. Most of the studies (58%) showed a low risk of bias. People with PD exhibit a shorter step when landing after crossing an obstacle (SMD=-0.50(-0.69, -0.31)). Compared to people without PD, people with PD also widen their support base (SMD=0.27(0.07,0.47)) and reduce gait velocity (SMD=-0.60(-0.80, -0.39)) when crossing the obstacle. Conclusions: People with PD adopt a more conservative motor behavior during obstacle crossing than those without PD, with a shorter step length when landing after crossing an obstacle, lower crossing speed and greater step width.

Title: Movement strategies during obstacle crossing in people with Parkinson's disease: a systematic review with meta-analysis

Running Head: Obstacle crossing in Parkinson's disease

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Movement strategies during obstacle crossing in people with Parkinson's disease: a systematic review with meta-analysis

Abstract

Objective: Obstacle walking requires adaptations in gait parameters when people need to step over obstacles. This review aims to compare the spatiotemporal gait parameters of people with and without Parkinson's disease (PD) while stepping over obstacles. **Literature Survey:** A systematic literature search was conducted in six databases (Pubmed, Scopus, Web of Science, EBSCO, Embase, and SciELO) from inception to September 2023. **Methodology:** Studies that evaluated gait parameters of people with and without PD while walking over obstacles were selected. Two independent researchers evaluated the eligibility and extracted gait parameters during obstacle crossing. The risk of bias was assessed using the Joanna Briggs Institute Critical Appraisal Checklist. Heterogeneity was assessed using I^2 tests. Random effects models were determined for effect sizes as standardized mean differences (SMD). **Synthesis:** Twenty-five studies were included in the review and 17 in the meta-analysis. Most of the studies (58%) showed a low risk of bias. People with PD exhibit a shorter step when landing after crossing an obstacle (SMD=-0.50(-0.69, -0.31)). Compared to people without PD, people with PD also widen their support base (SMD=0.27(0.07,0.47)) and reduce gait velocity (SMD=-0.60(-0.80, -0.39)) when crossing the obstacle. **Conclusions:** People with PD adopt a more conservative motor behavior during obstacle crossing than those without PD, with a shorter step length when landing after crossing an obstacle, lower crossing speed and greater step width.

Keywords

Parkinson's Disease, Gait Analysis, Obstacle Crossing, Falls, Motor Disorders

Abbreviations

CI: Confidence interval

CS: Crossing speed

CSW: Crossing step width

ES: Effect size

FOG: Freezing of gait

H&Y: Hoehn and Yahr stage

LFAO: Leading foot placement after the obstacle

LTC: Leading toe clearance

PD: Parkinson´s disease

SMD: Standardized mean difference

TTC: Trailing toe clearance

TFBO: Trailing foot placement before the obstacle

UPDRS: Unified Parkinson's Disease Rating Scale

INTRODUCTION

Parkinson's disease (PD) is the most common neurodegenerative movement disorder worldwide. PD affects about 1% of those over 60 years,[1,2] and the prevalence of PD increases with aging. Gait and balance disturbances may impair functional capacity, reduce mobility, quality of life, and independence, and increase the risk of falling and the disease burden for people with PD and society.[3-6] In Europe, nearly two-thirds of people with PD experience a fall each year.[7] These falls frequently occur during dynamic tasks such as walking in less stable environments or on uneven surfaces.[8] Situations involving obstacle avoidance and dual/multitasking[9,10] can be more challenging for people with PD because they can lead to slips, trips, and falls. The well-known gait adaptations in PD (e.g., reduced step length, stride length, and gait velocity), combined with the challenge and cognitive overload of crossing an obstacle, are among the most frequent causes of falls in this population.[7]

Obstacle walking can be stressful because it demands adapting gait parameters during the crossing and integrating them with sensory information (e.g., visual inputs).[11] Older adults who have fallen in the last year have more difficulty stepping over obstacles than those who did not, and these difficulties are even greater in those with PD.[12] Some studies report that people with PD adjust their movement strategies during obstacle crossing and adopt a more cautious behavior to maintain dynamic stability.[13] These strategies may include reducing the crossing speed and increasing step width when crossing, among others. By implementing these strategies, they intend to avoid bumping into obstacles and achieve a successful crossing.[14]

Even though the position of the foot and its relation to the obstacle has been studied in older people and those with PD,[14] to our knowledge, no study has performed a

meta-analysis to systematically compare the spatiotemporal gait adjustments of people with and without PD while walking over obstacles. Examining the motor strategies employed in obstacle crossing may enable clinicians to tailor effective rehabilitation interventions to enhance gait parameters and adaptability during obstacle navigation. Additionally, improving spatiotemporal parameters during obstacle negotiation can enhance functional mobility, mitigating the risk of falls and positively impacting the overall quality of life of people with PD. Therefore, this review aims to summarize the spatiotemporal gait parameters of people with PD while walking over obstacles and compare them with people without the disease.

METHODOLOGY

This systematic review was conducted following the Cochrane Collaboration guidelines,[15] the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), and the Guidelines for Meta-Analyses and Systematic Reviews of Observational Studies (MOOSE).[16]

Data sources and searches

The following databases were searched from inception to September 2023: Pubmed, Scopus, Web of Science, EBSCO, Embase, and SciELO. The search strategy included a combination of terms related to Parkinson's disease and obstacle gait. For the full search strategy, see Appendix 1.

Eligibility criteria, extraction, and selection of studies

We used the PECOT strategy to define the selection criteria (Table 1). Two reviewers (J.E. and C.C-M) independently read titles and abstracts to verify the eligibility criteria. Then, they selected the studies and independently read the full texts. Discrepancies were solved by a third reviewer (P.C.). Data extracted from the studies were: the number of participants, age, the severity of PD motor symptoms according to the Unified Parkinson's disease rating scale (UPDRS – Part III), level of disability according to the Hoehn and Yahr Scale (H&Y), time since the diagnosis, ON/OFF medication status, type of gait test, instruments used for acquiring gait data, spatiotemporal gait parameters during obstacle.

The UPDRS is an assessment tool for tracking the progression of the disease. The motor section encompasses 14 items, scored on a scale of 0 (normal) to 4 (severe), yielding a total score of 56. The H&Y scale a widely employed framework for assessing the level of disability in PD across stages 1 (mild) to 5 (severe).

Spatiotemporal parameters of obstacle walking that were reported by most of the included studies are selected for this meta-analysis (Figure 1). These parameters are defined according to the analyzed foot. The first foot to cross the obstacle is called the "leading foot" and the other foot is the "trailing foot". Thus, the parameters were: *a)* trailing foot placement before the obstacle (TFBO): the distance between the trailing foot contact with the ground and the obstacle before crossing; *b)* leading toe clearance (LTC): the vertical distance from the leading toe (metatarsal marker) to the top edge of the obstacle marker at the moment of crossing; *c)* trailing toe clearance (TTC): the vertical distance from the trailing toe (metatarsal marker) to the top edge of the obstacle marker at the moment of crossing; *d*) leading foot placement after the

obstacle (LFAO): the distance between the lead foot contact placement and the obstacle after crossing; *e)* crossing step width (CSW): the mediolateral distance between the metatarsal markers at the moment of contact of the leading foot in the crossing step; and *f)* crossing speed (CS), the leading and trailing mean horizontal velocity during obstacle crossing.

For each variable, we converted their values to express them in the same unit of measurement. Statistical data from three studies[17-19] were converted into mean and standard deviation.

Figure 1 near here

Risk of bias

The reviewers independently assessed the risk of bias using the Joanna Briggs Institute Critical Appraisal Checklist.[20] In case of disagreement, a third author (P.C.) was consulted. The answers checked were "yes", "not clear", "no" or "not applicable" for each criterion in the list. The number of "yes" responses was used to calculate the percentage score.[21] The risk of bias of each article was determined based on the cutoff values: “high”(score ≤ 49%), “moderate” (50% ≤ score ≤ 69%), and “low” (score ≥ 70%).

Meta-analysis

We conducted a meta-analysis of selected studies that presented similar measurements and compared people with and without PD. The effect size was estimated through the standard mean difference (SMD) of the six most reported variables during obstacle walking (LFAO, TFBO, LTC, TTC, CSW, and CS). The magnitude of the effect was estimated using a random effects model with inverse variance weights. Heterogeneity was calculated using Cochran's Q and inconsistency I^2 tests and interpreted as follows: low (0 to 40%), moderate (30 to 60%), substantial (50 to 90%), and considerable (75 to 100%).[15]

The meta-analysis results are reported as SMD, its 95% confidence interval (CI), and represented in a forest plot. The SMD represents the magnitude of the overall effect size and was interpreted as small = 0.2 to 0.5, moderate = 0.5 to 0.8, and large = 0.8 and above.[22] All statistical analyses were performed using R V4.0.5 and Review Manager V5.4 software with a significance of $P<0.05$.

RESULTS

Study selection

The initial database search identified 716 articles. After removing duplicates, 293 studies were reviewed. After screening abstracts and titles, 92 studies remained for full-text eligibility check, which excluded 67 articles (for details, see Appendix 2). Thus, 25 studies[9,13,17-19,23-42] were selected for the systematic review, and 17 of them were qualified for the meta-analysis.[9,17-19,26,27,29,31-33,35-38,40-42] The flowchart of selection and reasons for exclusions are shown in Figure 2.

Figure 2 near here

Analysis of the studies

Among the 25 studies included in the systematic review, the sample size of people with PD ranged from 10 to 68 (total sample = 525), and of people without PD ranged from 10 to 45 (total sample = 428). Sex distribution for PD participants was 168 women and 272 men, but six studies did not report sex distribution.[13,17,19,25,41] Among participants without PD, there were 162 women and 174 men. The sex information was unspecified in seven studies.[13,17,19,25,26,36,41] The average age was 68.5 (59.7-74.3) years for people with PD and 69.1 (61.8-76.4) years for their non-PD peers. The characteristics of studies included in the systematic review are presented in Table 2. Twenty studies indicated that their participants were people with idiopathic PD diagnosis while the other five studies did not report this information. All included studies used the UK Parkinson's Disease Society Brain Bank Diagnostic Criteria to define the diagnosis criteria.[18,19,38-40] Participants had a mean time since the diagnosis of 6.9 (3.5-11) years. The H&Y stage ranged between 1 and 3 for 22 studies while another study included people with H&Y stage of 4,[28] and the remaining two studies did not report the H&Y stage.[18,26] The UPDRS scale was used in all the studies, except for one,[11] and a mean score of 26.7 (15.3-40.5) points was reported. Most studies used the Mini-Mental State Examination (MMSE) to exclude people with cognitive impairment; three studies used the Montreal Cognitive Assessment (MOCA),[23,28,37] and two studies did not report cognitive assessment.[13,26] Nineteen studies evaluated

PD participants while in the “ON” medication state, four studies evaluated participants in both “ON and OFF” states,[25,26,34,36] and two studies did not report the medication state.[17,29] Regarding Freezing of Gait (FoG), two studies included participants with and without FoG,[18,23] one study included only participants with FoG,[28] and the rest of the selected studies included only participants without FoG.

The control groups were mainly age-matched people without PD. The walking distances used during gait examination ranged from 7 to 10 meters, but one study used a 30-meter walkway.[30] The devices used to record obstacle negotiation were mainly 3D camera-based motion capture systems,[9,17-19,24,27,33,35,40] instrumented walkway,[23,25,28,30,34] and digital camcorders.[36,41,42] Some studies combined camera systems or digital camcorders with walkway sensors.[13,23,26,29,31,32,38,39] For the test conditions, four studies applied obstacle walking only,[17,24,28,32] 11 studies used walking without obstacles as a baseline record,[13,23,25,27,30,32-34,36,39,42] eight studies tested different obstacle heights,[26,29,36-39,41,42] three adopted more than one obstacle,[23,31,32] three combined obstacle walking with dual-task,[9,18,30] one study utilized visual restraint[19] and another employed obstacles with different colors.[35]

Risk of bias

Fourteen studies were classified as low risk of bias,[13,19,23,25,27,28,30,31,34,36-40] nine as moderate,[9,18,24,29,32,33,35,41,42] and only one as high risk[26] (Table 3). The questions: "were confounding factors identified?" (44% yes), and "were strategies established to deal with confounding factors?" (41.6% yes), showed fewer affirmative answers. On the other hand, the questions "was the exposure measured in a valid and reliable

way?" and "were the outcomes measured in a valid and reliable way?" were positively identified in all the studies.

Quantitative analysis

For the meta-analysis, seventeen studies were included. The studies included in the meta-analysis showed a total of 351 people with PD ranging from 10 to 65. The distribution by sex was 159 women and 130 men. The age presented by the sample of people with PD was 68.3 (59.7 – 71.7) years. On the other hand, people without PD were 288 (between 10 and 45), with a distribution by sex of 111 women and 108 men. The age presented by this sample was 68.8 (61.8 – 74.7) years.

Eight studies [13,23-25,28,30,34,39] were excluded from the metanalysis for various reasons, including the merging samples of people with and without FOG, lack of information on obstacle walking strategies, omission of control group data, and data duplication. Various methods were employed in studies to assess walking over obstacles. To ensure comparability in conditions, we applied specific criteria for data extraction. For example, when multiple obstacle heights were presented, data for the intermediate height was collected. Given that the most frequently reported heights ranged between 15 and 20 cm, we selected the reported height closest to these values. Additionally, only data from crossing a simple obstacle without vision or light restrictions were retrieved. Additionally, if obstacles in different colors were used, the two most contrasting ones (black and white) were chosen. The data analyzed were combined between independent groups and between the conditions already mentioned to create a single pairwise comparison.

Trailing foot placement before the obstacle (TFBO)

Seventeen studies were analyzed. Supplemental Figure S.1 depicts the forest plot with small effects and moderate heterogeneity. People with PD showed reduced TFBO compared with those without PD, but this difference was not statically significant (SMD = -0.17, 95% CI: (-0.40, 0.05); *P*=0.125; I^2=45.0%).

Leading toe clearance (LTC)

Seventeen studies were analyzed. No significant difference was found between people with and without PD in the LTC when crossing the obstacle (Supplemental Figure S.2, SMD = 0.04, 95% CI: (-0.48, 0.57); *P*=0.870; I^2=79%).

Trailing toe clearance (TTC)

Fifteen studies were analyzed. Supplemental Figure S.3 displays the random effects model forest plot. No significant difference was detected between groups in the TTC when crossing the obstacle (SMD = -0.13, 95% CI: (-0.47, 0.20); *P*=0.434; I^2=70%).

Leading foot placement after the obstacle (LFAO)

Thirteen studies were analyzed. The meta-analysis yielded a moderate but statistically significant effect with low heterogeneity. People with PD showed a reduced LFAO compared with those without PD (Figure 3, SMD = -0.50, 95% CI: (-0.69, -0.31);

P<0.001; I^2=0.0%). This result reveals that people with PD, relative to adults without PD, adopt a shorter step length when landing after crossing an obstacle.

Crossing step width (CSW)

Ten studies were analyzed. Figure 4 illustrates the random effects model forest plot with low heterogeneity but a small pooled effect. People with PD showed a widened CSW compared with those without PD (SMD = 0.27, 95% CI: (0.07, 0.47); *P*=0.009; I^2=0%). This result indicates that people with PD increase their support base when crossing the obstacle compared with those without PD.

Crossing Speed (CS)

Twelve studies were analyzed (Figure 5). Meta-analysis reached a moderate overall effect size with low heterogeneity. People with PD showed a lower crossing speed when compared with those without PD (SMD = -0.60, 95% CI: (-0.80, -0.39); *P*<0.001; I^2=0%). This result suggests that people with PD walk more slowly when crossing the obstacle than those without PD.

Figure 3,4 and 5 near here

DISCUSSION

This study aimed to compare the spatiotemporal gait parameters between individuals with and without PD during obstacle crossing. Our results showed that people with PD place their feet closer to the obstacle after crossing it. The distance between the feet and the obstacle has been reported as an important factor in obstacle crossing.[42] Possibly due to the association between motor symptoms (e.g., bradykinesia and hypometria) and environmental constraints, people with PD cross the obstacle with more caution.[33, 43] Bringing the foot closer to the obstacle would allow for increasing the step width during crossing.[32] This strategy may be used to compensate for the reduction in step length and speed[13] resulting from the PD-induced dynamic instability.[27] Although we found no differences in the leading and trailing toe clearance, placing the foot very close to the obstacle may increase the probability of contact with it and, therefore, the risk of tripping or falling.[33]

Our results showed that people with PD exhibit a lower crossing speed and wider step width than those without PD. The reduced gait speed and the increased step width potentially allow the patient to lift their foot high enough to clear the obstacle.[29] However, a slowed-down obstacle crossing may imply more time consumption in the single-leg support phase, increasing the demand for postural control and support stability and, therefore, raising the probability of losing balance.[45,46] Even though slower walking has been proposed as a way to optimize dynamic stability in people with PD[46], the risk of falling tends to be higher in older individuals who exhibit a slower walking pace.[47]

The height of the foot during the obstacle crossing could be considered a crucial aspect for avoiding tripping over the obstacle.[23] However, our results did not show

differences in this parameter, neither for the leading nor for the trailing foot. Barret et al (2010), in their systematic review, concluded that the risk of tripping in older individuals is more closely associated with greater variability in foot clearance than with the actual height reached by the foot.[48] Therefore, it is reasonable to consider exploring the variability in this parameter, not solely the absolute height reached.

Our review has limitations that must be acknowledged. Most of studies affirmed that the obstacle's height was similar to those found in daily life situations. However, experiments were carried out in controlled lab environments, which can limit the transfer of our findings to real-life situations. Information about the frequency of falls or fear of falling was lacking among the included studies. It is difficult to analyze how the gait parameters during obstacle-crossing task correlate with fall risk in people with PD. Only one study classified and analyzed participants according to their level of physical activity, [17] and a few pointed out that recruitment was carried out from physical activity programs. However, these studies did not analyze whether level of physical activity influenced the results. Most studies analyzed the participants only in an ON state of medication. It remains unclear how patients in OFF state of medication deal with obstacles during the crossing. Finally, one study included in this review presented high risk of bias.[26] We chose not to exclude this study from the review or meta-analysis, as its inclusion did not alter the overall results. On the other hand, it is important to highlight that most of the studies included in this review used recognized instruments to measure spatiotemporal gait parameters, such as 3D capture systems and electronic walkways.

Future studies may investigate obstacle walking using inertial measurement units in real-life environments[50,51] and other medication conditions. It also remains important to determine the relationship between spatiotemporal gait parameters during obstacle

crossing and the risk/fear of falling. Moreover, future studies can investigate whether improvements in obstacle crossing can benefit regular walking as a way to comprehensively understand how to mitigate the risk of trips and falls, reduce the disease burden, and improve the quality of life in people with PD.

CONCLUSIONS

In summary, people with PD cope with obstacle walking through motor adaptations. They exhibit a more conservative movement strategy with a shorter step length when landing after crossing an obstacle, lower crossing speed, and greater step width. Our findings provide insight into motor control and adaptation of people with PD when they cross obstacles during gait.

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Table 1: PECOT strategy and eligibility criteria

	Inclusion	Exclusion
Population	People with a diagnosis of Parkinson's disease (PD), of any sex, age, duration of the diagnosis, and medication regimen, evaluated in the ON or OFF state.	Atypical or secondary Parkinson's, combination of PD with other populations in the same group, severe condition of PD. Insufficient data even after contacting the authors.
Exposure	Obstacle walking, walking over obstacles.	Protocols that included obstacle avoidance or collected data during other types of walking, such as in functional tests.
Comparison	Healthy individuals or people without PD.	
Outcome	Traditional gait spatiotemporal parameters and parameters during obstacle walking (e.g., foot position in relation to the obstacle).	Studies that reported data inadequately or insufficiently.
Type of study	Primary study with any design. Original research, full articles, or brief reports in which the applied methodology was clearly reported, written in English, Portuguese, or Spanish.	Unpublished studies, reviews, commentary articles, protocols, conference abstracts, posters, and letters to the editor.

Table 2: Characteristics of studies

Author/year	Country	Study design	people with PD n(w/m)	PD characteristics	Disease duration (mean years)	UPDRS (mean score)	People without PD n(w/m)	ON/OFF	Measurement trial	Device	Outcomes Gait	Outcomes Crossing
Alcock/2018[23]	UK	Cross-sectional	20 (12/8)	PD Idiopathic; H&Y 2- 3; PD-FOG and PD-NFOG	6.5	20.6	13 (4/9) older adults with a history of falls	ON	7 m-long walkway. Four conditions: (1) unobstructed walking, (2)small, (3)long and (4)tall obstacle	Instrumented walkway	Step length; Step width; Step duration; Single limb support; Double limb support	Toe-Obstacle distance; Obstacle-Heel distance
Barbieri/2018[25]	BR	Cross-sectional	13	PD Idiopathic; H&Y 1- 3; ON and OFF		ON 24.08; OFF 29.08	13	ON and OFF	10 m-long walkway. Two conditions: (a) unobstructed walking, and (b) obstacle avoidance.	Instrumented walkway	Step length; Step duration; Step width; Step velocity; Limb swing duration; Double support duration; Symmetric index	NR
Hardeman/2020[28]	UK	Cross-sectional	12 (7/5)	PD Idiopathic; H&Y 2- 4; FoG	9.1	15.3	12 (5/7)	ON	8 m-long walkway. Obstacle avoidance walking and a narrow doorway at the end of the walkway	Instrumented walkway	Gait velocity; Stride velocity; Step length; Stride velocity variability; Step length variability; Step time; Step time variability; Base of support, and single and double limb support	NR
Liu/2018[29]	TW	Cross-sectional	15(9/6)	PD Idiopathic; H&Y 1			15(10/5)	NR	10 m-long walkway. Three conditions crossing obstacles: (1) height of 10%; (2)20% and (3) 30% leg length.	3D optoelectronic system + Force platform		Crossing speed; Crossing stride length; Crossing step length; Crossing step width; Horizontal toe-obstacle distance; Horizontal heel-obstacle distance; Leading toe clearance; Trailing toe clearance. Center of mass; Center of pressure
Maidan/2016[30]	IL, NL	Cross-sectional	68 (46/22)	PD Idiopathic; H&Y 2- 3	9.1	32,9	38(20/18)	ON	30-m long walkway back and forth. Three conditions: (1) unobstructed walking; (2) Dual-Task walking, and (3) obstacles negotiation	Instrumented walkway	Stride length; Gait speed; Step over duration; Change in step duration.	NR
Orcioli-Silva/2017[32]	BR	Cross-sectional	19 (10/9)	PD Idiopathic; H&Y 1- 3		27.05	19 (10/9)	ON	8 m-long walkway. Three conditions: (1) unobstructed walking; (2) walking with one obstacles (Single); (3) walking with two obstacles (double).	Instrumented walkway + 3D optoelectronic system	Stride length; Stride duration; Stride velocity; Swing phase	Leading limb and Trailing limb: Step length; Step width; Foot placement before obstacle; Foot placement after obstacle; Toe clearance

Orcioli-Silva/2018[33]	BR	Cross-sectional	PIGD 35 (17/18); TD 30(20/10)	PD Idiopathic; H&Y 1- 3; PD PIGD and PD TD	PIGD 6.17; TD 6.25	PIGD 25.03; TD 23.03	45(21/24)	ON	8 m-long walkway. Two conditions: (a) unobstructed walking, and (b) obstacle avoidance.	3D optoelectronic system	Stride length; Stride duration; Stride velocity; Double support.	Leading limb and Trailing limb: Step length; Step width; Foot placement before obstacle; Foot placement after obstacle; Toe clearance; Horizontal velocity during obstacle crossing
Orcioli-Silva/2020[31]	BR	Cross-sectional	19 (10/9)	PD Idiopathic; H&Y 1- 2.5	5.19	27.05	19 (10/9)	ON	8 m-long walkway. Three conditions: (1) walking with one obstacle (Single); (2) walking with two obstacles (50cm distance); (3) walking with two obstacles (108 cm distance).	Instrumented walkway + 3D optoelectronic system	Step Length; Step duration; Swing phase; Step velocity	Leading foot placement; Trailling foot placement; Leading toe clearance; Trailling toe clearance.
Orcioli-Silva/2021[34]	BR	Cross-sectional	23 (18/5)	PD Idiopathic; H&Y 1- 3	5.26	ON 29.91; OFF 37.70	30 (15/15)	ON and OFF	7 m-long walkway. Two conditions:. (1) unobstructed walking, (2) obstacle avoidance	Instrumented walkway	Step Length; Step time; Step velocity; Variability step length, time and velocity	NR
Penedo/2018[35]	BR	Cross-sectional	13 (7/6)	Idiopatico, HY 1 y 3.	6.23	22	11 (4/7)	ON	8 m-long walkway. Five conditions walking with colored obstacles: (1) white; (2) black; (3) red and (4) blue	3D optoelectronic system	Stride Length; Step Width; Stride Duration; Stride Velocity; Double support time	Trailing foot placement before the obstacle; Trailing foot placement after the obstacle; Trailing toe-clearance; Leading foot placement before the obstacle; Leading foot placement after the obstacle; Leading toe-clearance
Pieruccini-Faria/2014a[19]	BR	Cross-sectional	18	H&Y 1- 3		25	15	ON	10 m-long walkway. Three conditions obstacles negotiation: (1) no visual restrictions; (2) vision of the obstacle and their lower limbs while in complete darkness; (3) vision of the obstacle only while in complete darkness. Conditions including a dual task versus without a dual task.	3D optoelectronic system	Gait velocity; Step time variability; Step length variability	Trail horizontal distance before obstacle; Lead toe clearance; Lead horizontal distance beyond obstacle; Trail horizontal distance before obstacle variability; Lead toe clearance variability; Lead horizontal distance beyond obstacle variability; Crossing velocity.
Pieruccini-Faria/2014b[18]	CA	Cross-sectional	PD-FOG 14 (14/0); PD-NFOG 13(10/3)	PD-FOG and PD-NFOG	PD-FOG 8.3; PD-NFOG 7.6	PD-FOG 37.3; PD-NFOG 33.1	14(8/6)	ON	10 m-long walkway. Three conditions: (1) obstacles negotiation; (2) dual task condition 1; (3) dual task condition 2	3D optoelectronic system	Gait velocity; Step length; Step length variability; Step time variability; Crossing velocity; Crossing step	Trail foot horizontal distance before obstacle; Lead foot horizontal distance after obstacle; Lead foot vertical clearance; Trail foot vertical clearance; Crossing step width; Crossing velocity; Crossing step.

Pieruccini-Faria/2013[36]	BR	Cross-sectional	12	PD Idiopathic; H&Y 1.5- 3; ON and OFF	7.13	40.5	12	ON and OFF	8 m-long walkway. Four conditions: (1) unobstructed walking; (2) low obstacle; (3) high obstacle	Digital camcorders	Step length; Step to step length variability; Step time; Step time variability.	Lead horizontal distance before obstacle; Trail horizontal distance before obstacle; Lead foot clearance; Trail foot clearance; Lead horizontal distance after obstacle; Crossing step length; Step width; Time to lead foot clearance.
dos Santos/2021[17]	BR	Experimental	PD Inactive 10; PD Active 10	PD Idiopathic; H&Y 1- 3		PD Inactive 29.1; PD Active 31.8	Inactive 10; Active 10	NR	7 m-long walkway. Obstacle avoidance walking	3D optoelectronic system	Stride Length; Step Width; Stride Duration; Stride Velocity.	Step Length; Step Width; Step Duration; Step Velocity; Leading placement to obstacle; Trailing placement to obstacle; Leading clearance; Trailing clearance
Sharon/2020[37]	IL	Cross-sectional	34(20/14)	PD Idiopathic; H&Y 1- 3	3.5	27	26(15/11)	ON	8 m-long walkway. Two conditions: (1) obstacles height 50; (2) obstacles height 100. Each with anticipated and unanticipated obstacles	electronic walkway + Kinect camera	Gait speed; Step length	Distance of the trailing foot before the obstacle; Clearance of the leading foot; Distance of the leading foot after the obstacle; Clearance of the trailing foot
Simieli/2017[39]	BR	Cross-sectional	15 (8/7)	H&Y 1- 3		24.75	13 (7/6)	ON	8 m-long walkway. Four conditions: (1) unobstructed walking; (2) low obstacle; (3) intermediate obstacle, and (4) high obstacle	Instrumented walkway + 3D optoelectronic system	Step length; Step duration; Step width; Step velocity; Limb swing duration; Single support; Double support duration	Toe clearance trail y leading limb
Simieli/2018[38]	BR	Cross-sectional	15 (8/7)	H&Y 1- 3		24.75	13 (7/6)	ON	8 m-long walkway. Three conditions: (1) low obstacle; (2) intermediate obstacle; (3) high obstacle.	Instrumented walkway + 3D optoelectronic system	Step length; Step duration; Step velocity; Step width; Double support time; Single support time; Variability of step	Toe clearance of the leading and trailing limbs; Horizontal distance from the leading and trailing limb to the obstacle before and after obstacle crossing; Braking and propulsive vertical impulses.
Stegemöller/ 2012[13]	US	Cross-sectional	10	PD Idiopathic; H&Y 1- 3	11		10	ON	9 m-long walkway. Two conditions: (1) unobstructed walking and (2) obstacle avoidance.	3D optoelectronic system + Force platform	Step length; Step width; Step velocity; Stance time; Center of mass; Center of pressure	Leading and trailing foot vertical clearance; Trailing foot placement before the obstacle; Leading foot placement after obstacle crossing; Trailing foot placement after obstacle crossing

Vitório/2010[42]	BR	Cross-sectional	12(8/4)	PD Idiopathic; H&Y 1- 3	7.1	30.91	12(8/4)	ON	8 m-long walkway. Four conditions: (1) unobstructed walking; (2) low obstacle; (3) intermediate obstacle, and (4) high obstacle	Digital camcorders	Stride length, Stride duration; Stance phase duration and swing phase duration.	Step length; Leading foot placement in front of the obstacle; Trailing foot placement in front of the obstacle; Leading toe clearance; Trailing toe clearance; Leading foot placement after crossing the obstacle
Vitório/2013[41]	BR	Cross-sectional	12	PD Idiopathic; H&Y 1- 2.5		19.8	12	ON	8 m-long walkway. Two conditions: (1) obstacles ankle height or (2) half-knee height. Three visual sampling conditions: dynamic, static, and voluntary visual sampling.	Digital camcorders	NR	Trailing foot placement before the obstacle; Leading toe clearance; Trailing toe clearance; Crossing step width; Leading horizontal mean velocity during obstacle crossing; Trailing horizontal mean velocity during obstacle crossing.
Vitório/2014[40]	BR	Cross-sectional	mild PD 15(7/8); moderate PD 15(7/8)	mild PD H&Y 1-1.5; moderate PD H&Y 2-3		mild PD 18.2; moderate PD 28.9	15(7/8)	ON	8 m-long walkway. Obstacle avoidance walking	3D optoelectronic system	NR	Leading foot placement before the obstacle; Trailing foot placement before the obstacle; Leading toe clearance; Trailing toe clearance; Leading foot placement after obstacle crossing; Crossing step width; Leading horizontal mean velocity during obstacle crossing; Trailing horizontal mean velocity during obstacle crossing.
Ambike/2021[24]	BR	Cross-sectional	13(7/6)	PD Idiopathic; H&Y 1- 3	6.2	22	11(7/4)	ON	8 m-long walkway. Obstacle avoidance walking	3D optoelectronic system	NR	Leading foot placement before the obstacle; Leading foot placement after obstacle crossing; Step length; Step velocity; Lengths of two steps prior.
Brown/2010[9]	CA	Cross-sectional	10(3/7)	PD Idiopathic; H&Y 2- 3	4.2	27.3	10(7/3)	ON	10 m-long walkway. Six testing conditions: (1) no music/music; (2) single task/dual task; (3) no obstacle/obstacle	3D optoelectronic system	NR	Step length for lead foot; Step length for trail foot; Trailing foot placement before the obstacle; Leading foot placement after obstacle crossing; Leading toe clearance; Trailing toe clearance; Leading horizontal mean velocity during obstacle crossing; Trailing horizontal mean velocity during obstacle crossing.

Doan/2013[26]	CA	Cross-sectional	10(5/5)	PD Idiopathic.	8.2	ON 18.1; OFF 36.2	10	ON and OFF	4.7 m-long walkway. Obstacle avoidance walking two conditions: (1) High condition (test walkway above the ground); (2) Low condition (walkway was outlined on the laboratory floor)	3D optoelectronic system + Force platform	NR	Trailing foot placement before the obstacle; Leading foot placement after obstacle crossing; Leading toe clearance; Step length for lead foot; Step length for trail foot; Horizontal velocity CoM
Galna/2010[27]	AU	Cross-sectional	20(4/16)	PD Idiopathic; H&Y 1- 3		12.6	20(4/16)	ON	10 m-long walkway. Two conditions: (1) unobstructed walking and (2) obstacle avoidance.	3D optoelectronic system	step length, step duration, single limb support duration, double limb support duration, and step width.	Trailing foot placement before the obstacle; Leading foot placement after obstacle crossing; Leading toe clearance; Trailing toe clearance

Note: PD= Parkinson's disease; H&Y= Hoehn and Yahr; n= number of participants; w= women; m= men; UPDRS= Unified Parkinson's Disease Rating Scale; MMSE=Mini-Mental State Examination; MOCA=Montreal cognitive assessment; FOG=Freezing of Gait; N-FOG=No-Freezing of Gait; NR=not reported; UK: United Kingdom; BR: Brazil; TW: Taiwan; IL: Israel; NL: Netherlands; CA: Canada; US: United States; AU: Australia.

Table 3. Risk of bias assessed by Joanna Briggs Institute Critical Appraisal Checklist

	Were the criteria for inclusion in the sample clearly defined?	Were the study subjects and the setting described in detail?	Was the exposure measured in a valid and reliable way?	Were objective, standard criteria used for measurement of the condition?	Were confounding factors identified?	Were strategies to deal with confounding factors stated?	Were the outcomes measured in a valid and reliable way?	Was appropriate statistical analysis used?	% Yes	Risk
Alcock (2018)	Y	Y	Y	Y	Y	Y	Y	Y	100	Low
Barbieri (2018)	Y	Y	Y	Y	Y	Y	Y	N	87.5	Low
Hardeman (2020)	N	Y	Y	U	Y	Y	Y	Y	75	Low
Liu (2018)	Y	U	Y	Y	N	N	Y	N	50	Moderate
Maidan (2016)	Y	Y	Y	Y	N	N	Y	Y	75	Low
Orcioli-Silva (2017)	Y	Y	Y	Y	N	N	Y	N	62.5	Moderate
Orcioli-Silva (2018)	Y	N	Y	Y	N	N	Y	N	50	Moderate
Orcioli-Silva (2020)	Y	Y	Y	Y	N	Y	Y	Y	87.5	Low
Orcioli-Silva (2021)	Y	Y	Y	U	Y	Y	Y	Y	87.5	Low
Penedo (2018)	Y	N	Y	Y	N	N	Y	Y	62.5	Moderate
Pieruccini-Faria (2014_1)	Y	N	Y	Y	Y	Y	Y	N	75	Low
Pieruccini-Faria (2014_2)	Y	N	Y	U	U	U	Y	Y	50	Moderate
Pieruccini-Faria (2013)	N	N	Y	Y	Y	Y	Y	Y	75	Low
Sharon (2020)	Y	Y	Y	Y	Y	Y	Y	Y	100	Low
Simieli (2017)	Y	Y	Y	Y	Y	Y	Y	Y	100	Low
Simieli (2018)	Y	Y	Y	Y	Y	Y	Y	Y	100	Low
Stegemöller (2012)	Y	N	Y	Y	Y	Y	Y	Y	87.5	Low
Vitório (2010)	Y	Y	Y	Y	N	N	Y	N	62.5	Moderate
Vitório (2013)	Y	N	Y	Y	N	N	Y	N	50	Moderate
Vitório (2014)	Y	Y	Y	Y	U	N	Y	Y	75	Low
Ambike (2021)	N	Y	Y	Y	N	N	Y	Y	62.5	Moderate
Brown (2010)	Y	Y	Y	Y	N	N	Y	N	62.5	Moderate
Doan (2013)	N	N	Y	N	U	N	Y	N	25	High
Galna (2010)	Y	Y	Y	Y	Y	Y	Y	Y	100	Low
Score:	20	12	24	20	12	12	24	15	**73.4**	
% Yes	83.3	50	100	83.3	50	50	100	62.5	**72.4**	

Note: Y: Yes; N: No

Figure 1: Illustration of other spatiotemporal gait parameters related to obstacle walking. The image depicts the leading foot (red), which crosses the obstacle first, and the trailing foot (blue), which crosses lastly. **1) Trailing foot placement before the obstacle (TFBO):** horizontal distance between the trailing foot and the obstacle before crossing; **2) Leading toe clearance (LTC):** vertical distance between the leading toe to the top edge of the obstacle; **3) Trailing toe clearance (TTC):** vertical distance between the trailing toe to the top edge of the obstacle; **4) Leading foot placement after the obstacle (LFAO):** horizontal distance between the leading foot and the obstacle after crossing; **5) Crossing step width (CSW):** mediolateral distance between the contact of the leading and trailing foot in the crossing step; **6) Crossing speed (CS):** mean horizontal velocity during obstacle crossing.

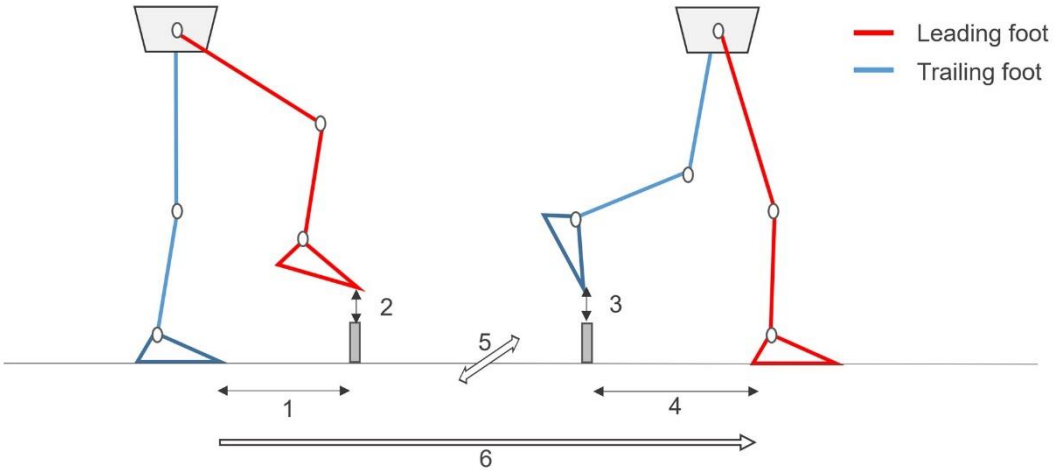


Figure 2: PRISMA flowchart showing the study selection process.

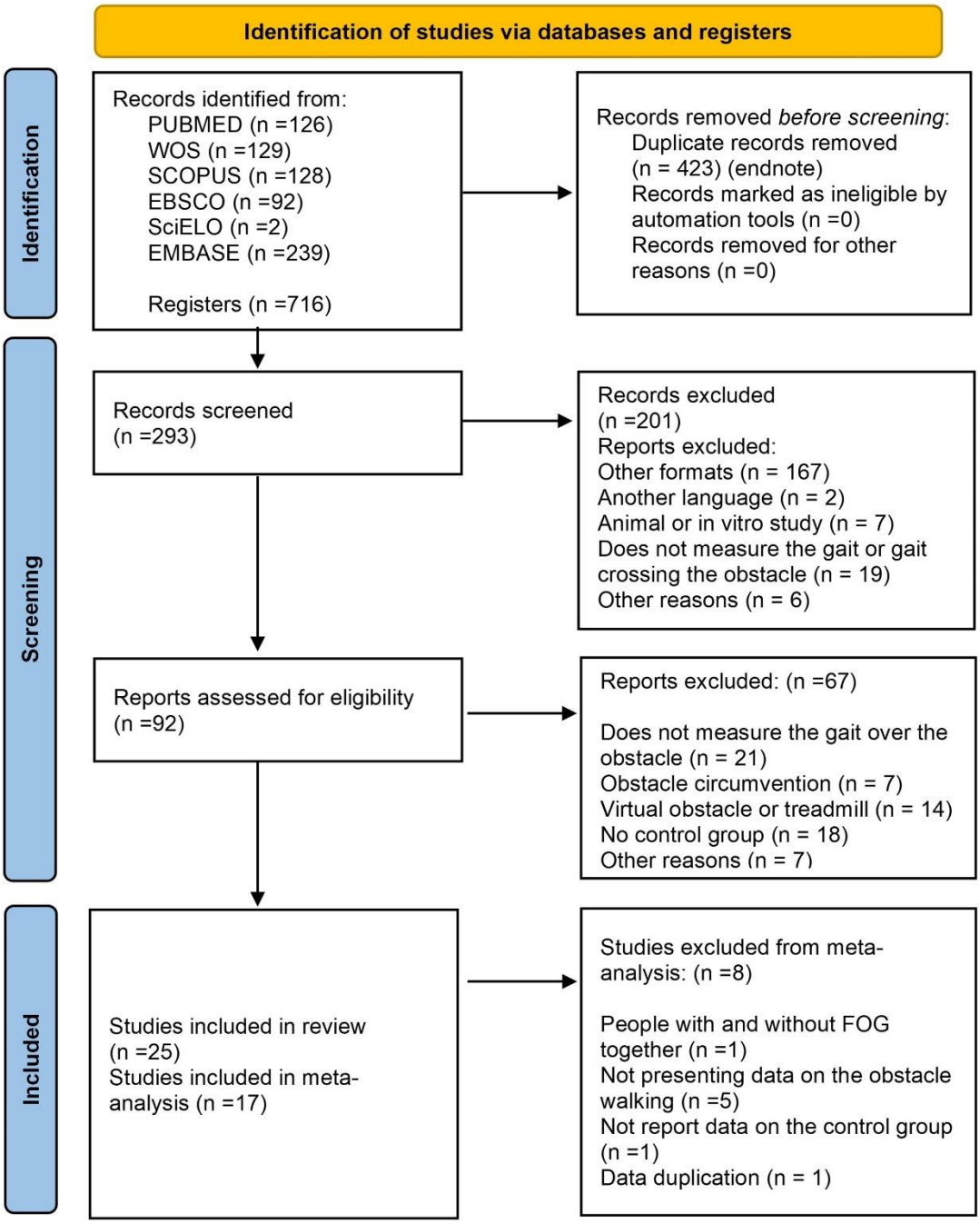


Figure 3: Forest plot of effect sizes (ES) showing the Leading foot placement after the obstacle (LFAO) comparison between people with and without Parkinson's disease. The ES was characterized by the standardized mean difference (SMD) and meta-analyzed by a random-effects model with the inverse variance weight.

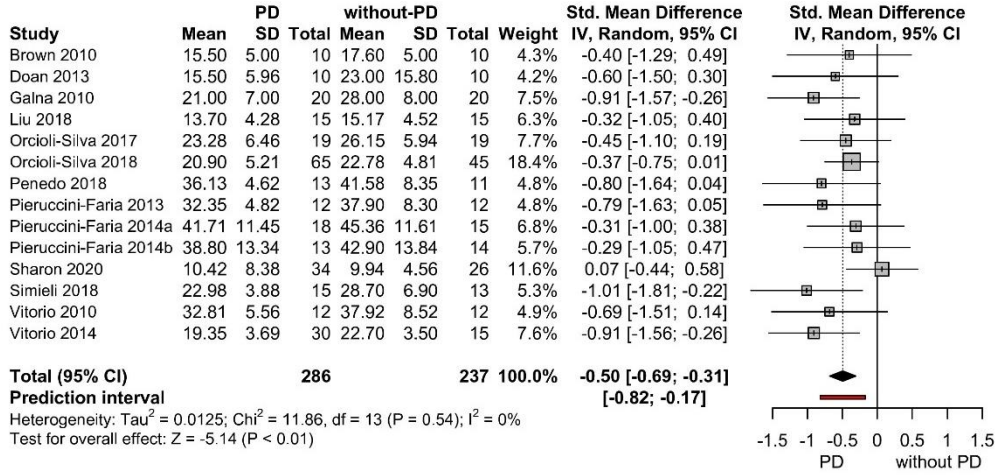


Figure 4: Forest plot of effect sizes (ES) showing the Crossing step width (CSW) comparison between people with and without Parkinson's disease. The ES was characterized by the standardized mean difference (SMD) and meta-analyzed by a random-effects model with the inverse variance weight.

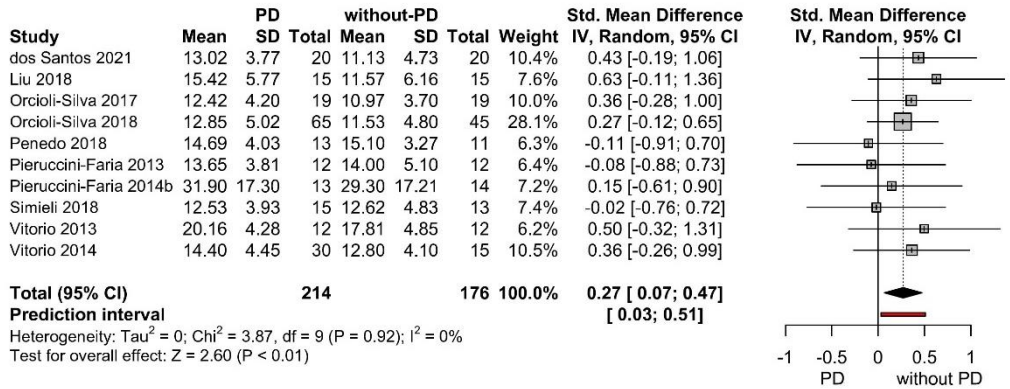
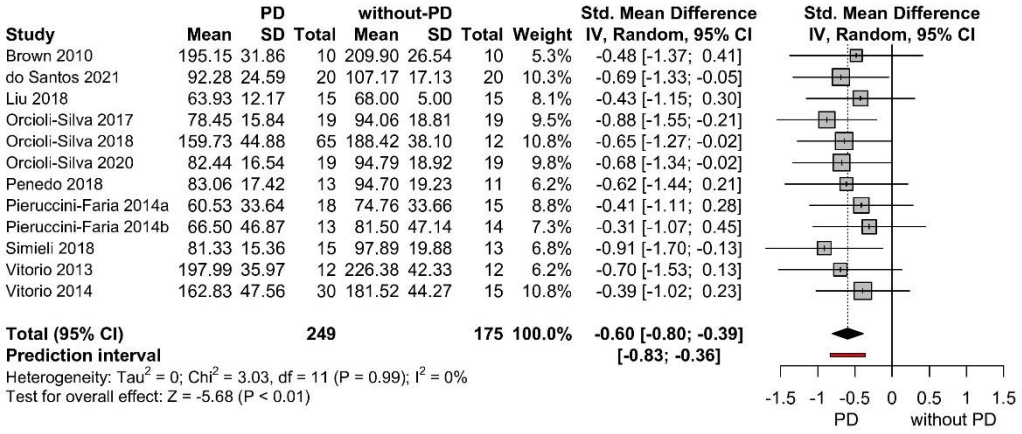


Figure 5: Forest plot of effect sizes (ES) showing the Crossing speed (CS) comparison between people with and without Parkinson's disease. The ES was characterized by the standardized mean difference (SMD) and meta-analyzed by a random-effects model with the inverse variance weight.



Appendix 1: Search strategy for the different databases.

Pubmed (n= 126)
(“Parkinson Disease”[Mesh] OR “Idiopathic Parkinson's Disease” OR “Lewy Body Parkinson's Disease” OR “Parkinson's Disease, Idiopathic” OR “Parkinson's Disease, Lewy Body” OR “Parkinson Disease, Idiopathic” OR “Parkinson's Disease” OR “Idiopathic Parkinson Disease” OR “Lewy Body Parkinson Disease” OR “Primary Parkinsonism” OR “Parkinsonism, Primary” OR “Paralysis Agitans”) AND (“obstacle” OR “obstacles” OR “obstacle crossing” OR “obstacle negotiation” OR “obstacle gait” OR “negotiation gait” OR “obstacle avoidance”) AND (“Gait”[Mesh] OR “Gaits” OR “Walking” OR “Ambulation” OR “Gait Analysis” OR “Analysis, Gait” OR “Gait Analyses” OR “Walking Speed” OR “Speed, Walking” OR “Speeds, Walking” OR “Walking Speeds” OR “Gait Speed” OR “Gait Speeds” OR “Speed, Gait” OR “Speeds, Gait” OR “Walking Pace” OR “Pace, Walking” OR “Paces, Walking” OR “Walking Paces” OR “Gait variability” OR “Variability gait” OR “Variability of gait” OR “Gait Variability Index” OR “Gait kinematic variability” OR “Spatiotemporal gait variables” OR “variability” OR “complexity” OR “unsteadiness” OR “inconsist” OR “arrhythmicity” OR “stability” OR “fractal” OR “equilibrium” OR “dynamics” OR “asymmetries” OR “Symmetry” OR “symmetries” OR “Gait Variable Scores” OR “Gait Profile Score” OR “Gait Deviation Index” OR “Gait quality” OR “Locomotion” OR “Locomotor Activity” OR “Activities, Locomotor” OR “Activity, Locomotor” OR “Locomotor Activities”)

Web of Knowledge: Web of Science (n=129)
((TS=(“Parkinson Disease”[Mesh] OR “Idiopathic Parkinson's Disease” OR “Lewy Body Parkinson's Disease” OR “Parkinson's Disease, Idiopathic” OR “Parkinson's Disease, Lewy Body” OR “Parkinson Disease, Idiopathic” OR “Parkinson's Disease” OR “Idiopathic Parkinson Disease” OR “Lewy Body Parkinson Disease” OR “Primary Parkinsonism” OR “Parkinsonism, Primary” OR “Paralysis Agitans”)) AND TS=(“obstacle” OR “obstacles” OR “obstacle crossing” OR “obstacle negotiation” OR “obstacle gait” OR “negotiation gait” OR “obstacle avoidance”)) AND TS=(“Gait”[Mesh] OR “Gaits” OR “Walking” OR “Ambulation” OR “Gait Analysis” OR “Analysis, Gait” OR “Gait Analyses” OR “Walking Speed” OR “Speed, Walking” OR “Speeds, Walking” OR “Walking Speeds” OR “Gait Speed” OR “Gait Speeds” OR “Speed, Gait” OR “Speeds, Gait” OR “Walking Pace” OR “Pace, Walking” OR “Paces, Walking” OR “Walking Paces” OR “Gait variability” OR “Variability gait” OR “Variability of gait” OR “Gait Variability Index” OR “Gait kinematic variability” OR “Spatiotemporal gait variables” OR “variability” OR “complexity” OR “unsteadiness” OR “isconsist” OR “arrhythmicity” OR “stability” OR “fractal” OR “equilibrium” OR “dynamics” OR “asymmetries” OR “Symmetry” OR “symmetries” OR “Gait Variable Scores” OR “Gait Profile Score” OR “Gait Deviation Index” OR “Gait quality” OR “Locomotion” OR “Locomotor Activity” OR “Activities, Locomotor” OR “Activity, Locomotor” OR “Locomotor Activities”)

Scopus (n=128)
(TITLE-ABS-KEY ("Parkinson Disease" [mesh] OR "Idiopathic Parkinson's Disease" OR "Lewy Body Parkinson's Disease" OR "Parkinson's Disease, Idiopathic" OR "Parkinson's Disease, Lewy Body" OR "Parkinson Disease, Idiopathic" OR "Parkinson's Disease" OR "Idiopathic Parkinson Disease" OR "Lewy Body Parkinson Disease" OR "Primary

Parkinsonism" OR "Parkinsonism, Primary" OR "Paralysis Agitans") AND TITLE-ABS-KEY ("obstacle" OR "obstacles" OR "obstacle crossing" OR "obstacle negotiation" OR "obstacle gait" OR "negotiation gait" OR "obstacle avoidance") AND TITLE-ABS-KEY ("Gait" [mesh] OR "Gaits" OR "Walking" OR "Ambulation" OR "Gait Analysis" OR "Analysis, Gait" OR "Gait Analyses" OR "Walking Speed" OR "Speed, Walking" OR "Speeds, Walking" OR "Walking Speeds" OR "Gait Speed" OR "Gait Speeds" OR "Speed, Gait" OR "Speeds, Gait" OR "Walking Pace" OR "Pace, Walking" OR "Paces, Walking" OR "Walking Paces" OR "Gait variability" OR "Variability gait" OR "Variability of gait" OR "Gait Variability Index" OR "Gait kinematic variability" OR "Spatiotemporal gait variables" OR "variability" OR "complexity" OR "unsteadiness" OR "inconsist" OR "arrhythmicity" OR "stability" OR "fractal" OR "equilibrium" OR "dynamics" OR "asymmetries" OR "Symmetry" OR "symmetries" OR "Gait Variable Scores" OR "Gait Profile Score" OR "Gait Deviation Index" OR "Gait quality" OR "Locomotion" OR "Locomotor Activity" OR "Activities, Locomotor" OR "Activity, Locomotor" OR "Locomotor Activities"))

EBSCO (n=92)

("Parkinson Disease" OR "Idiopathic Parkinson's Disease" OR "Lewy Body Parkinson's Disease" OR "Parkinson's Disease, Idiopathic" OR "Parkinson's Disease, Lewy Body" OR "Parkinson Disease, Idiopathic" OR "Parkinson's Disease" OR "Idiopathic Parkinson Disease" OR "Lewy Body Parkinson Disease" OR "Primary Parkinsonism" OR "Parkinsonism, Primary" OR "Paralysis Agitans") AND ("obstacle" OR "obstacles" OR "obstacle crossing" OR "obstacle negotiation" OR "obstacle gait" OR "negotiation gait" OR "obstacle avoidance") AND ("Gait" OR "Gaits" OR "Walking" OR "Ambulation" OR "Gait Analysis" OR "Analysis, Gait" OR "Gait Analyses" OR "Walking Speed" OR "Speed, Walking" OR "Speeds, Walking" OR "Walking Speeds" OR "Gait Speed" OR "Gait Speeds" OR "Speed, Gait" OR "Speeds, Gait" OR "Walking Pace" OR "Pace, Walking" OR "Paces, Walking" OR "Walking Paces" OR "Gait variability" OR "Variability gait" OR "Variability of gait" OR "Gait Variability Index" OR "Gait kinematic variability" OR "Spatiotemporal gait variables" OR "variability" OR "complexity" OR "unsteadiness" OR "inconsist" OR "arrhythmicity" OR "stability" OR "fractal" OR "equilibrium" OR "dynamics" OR "asymmetries" OR "Symmetry" OR "symmetries" OR "Gait Variable Scores" OR "Gait Profile Score" OR "Gait Deviation Index" OR "Gait quality" OR "Locomotion" OR "Locomotor Activity" OR "Activities, Locomotor" OR "Activity, Locomotor" OR "Locomotor Activities")

EMBASE (n=239)

('parkinson disease' OR 'idiopathic parkinsons disease' OR 'lewy body parkinsons disease' OR 'parkinsons disease, idiopathic' OR 'parkinsons disease, lewy body' OR 'parkinson disease, idiopathic' OR 'parkinsons disease'/exp OR 'parkinsons disease' OR 'idiopathic parkinson disease'/exp OR 'idiopathic parkinson disease' OR 'lewy body parkinson disease' OR 'primary parkinsonism' OR 'parkinsonism, primary' OR 'paralysis agitans') AND ('obstacle':ab,ti OR 'obstacles':ab,ti OR 'obstacle crossing':ab,ti OR 'obstacle negotiation':ab,ti OR 'obstacle gait':ab,ti OR 'negotiation gait':ab,ti OR 'obstacle avoidance':ab,ti) AND ('gait':ab,ti OR 'gaits':ab,ti OR 'walking':ab,ti OR 'ambulation':ab,ti OR 'gait analysis':ab,ti OR 'analysis, gait':ab,ti OR 'gait analyses':ab,ti OR 'walking speed':ab,ti OR 'speed, walking':ab,ti OR 'speeds, walking':ab,ti OR 'walking speeds':ab,ti OR 'gait speed':ab,ti OR 'gait speeds':ab,ti OR 'speed, gait':ab,ti OR 'speeds, gait':ab,ti OR 'walking pace':ab,ti OR 'pace, walking':ab,ti OR 'paces, walking':ab,ti OR 'walking paces':ab,ti OR 'gait variability':ab,ti OR 'variability gait':ab,ti

OR 'variability of gait':ab,ti OR 'gait variability index':ab,ti OR 'gait kinematic variability':ab,ti OR 'spatiotemporal gait variables':ab,ti OR 'variability':ab,ti OR 'complexity':ab,ti OR 'unsteadiness':ab,ti OR 'inconsist':ab,ti OR 'arrhythmicity':ab,ti OR 'stability':ab,ti OR 'fractal':ab,ti OR 'equilibrium':ab,ti OR 'dynamics':ab,ti OR 'asymmetries':ab,ti OR 'symmetry':ab,ti OR 'symmetries':ab,ti OR 'gait variable scores':ab,ti OR 'gait profile score':ab,ti OR 'gait deviation index':ab,ti OR 'gait quality':ab,ti OR 'locomotion':ab,ti OR 'locomotor activity':ab,ti OR 'activities, locomotor':ab,ti OR 'activity, locomotor':ab,ti OR 'locomotor activities':ab,ti)
SciELO (n=2)
"Parkinson Disease" AND "obstacle" AND "Gait"

n: number of hits.

Appendix 2: Study selection and reasons for exclusion of reports assessed for eligibility

Included	Studies (*k* = 84)	Reasons for exclusion based on full text
No	1. Alberts 2022	Does not have a control group
Yes	2. Alcock 2018	
No	3. Alcock 2020	Does not analyze temporal-spatial variables of walking
Yes	4. Ambike 2021	
No	5. Assad 2022	Does not have a control group
No	6. Barbieri 2018 a	Does not analyze crossing over the obstacle
Yes	7. Barbieri 2018 b	
No	8. Breu 2021	Does not analyze temporal-spatial variables of walking
Yes	9. Brown 2010	
No	10. Brugger 2021	Does not analyze crossing over the obstacle
No	11. Bueno 2023	Does not have a control group
No	12. Caetano 2018	Obstacle analyzed is virtual
No	13. Caetano 2019	Obstacle analyzed is virtual
No	14. Casal 2021	Does not have a control group
No	15. Chen 2021	Does not provide quantitative walking data
No	16. Conceição 2019	Does not analyze temporal-spatial variables of walking
No	17. Corradini 2022	Does not analyze crossing over the obstacle
No	18. Cremers 2012	Does not provide quantitative walking data
No	19. Davidashvilly 2022	Other formats
No	20. Delval 2010	Obstacle analyzed is virtual
No	21. Dietz 2008	Obstacle analyzed is virtual
Yes	22. Doan 2013	
No	23. Faria 2023	Analyze only the beginning of walking
Yes	24. Galna 2010	
No	25. Galna 2013	Does not analyze temporal-spatial variables of walking
No	26. Geerse 2019	Obstacle analyzed is virtual
Yes	27. Hardeman 2020	
No	28. Hunt 2018	Does not analyze temporal-spatial variables of walking

No	29. Juras 2020	Analyze only the beginning of walking
No	30. Kamieniarz 2020	Analyze only the beginning of walking
No	31. Kegelmeyer 2013	Does not analyze crossing over the obstacle
No	32. Kim 2019	Does not evaluate people with Parkinson's disease
No	33. Kim 2014	Does not analyze temporal-spatial variables of walking
No	34. Kim 2012	Does not analyze temporal-spatial variables of walking
No	35. Kim 2021	Does not analyze temporal-spatial variables of walking
No	36. Landers 2016	Does not analyze temporal-spatial variables of walking
No	37. Landers 2018	Does not analyze temporal-spatial variables of walking
No	38. Law 2023	Does not evaluate healthy control group
No	39. Li 2022	Does not evaluate healthy control group
No	40. Liao 2015	Does not evaluate healthy control group
No	41. Liao 2014	Does not evaluate healthy control group
Yes	42. Liu 2018	
No	43. Lu 2019	Obstacle analyzed is virtual
No	44. Maidan 2014	Does not provide quantitative walking data
No	45. Maidan 2018	Does not provide quantitative walking data
Yes	46. Maidan 2016	
No	47. Maidan 2017	Obstacle analyzed is imaginary
No	48. Marsh 2019	Does not evaluate healthy control group
No	49. Martens 2012	Does not provide quantitative walking data
No	50. McIsaac 2012	Does not analyze temporal-spatial variables of walking
No	51. McKee 2014	Analyze only the beginning of walking
No	52. Michel 2009	Does not provide clear quantitative walking data
No	53. Mirelman 2011	Does not evaluate healthy control group
No	54. Mirelman 2016	Does not evaluate healthy control group
No	55. Moore 2008	Does not provide quantitative walking data
No	56. Nanhoe-Mahabier 2012	Does not evaluate healthy control group
No	57. Nieuwboer 2001	Does not evaluate healthy control group
No	58. Nóbrega-Sousa 2019	Does not evaluate healthy control group
No	59. Nuic 2018	Analyze only the beginning of walking
Yes	60. Orcioli-Silva 2020	
Yes	61. Orcioli-Silva 2017	
Yes	62. Orcioli-Silva 2021	
Yes	63. Orcioli-Silva 2018	
No	64. Orcioli-Silva 2021	Does not provide quantitative walking data
No	65. Pelicioni 2022	Obstacle analyzed is virtual
No	66. Pelosin 2020	Does not independently assess people with Parkinson's disease
No	67. Pelosin 2021	Does not evaluate healthy control group
Yes	68. Penedo 2018	
No	69. Pereira 2015	Does not evaluate healthy control group
No	70. Pereira 2019	Does not analyze crossing over the obstacle
Yes	71. Pieruccini-Faria 2014 a	

Yes	72. Pieruccini-Faria 2014 b	
No	73. Pieruccini-Faria 2016	Does not analyze temporal-spatial variables of walking
No	74. Pieruccini-Faria 2006	Does not evaluate healthy control group
Yes	75. Pieruccini-Faria 2013	
Yes	76. Santos 2021	
Yes	77. Sharon 2020	
No	78. Silveira-Ciola 2021	Does not analyze crossing over the obstacle
No	79. Silveira-Ciola 2023	Does not analyze crossing over the obstacle
Yes	80. Simieli 2018	
Yes	81. Simieli 2017 a	
No	82. Simieli 2017 b	Does not analyze crossing over the obstacle
No	83. Sinjders 2010	Does not evaluate healthy control group
Yes	84. Stegemöller 2012	
No	85. van Hedel 2006	Does not provide quantitative walking data
Yes	86. Vitório 2014	
Yes	87. Vitório 2013	
Yes	88. Vitório 2010	
No	89. Vitório 2023	Does not analyze crossing over the obstacle
No	90. Wang 2022	Does not analyze crossing over the obstacle
No	91. Wendel 2018	Does not analyze crossing over the obstacle
No	92. Wilczyński 2021	Does not analyze crossing over the obstacle

Appendices 3: Supplemental figure

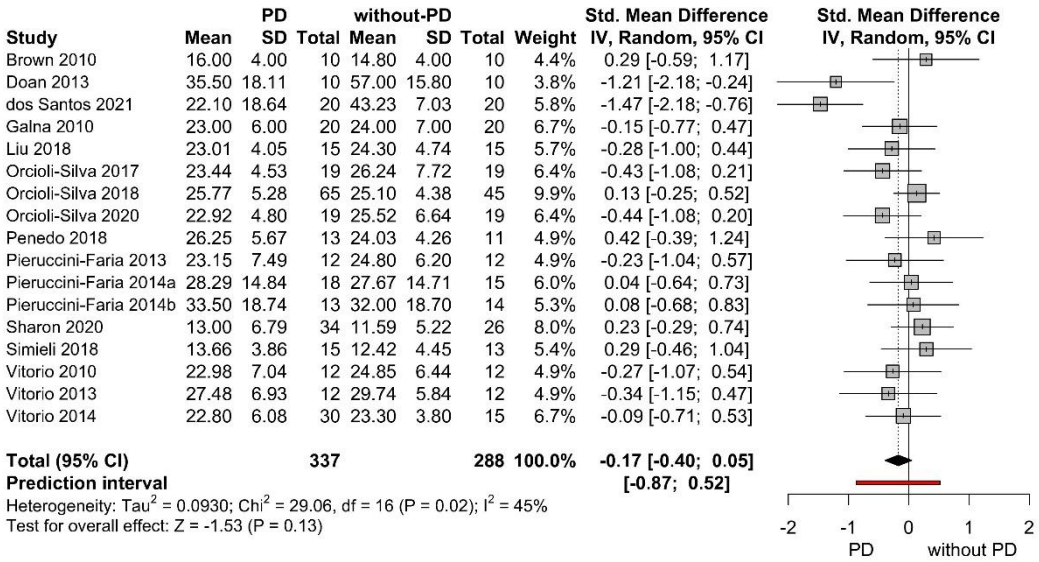


Figure S.1: Forest plot of effect sizes (ES) showing the comparison in the trailing foot placement before the obstacle (TFBO) between people with and without Parkinson's disease. The ES was characterized by the standardized mean difference (SMD) and meta-analyzed by a random-effects model with the inverse variance weight.

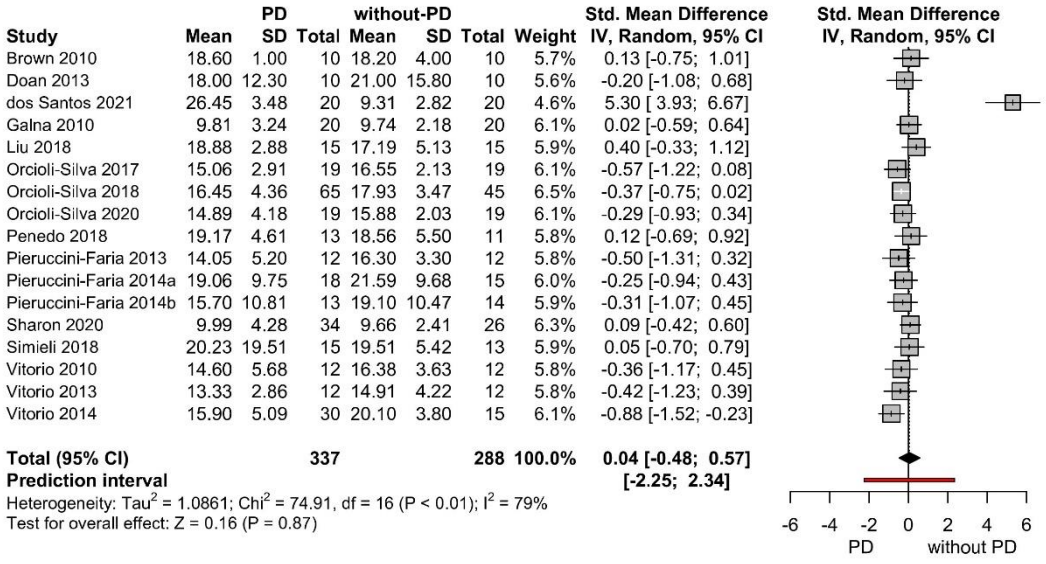


Figure S.2: Forest plot of effect sizes (ES) showing the Leading toe clearance (LTC) comparison between people with and without Parkinson's disease. The ES was characterized by the standardized mean difference (SMD) and meta-analyzed by a random-effects model with the inverse variance weight.

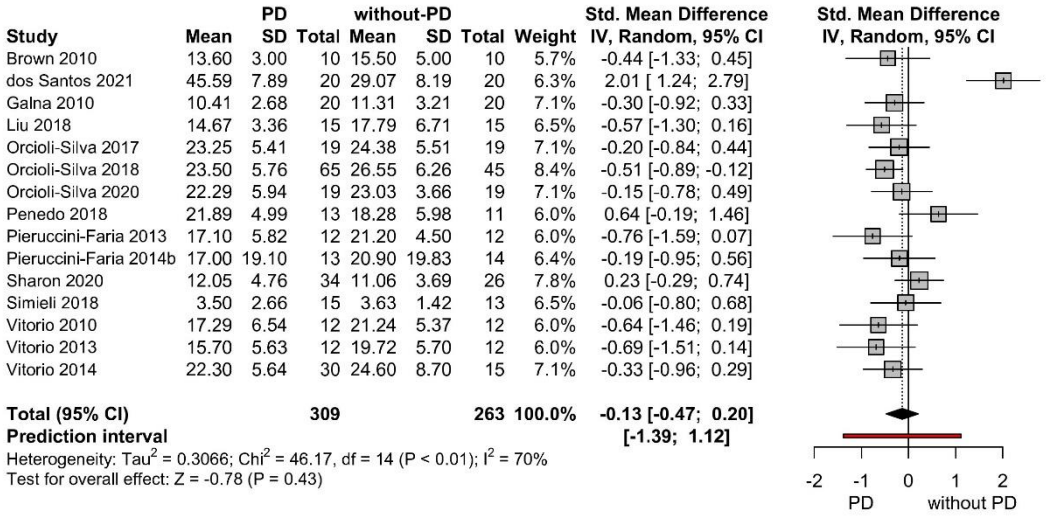


Figure S.3: Forest plot of effect sizes (ES) showing the Trailing toe clearance (TTC) comparison between people with and without Parkinson's disease. The ES was characterized by the standardized mean difference (SMD) and meta-analyzed by a random-effects model with the inverse variance weight.

4 ARTIGO 2

Obstacle crossing and fall risk factors in people with Parkinson's disease trained with high challenging balance: study protocol for a randomized controlled trial

(Artigo a ser submetido ao periódico Gerontology – *Qualis A2, Fator de Impacto 3.5*)

Obstacle crossing and fall risk factors in people with Parkinson's disease trained with high challenging balance: study protocol for a randomized controlled trial.

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Filiation

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Short Title: Obstacle walk and balance training

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Number of Tables: 4

Number of Figures: 2

Keywords: Parkinson's disease, gait, balance, obstacle crossing, risk of fall

Abstract

Background: Crossing obstacles while walking can be a problem for people with Parkinson's disease (PD). Impairments in postural control and the challenges faced during the single-leg stance may lead to a greater risk of tripping and falling. Highly challenging balance (HB) training may be helpful for obstacle-crossing gait because it is based on exercises that address critical postural and balance control components. We hypothesize that enhancing these components will improve spatiotemporal obstacle-crossing gait parameters and fall-related outcomes.

Objective: Describe a twelve-week HiBalance intervention for a randomized controlled trial focusing on improving obstacle-crossing spatiotemporal parameters and fall risk factors in people with PD.

Methods: This is a protocol for a randomized clinical trial. Forty individuals with idiopathic PD diagnosis will be randomly assigned to two groups: (1) HiBalance or (2) gait training. Interventions will take place twice a week for twelve-week. Each session will last 50 minutes. Assessments will be conducted pre, post, and in a six-month follow-up. Primary outcomes will include obstacle-crossing spatiotemporal parameters. Secondary outcomes will include variables related to the risk of falling (i.e., postural balance, muscle strength, muscle power, and fear of falling).

Discussion: This protocol describes a randomized controlled trial in people with PD that proposes to demonstrate that a twelve-week HiBalance training improves the spatiotemporal parameters for crossing obstacles and favors factors related to loss of balance compared to a gait training group, minimizing the risk of falls. The results of this trial will allow us to discuss its usefulness in rehabilitation and prevention programs for people with PD.

Introduction

People with Parkinson's disease (PD) have a reduced ability to adapt or respond to complex scenarios, such as navigating through obstacles while walking. Obstacle walking, mainly when it involves obstacle crossing, can pose a significant challenge for individuals with PD, increasing their susceptibility to tripping or falling [1,2]. PD motor symptoms, such as bradykinesia, rigidity, and postural instability, may limit adequate responses during obstacle crossing, causing greater fear and risk of falling, increasing the individual's disease burden, and impairing the quality of life [3,4]. In a previous review from our research group, we found that people with PD exhibit different spatiotemporal parameters during obstacle crossing than those without PD [5]. Our results showed that people with PD present lower crossing speed, wider step width, and shorter steps when landing after crossing an obstacle. These movement adaptations allow the person to lift the foot high enough to overcome the obstacle and land safely [6]. However, a lower crossing speed may require more time in single-leg support, which, in turn, demands greater postural control, mediolateral stability, muscle strength, and sensory integration [1]. Our review found no differences in foot height during obstacle crossing when we compared people with and without PD. Then, we hypothesize that the risk of tripping and falling may rely more on the foot clearance variability than on the absolute height reached during obstacle crossing. This variability would increase the probability of losing balance and falling [7,8].

Highly challenging balance training, known as HiBalance (HB), is an intervention aimed at specific training in balance and gait performance [9,10]. HB is based on exercises that stimulate the limit of capacity and are progressively planned to target four critical components of postural balance control, according to the principles proposed by Horak [11]. These components are frequently compromised in people with PD, including sensory integration, anticipatory postural adjustments, motor agility, and stability limits [12]. Furthermore, gait disturbances have been related to a lower ability to negotiate gait, control of a double task (motor and cognitive task) and a lower automation of movement in people with PD, showing a greater use of cognitive resources for motor planning, visuomotor capacity, attention capacity and working memory, than healthy people [13]. The use of dual tasks has been frequently incorporated into gait and balance training in people with PD, with the aim of reducing balance deterioration and therefore vulnerability to falls. In this sense, HB uses the principles of motor learning, emphasizing specificity, progressive overload, and exercise variation, incorporating challenging scenarios through multitasking [10]. In people with PD, HB training for 10 to 12 weeks has proven to be more effective than regular physical activity or once-weekly home exercise programs focused on aerobic capacity and strengthening leg muscles, in improving balance control [12,14], walking

speed, step length [12,14], and activities of daily living [12]. Additionally, HB training may reduce the fear of falling [15].

The conditions of the highly challenging and progressive exercises used in HB are designed by altering the base of support, increasing the speed and amplitude of movements, applying different complexities of multitasking (cognitive and motor), and restricting vision to increase difficulty [9]. Implementing these highly demanding strategies targeting balance and gait performance would be suitable to induce a more efficient adaptation in the ability to cross over obstacles. We expect these improvements to benefit spatiotemporal parameters during obstacle crossing, increasing step speed and length, and reducing the variability in the foot clearance height. We hypothesize that HB training will improve postural balance and fear of falling positively. The exercise prescription proposed by HB based on the intensity and difficulty of the exercises would also favor the responsiveness of lower limb muscle strength and power, which is necessary to respond to tripping or body disturbances [16] and that present significant impairment in people with PD [17, 18]. Although the resistance training approach is adequate to increase muscle strength and power, some studies have reported that, in demanding balance training in older people, muscle strength and the rate of force development show neuromuscular gains induced by the progression of this type of training [19,20]. In this sense, HB training would allow a sufficient exercise load to cause neuromuscular gains in people with PD.

Therefore, this protocol describes in detail a twelve-week HB intervention for a future randomized clinical trial. In the future trial, we will verify the effects of this protocol on obstacle-crossing spatiotemporal parameters of people with PD. Secondarily, we will also investigate the effects of treatment on variables related to the risk of falling (i.e., postural balance, muscle strength, muscle power, and fear of falling). We hypothesize that twelve-week training with this HB protocol will be more effective than gait training (i.e., gait training) to improve movement strategies during obstacle crossing (i.e., increase obstacle crossing speed and step length and reduce step width and step height variability). Moreover, HB protocol will be more effective than gait training in improving balance, lower limb muscle strength, and power and reducing the fear of falling.

Methods/Design

Study design

This research project was approved by the Research Committee from Universidad de Talca under number XXXXX, and will be conducted according to the principles of the Declaration of Helsinki. A randomized clinical trial (RCT) will be. The trial registration has been recorded on ClinicalTrials.gov under Protocol ID: XXXX. We followed the SPIRIT guidelines (Standard Protocol Items: Recommendations for Interventional Trials) [21] to report this RCT trial. Additionally, we followed the TIDieR (Template for Intervention Description and Replication) guideline [22] to provide a structured framework for describing the protocol and allow for the replication of our intervention. In the future, we will follow the CONSORT (Consolidated Standards of Reporting Trials) statement when reporting the results of our RCT.

Location and setting

The study will be carried out in two locations. The interventions will be performed in the Kinesiology Clinic, and the results will be measured in the Human Movement Analysis Laboratory, all located at the University of Talca, Chile. People with PD will be recruited through centers in the city where this population participates: the Kinesiology Clinic of the University, community centers for older people, and public health centers.

Participants

People with the following criteria will be included in the study: diagnosis of idiopathic PD using the UK Brain Bank criteria [23], aged 60 years or older, able to walk independently or without technical aids, classified in stage I-III on the scale of Hoehn and Yahr (H&Y) disability and currently undergoing medical supervision of the disease.

Participants will be excluded if they present the following conditions: musculoskeletal or cardiopulmonary diseases that can compromise the study procedures, cognitive impairment determined by the Montreal Cognitive Assessment (MoCA) test with a score <26 points [24], history of surgery or illness recent with contraindication to exercise, significant or uncorrected hearing or vision problems, presence of deep brain stimulation devices, presence a body mass index classified as type 2 or 3 obesity, and habitual consumption of drugs with sedative, anticholinergic or antihypertensive effects, which are related to an increased risk of falls.

Sample size calculation

The sample was calculated by estimating a measure of the effect size of the group*evaluation interaction of Cohen f=0.25 corresponding to a medium effect size according to the intervention results with HiBalance [12, 14]. Considering a significance level of 0.05 and a power of 80% for two groups and pre-post evaluations, 18 participants will be needed in each group. With a 10% loss, 20 participants per group will finally be selected.

Recruitment, randomization, blinding, and treatment allocation

Recruitment will be carried out in the centers mentioned above after coordination and authorization meetings with the directors of each center. In meetings with potential participants, all the information and purposes of the study will be given to attendees. Those interested in participating will read the informed consent for signature. After the informed consent signature, we will administer a self-developed questionnaire to verify the eligibility criteria. The Montreal Cognitive Assessment (MoCA) will be used to determine cognitive impairment, and the Hoehn and Yahr (H&Y) scale will be applied to determine the stage of the disease.

Prior to random assignment, the sample will be proportionally stratified into three strata according to the disability of the PD disease using the H&Y scale (Stage I: unilateral involvement with minimal or functional dysfunction; Stage II: bilateral involvement or medial without balance damage; Stage III: bilateral disease, mild-moderate dysfunction with altered postural reflex and physically independent). Subsequently, random assignment will be carried out by a research assistant external to the project, who will assign random numbers to the selected participants. The randomization list will be done using a 1:1 ratio through computer software (randomizer.org) and will be assigned into six blocks of six or seven participants each. The number of participants will not be restricted in the allocation based on their sex or level of physical activity. In this way, participants will be anonymously assigned to 1) a group trained with HiBalance (HB) or 2) gait training (GT). During this process, the person in charge of the allocation will generate two sealed envelopes, one for each group, which will be opened after the initial evaluation and before starting the intervention. The investigators conducting the study evaluations and the study data analysts will be blinded to this assignment. Therapists working training may not be blinded due to the nature of the study. Participants will be asked to keep information about their intervention private from evaluators. The research assistant will make the appointments for the study evaluations in a single coded list, which will be delivered to the evaluators and data analysts.

Interventions

The choice of comparing the HiBalance vs. gait training interventions in people with PD responds to the fact that both interventions have reported positive effects on functional and clinical parameters in walking [25]. However, there is little information on the effects of HB on the adaptation of walking over obstacles and its relationship with postural balance, strength, and muscle power as risk factors for falls, as well as the comparison between both types of training.

The training of both groups will be carried out in twelve-week programs with 50-minute sessions. Each session of HiBalance or gait training will include a warm-up stage, exercises, and a cool-down phase (see Table 1). The comparative volume between the 2 workouts will be through the duration per session of 50 min. Each session will have a volume of 8 work periods of 5 min (2 sets of 4 repetitions each period) with a total work time of 40 min. The exercise prescription for each training is presented in Table 2. The participant must complete at least 80% of the total planned sessions. The sessions will run in the mornings. It will begin in the ON period of the drug treatment self-reported by the participant (during the first or second hour after taking the medication). At the beginning and end of each session, vital signs will be measured, such as resting heart rate with a heart rate monitor, blood pressure with a sphygmomanometer, and respiratory rate with a stopwatch, and perception of effort with the Borg scale. Signs and symptoms will be consistently monitored throughout the implementation of both protocols, and the exercise will be promptly halted if any participant reports discomfort.

Participants will be asked to maintain their regular medical checkups, any changes in the dosage of their medications will be monitored, and their usual activities during the study will be monitored with a study log sheet. Both groups will not be restricted from other types of physical activity during the twelve-week study period. The participants' exercises and physical activities on non-intervention days will be monitored through a telephone call and recorded on a control sheet. As a strategy to maintain or improve adherence, three actions will be applied: a) monitoring and positive feedback via telephone on days without session (Monday to Friday); b) access to consultations by participants on days without session (Monday to Friday); c) and carry out a recreational activity with each training group at least once a month (non-training day) to strengthen social motivation.

HiBalance training

Training with HiBalance was designed with progressive exercises that demand the four components of balance frequently impaired in people with PD, according to the recommendations of literature [9]. The progression and overload will be defined in 3 blocks that allow adequate programming of the challenging balance stimuli: Block A: its objective is to incorporate the initial performance of each balance component separately and thus achieve familiarity and motor learning specific to each task; Block B: its objective is to improve balance performance by increasing the difficulty and variation of the exercises per balance component, and incorporating multiple tasks (cognitive OR motor); Block C: its objective is to increase the challenge, variation, and complexity of the exercise, through the integration of balance components and greater demand for multiple tasks (cognitive AND motor).

The distribution for a twelve-week training according to the progression blocks is seen in Table 3. Our protocol presents a proposal of exercises for 24 intervention sessions, built with two physiotherapists with experience in neurorehabilitation and according to the principles of specificity, progression, and variation recommended in the literature [9]. The four balance component criteria proposed by HiBalance were used for greater specificity. For exercise variation, as a critical factor in motor learning, exercises that require or provoke postural adjustments in different positions, directions, and speeds were considered. For overload, although the recommendations in HiBalance training propose an individual adjustment of the difficulty levels of each exercise in the training progression, our protocol suggests detailed prior planning of each exercise to achieve the progression blocks according to these recommendations (Table 4).

In this sense, to ensure the achievement of each station, we will include constant and motivating verbal feedback aimed at each objective. HB training will be performed at a progressive training intensity between 60 and 80% of heart rate reserve (HCR) assessed with a heart rate monitor. Additionally, each participant will rate the challenge level of each exercise using a 10-point Likert self-perception scale [15], with 10 being the most significant level of challenge and 1 being no challenge. As the principle of this training is motor learning, there will not be a familiarization of the exercises but rather an education on how the training will develop. Each session will record achievements, difficulties, and adverse events, which the physiotherapists and their assistants will carry out.

The training circuit will consider four stations with 40 minutes of exercise for each session. Each station has a total time of 10 minutes, which includes 2 circuit rotations for each participant. Rest will be in a 2:1 ratio concerning exercise (for example, for every 20 s of exercise, 10 s of rest). Rest will be passive and will mainly be considered deep breathing exercises. If the participant requires more rest, the station schedule will be modified. In addition, the perception of effort will be controlled through the Borg scale (Borg >6-20 Scale) [26].

The HB training programs will be carried out by two physiotherapists with experience in rehabilitating people with PD, assisted by two health assistants who supervise and assist participants in each session. Depending on the degree of complexity and difficulty of the exercises, participants will receive permanent assistance during their execution. All participants will be prepared for each intervention, accompanied, and monitored by the researchers, thus controlling the appearance of adverse events. In the event of adverse events related to the, the plan will be to accompany the participant and interrupt the activity immediately. In addition, the event will be recorded on a tracking form, and the principal investigator will be informed. If necessary, according to the nature of the adverse event, the participant will be oriented and accompanied to attend a medical examination at a health care center. The criterion for suspending interventions will be the participant's request to voluntarily reject or abandon the intervention or evaluations at any time during the study. If a participant presents any health complication during the intervention, they will be excluded from the study for their safety and will be medically assisted.

Gait training

Gait training (GT) will consider a progression to improve step length by systematically repeating walking in different directions and speeds. GT training will be performed at a progressive training intensity between 60 and 80% of heart rate reserve (HRR) and with a perceived effort of 13 to 17, according to the Borg scale. The indicated training intensity will be determined based on the theoretical age-adjusted maximum heart rate and heart rate reserve, as proposed by Karvonen [27]. The progression time defined for HiBalance will be used, so the progression of GT will be in weeks 1 to 3 with an intensity of 60%, weeks 4 to 9 with an intensity of 70%, and weeks 10 to 12 with an intensity of 80% HRR. In this GT, target work will incorporate instructions verbal and visual stimuli from physical therapists to achieve more notable performance in walking mobility, step length, and speed, and changes in pace and direction. GT will be scheduled twice a week

with the same 12-week prescription in 50-minute sessions as the HB group. Each session will be worked on in 2 series of 4 periods of the workstation. A therapist will supervise each session and carry out in a group. Compliance with the GT sessions will be monitored.

Outcome measures

The outcome measures will be performed by two evaluators blinded to the group assignment. The evaluations will be carried out three times: pre-training or baseline (week 0), post-training (week 13), and six-month follow-up. The evaluation times will be carried out on two alternate, non-continuous days to avoid the appearance of fatigue in the participants and with an interval of 48 hours before and after the intervention. The order of the physical tests will be randomized for each day. All demographic, health, and disease status measures in people with PD will be collected in advance. Figure 1 shows the flow chart according to the SPIRIT guidelines [21].
Before the intervention, the evaluation of the motor and non-motor symptoms of the disease recommended for the clinical evaluation and progression of the disease will be carried out using the Unified Parkinson's Disease Rating Scale (UPDRS) following the recommendations of the literature [28]. With the result of the UPDRS scale, the most affected side (highest score) and the least affected (lowest score) will be determined [29].

Primary outcomes

Obstacle crossing: Frequently studied temporospatial parameters of the crossing during walking over obstacles such as trailing foot placement before the obstacle (cm), leading toe clearance (cm), trailing toe clearance (cm), leading foot placement after the obstacle (cm), crossing step width (cm), and crossing speed (cm/s). In addition, we will include the variability of the Height of the foot with the obstacle of the leading and trailing foot through the coefficient of variation (CV=standard deviation/mean x 100).
Walking in a 10 m corridor will be evaluated. The participant must walk barefoot at a comfortable, self-selected speed. Each participant must perform five repetitions of walking without obstacles and five repetitions with an obstacle located 5 m from the start of the runner. Additionally, they must perform five repetitions on the ground without obstacles with a dual task (motor and cognitive) while counting backwards from a 3-digit number by 3 and five repetitions of a double task while walking over the obstacle. The order of the walks will be random. The obstacle will be light material, such as foam, if the participant contacts it. It will be

100 cm wide, 5 cm deep, and 20 cm high (similar to the Height of steps or curbs). An evaluator will accompany the participant for safety during each test and assist them if required. After three attempts prior to the test, the initial position will be adjusted to achieve a comfortable obstacle crossing. The number of crossings will be recorded for the left and right feet; the leading foot will be defined as the first to cross the obstacle, and the trailing foot will be defined as the left behind. For obstacle walking, each participant will be instructed to cross, avoid contact with the obstacle, and continue walking to the end of the corridor. The attempt will be repeated if it contacts the obstacle.

A 3D motion capture system of 8 Optitrack infrared cameras (Naturalpoint, Inc., USA) will record the walk at 100 fps. Nineteen retroreflective markers (Helen Hayes lower limbs model) will be located in the bilateral anterior iliac spine, lower spine, lateral and medial epicondyle of the bilateral femur, bilateral Thigh, bilateral superior knee, bilateral Lateral Fibula Ankle, bilateral Medial Talus Ankle, bilateral Foot Calcaneus and Foot Bilateral 2nd Distal Phalanx. Additionally, two markers will be placed on the obstacle to determine its position during the crossing tests.

Once the lower limb skeleton model is built, walking with and without obstacles will be recorded. The trajectories obtained will be low-pass filtered using a fourth-order Butterworth filter at a cut-off frequency of 6 Hz. The temporospatial parameters of gait will be determined, and the leading and trailing feet will be analyzed. Three strides will be analyzed during each repetition, as done by Penedo et al 2018 [30]. Firstly, an approach phase defined as the complete final stride before the obstacle will be determined, obtaining the length, width, duration, and speed of the stride. In the crossing phase to determine the vertical distance, the second metatarsal marker (2°MTT) will be used, and it will be measured to the top marker of the obstacle; for leading foot placement after the obstacle, the horizontal distance from the 2°MTT to the marker at the base of the obstacle; trailing foot placement before the obstacle, the distance from the calcaneus marker to the marker at the base of the obstacle; crossing step width, the distance perpendicular to the anterior projection of the calcaneal marker between both feet; and crossing speed, as the speed of crossing during the stride of the leading foot. The temporal-spatial parameters will be obtained through a Matlab script to define the primary results.

Secondary outcomes

Postural Balance: The posture with two or a single leg has been correlated with the amplitude and speed of postural balance in posturographic analysis. This correlation enables the balance

problem detection in different populations and measures the improvements in rehabilitation programs.

a) *Two-Leg Stance:* The participant will be placed on a force platform (Bertec, USA) in a bipedal position, barefoot, with heels 15 cm apart and arms at the side of the body. Four conditions of 30 seconds each will be evaluated: eyes open (looking at a point marked in front at 3 meters and at eye level), eyes closed on the platform, and eyes open and closed on a medium-density foam. The participant will be instructed not to move and remain silent during each test. The test will be repeated twice for each participant, and the average will be used to analyze the results. The variables anterioposterior and mediolateral oscillation, average velocity, and 95% ellipse will be calculated from the recorded center of pressure [31].

b) *One-Leg Stance:* Participants will stand barefoot on a force platform on their less affected or dominant leg, with arms crossed over their chest and gaze forward focused on a point on the wall. The participant will be instructed to remain on one leg as long as possible so that the raised foot is close to the ankle but not touching it or resting it on the ground [32]. The time obtained will be recorded with a maximum of 60 seconds, and three repetitions will be requested with 1-minute breaks between each repetition. From the force platform records, the anteroposterior and mediolateral oscillation variables of the center of pressure will be obtained, and the average of the repetitions analyzed will be used.

For the postural balance analysis, a 50 x 43 cm force platform (Balance Bertec, USA) will be used for the analysis with one- or two-leg stance. It will be configured at 100 Hz capture with a recording time of 30 seconds for each test. The platform will be located 2 m away from a wall, and a cross-shaped mark will be placed, which will adjust to the Height of each person's horizontal vision for the open-eye tests. An evaluator will be permanently located next to the participant to assist them if required. The position of the feet will be recorded to reproduce a medium-density foam that will be used in the soft surface tests. In each test, the center of pressure will be registered with the Digital Acquire software (Bertec, USA) and then exported to be analyzed in a script in the Matlab (Mathworks, MA) software. The variables anteroposterior and mediolateral oscillation, average velocity, and 95% ellipse will be calculated from the recorded center of pressure.

Muscle strength and power: Both muscle strength and power are compromised in Parkinson's disease, and it has been reported that balance training can benefit muscle function. Before the strength and power tests, participants will warm up on a stationary bike for 5 minutes at 60 RPM. The objective is to prepare the lower limbs for a performance test and prevent the appearance of fatigue or premature discomfort.

a) *The Five Times Sit-To-Stand (5TSTS)* provides a method to measure muscular power of the lower limbs. With the participant sitting in a standard 43 cm chair and his arms crossed over his chest, he will be instructed to get up and sit down five times in a row as quickly as possible. The response variables will be the time of the test and the calculation of relative muscle power, as proposed by Alcazar et al. 2018 [33]:

$$STS\ mean\ power = \frac{[Body\ mass\ x\ 0.9\ x\ g\ x\ [Height\ x\ 0.5 - Chair\ height]}{Five\ STS\ time\ x\ 0.1}$$

where the STS mean muscle power (W) is the product of STS mean speed (vertical distance traveled by the center of mass (difference between the length of the legs (0.50 height) and the Height of the chair) and force (represented by the total body mass displaced during the test minus the mass of the legs and feet (0.90) multiplied by gravity (g=9.8m/s2) and divided by the mean time taken to complete the 5TSTS test.

b) *Muscle strength and rate of force development:* The maximum voluntary isometric strength of knee extension will be measured in both lower limbs (dominant limb first, [34]). Each participant will sit in a chair with a force transducer connected, with the hip and knee at 90°. Initially, participants will perform submaximal contractions (50%, 70%, 80%, and 90% of their self-perceived maximum intensity) for 3 s. Then, the participant will be instructed to perform a maximum isometric knee extension "as fast and strong as possible" for 3 seconds and verbally motivated in each one. It will be repeated three times for each lower limb. The outcomes of the test will be the maximum strength (MS) obtained from the highest record of the three attempts and the rate of force development (RFD) obtained from the force/time relationship in the first 50, 100, and 200 ms of the record of strength, with the average of the three repetitions being the representative value of each RFD [35].

For maximum force and rate of force development (RFD), an "S"-shaped force transducer (Load Cell −500 lb. Sensortronics, USA) attached perpendicularly to a chair will be used. The other end will be connected to the participant's ankle. The transducer will be configured at 500 Hz capture and communicated with the IgorPro V6.1 software (WaveMetrics, Inc. US) to record and store each test. The force signal will be filtered and smoothed with a 20 Hz low-pass filter, and its offset will be corrected. The maximum force of each record will be determined from a 2-second plateau, and the best record will be considered the maximum strength.

Each recorded force signal will be analyzed for the rate of force development (RFD). The maximum force value will be used to normalize the RDF. The RFD (Force/time) will be obtained in the first 200 ms of the record, and three intervals will be established: 0 to 50 ms, 0 to 100 ms, and 0 to 200 ms. The onset of the force will be considered when the force exceeds 3SD of the rest signal in considering the average value of the RFD of each time interval [36].

Fall risk: Fear or concern of falling, determined through the Short Falls Efficacy Scale-International instrument, is common in people with Parkinson's disease (PD) and is associated with an increased risk of falls [37].

a) *Short FES-I:* Short Falls Efficacy Scale-International instrument that measures fear or concerns about falling. It consists of 7 questions oriented towards the concern of falls in different daily life activities. It has a score that ranges from 7 (no concern about falling) to a maximum of 28 (severe concern). The score will allow classification into three states according to Delbaere et al. 2010 [38]: Low concern (7-8 points), Moderate concern (9-13 points), and High concern (14-28 points).

Other outcomes

a) *Functional mobility:* Functional mobility determined with the instrumented Timed Up and Go (iTUG) has been related to the probability of falling [39]. The participant sitting in a standard chair leaning against the wall will be instructed to get up without arm support, walk to a marker located 3 meters away, and walk around until sitting down again. The time in seconds of each of the test phases will be recorded. An inertial measurement unit (G-sensor- BTS, Italy) will be located at lumbar Height fixed with an

elastic belt, configured with a capture frequency of 1000 Hz, and communicated via wireless with a personal computer. A predetermined program (G-study- BTS, Italy) will store and analyze each test. The measures that will be analyzed will be the total time of the test, the partial time of each phase of the test (standing, walking forward, turning, walking back, and sitting), and the acceleration when standing.

b) *IPAQ-SF:* The International Physical Activity Questionnaire - Short Form (IPAQ-SF) is recommended to evaluate the level of physical activity. This 9-item instrument records self-reported activity at four levels of intensity: 1) vigorous-intensity activity such as aerobics, 2) moderate-intensity activity such as leisure cycling, 3) walking, and 4) sitting. Information recommendations will be used according to the "remembering of the last 7 days".

Participant data, such as recruitment screening data for initial and final evaluations, will be stored and encrypted on a personal computer with password-restricted access to the principal and secondary researchers. The printed informed consent documents, as well as the adherence control records, will be archived and labeled with a code to be stored safely in a single personal office of the principal investigator. For the analysis data, an identifying code will be used for the confidentiality of the participants.

Six-month follow-up

A follow-up will be carried out six months after completing the training. The occurrence of falls and near falls in that period will be evaluated in a structured interview via telephone, and the Short Falls Efficacy Scale-International instrument will be applied again. For the telephone interview, a fall will be defined as an event that resulted in the individual inadvertently stopping on the floor or at a lower level, not due to a significant intrinsic event (e.g., seizure, stroke, or loss of consciousness) or danger (e.g., suffering a violent blow). In the telephone interview, the evaluator will ask: Did you fall in the last six months? If yes, how many times? How did this fall occurred? Are you afraid of falling? On a scale of 0-10, where 0 is no fear at all and 10 is extreme fear, how do you classify your fear of falling? Do you think you can fall in the next few months? Did you stop doing something, or are you avoiding activities for fear of falling? All responses will

be recorded on a form. The level of physical activity (type, frequency, duration, and intensity) will be recorded.

Statistical analysis

Descriptive data analysis and tabulation will be carried out for all variables in both groups. The normality distribution for each continuous variable will be checked using the Shapiro-Wilk test and Levene's test of homogeneity of variance. Baseline data will be compared between groups with independent tests. To determine the effects of training on the outcome measures, a repeated measure analysis of variance will be applied, with time factors (before, after training, and follow-up) and group (HB and GT). If significant main effects are obtained, a Bonferroni post hoc test will be applied for comparisons. To estimate the effect size, partial eta squared (represented as η^2) will be used. Values of $\eta^2 = 0.01$ indicate a small effect, $\eta^2 = 0.06$ indicates a medium effect, and $\eta^2 = 0.14$ indicates a large effect [40]. The relative increases or decreases of the variables will be determined through the deltas obtained from each variable (Post value-Pre value/Pre value x 100).

To estimate the relationship between the temporal-spatial parameters of walking over obstacles with the outcomes of balance, strength, muscular power, and FES-I, a bivariate correlation test will be applied, and then a multiple regression analysis.

A regression imputation method will be used to treat missing longitudinal data (missing data). The statistical package SPSS version 25 (Chicago, IL, USA) and Graphpad Prism version 8 (San Diego, CA, USA) will be used for the analyses and graphs. All results will be considered statistically significant with a p-value <0.05.

Discussion/Conclusion

The impairment of gait and balance in people with PD limits adaptive responses during walking in challenging environments, such as obstacle crossing. Although falls in people with PD are multifactorial, poor postural control, together with the other motor symptoms they present, would increase the probability of falling during obstacle crossing [2]. Our proposed hypothesis is that improving the performance of spatiotemporal parameters during the crossing, specifically increasing crossing speed and step length and reducing step height variability, would improve the movement strategy during the crossing, minimizing the risk of losing balance. To achieve this improvement, we propose to apply training that uses different components of postural control

affected in people with PD, such as highly challenging balance training (HiBalance), which allows applying specific stimuli for specific balance and walk performance problems [9].

Exercise and physical activity have shown benefits on gait alterations in people with PD [41]. However, it is still debated whether the characteristics of the exercises would be adequate to stimulate balance control abilities and gait performance and maintain these benefits when interrupting or discontinuing the exercises [42]. For this reason, we propose to carry out a clinical trial with HB training, which is designed with principles of motor learning, by applying highly challenging, progressive, and variable exercises, which would allow sufficient stimulation to adapt postural control and, therefore improve the performance of the spatiotemporal parameters of gait when crossing obstacles. Furthermore, the early loss of muscle strength and power and functional mobility in people with PD are essential factors in postural control to achieve a timely response to a disturbance or recover stability when losing balance [16]. The exercise prescription in HB, which recommends using the progressive difficulty of the 4-component balance exercises as stability limits, anticipated postural adjustments, sensory integration, and motor agility, would improve the performance of the lower limb muscles in the participants, providing more motor resources to minimize the loss of balance and, therefore, generate less fear of falling when walking over obstacles.

As possible limitations of this study protocol, we found that people with PD present differences in the severity of the disease, which may present little motor commitment compared to tests in the early stages, underestimating the results. To mitigate this, we will perform a proportional stratification for both groups according to the severity stage of the H&Y scale. Likewise, we will monitor the medical control of the participants during the intervention and identify any modification in medical treatment during the study period. Furthermore, for future results, it will be planned to apply a compilation of walking with dual tasks (motor + cognitive) to improve the understanding of motor deficits in this type of intervention.

To our knowledge, this is the first study to investigate the effects of HB when walking over obstacles and its effects on fall risk factors that are compromised by the disease, such as balance ability, strength, muscle power, and the fear of falling. The data obtained from this protocol will allow for better guidance and decision-making in the prescription of HB training, as well as in the outcome measures selected to quantify the objectives of the intervention. The results of this study will allow this modality to be considered a potential form of intervention that integrates different clinical benefits in rehabilitation and prevention programs by health professionals who participate with people with PD.

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Figure 1: Study design randomized clinical trial

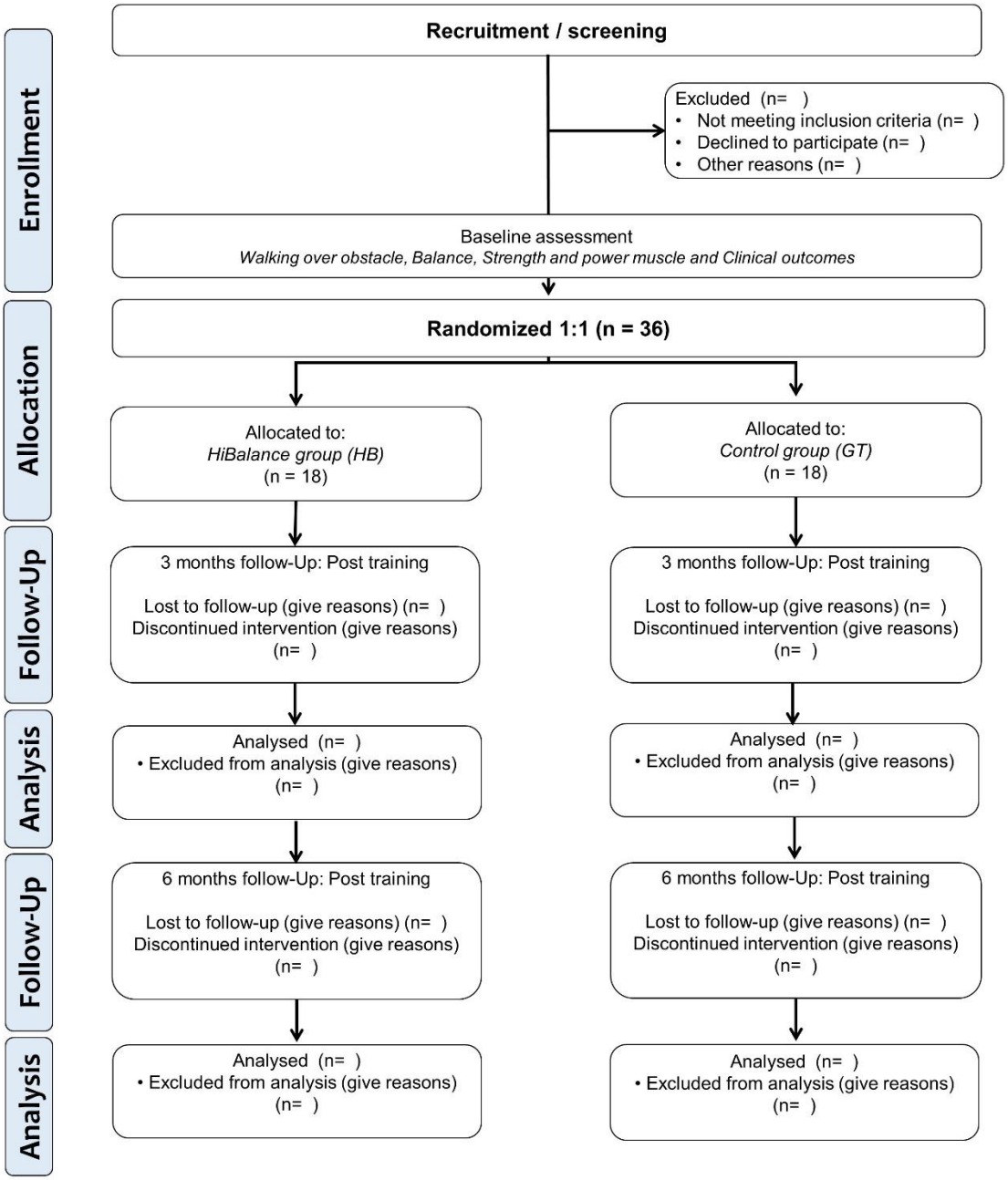

Table 1. Parts of each training session

Session	***Time***	***Exercise***
Warm-up	5’	In a group, 2 series of 10 repetitions of wide joint movement exercises will be performed in the main joints of the lower and upper limbs, in different axes of movement, in a standing position and with the possibility of resting on a chair for safety. Likewise, 2 series of 10 repetitions of global trunk mobility exercises will be performed. It will end with 2 series of 8 seconds each of muscle stretching exercises for the main muscles of the upper and lower limbs.
Training	40’	HiBalance: Progressive balance exercises in circuit and according to balance components. Gait Training: Gait training at a training intensity between 60 and 80% of heart rate reserve.
Cool down	5’	Two series of slow walking exercises will be performed combined with 10 repetitions of breathing exercises. Then 2 sets of 10 seconds of stretching exercises combined with breathing and finally, 2 sets of 10 repetitions of breathing exercises and slow mobility of the upper and lower limbs.

Table 2: Training programs prescription

Prescription	***HiBalance***	***Gait Training***
Design	Circuit training per group of 6 to 8 people	Training per group of 6 to 8 people
Workstation	4	1
Duration	three months	three months
Frequency	2 alternate days of the week (not including Saturday and Sunday)	2 alternate days of the week (not including Saturday and Sunday)
Progression	According to the recommendations for training with HB [15], the progression will be structured in Three Blocks = Block A: 3 weeks; Block B: 6 weeks; Block C: 3 weeks.	The workouts will begin with 3' rest intervals, and the physiotherapist will adjust these intervals until continuous walking is achieved.
Session	24 sessions in total. Each 50-minute session organized into warm-up (5'), balance exercises (40') and cool-down (5')	24 sessions in total. Each 50-minute session organized into warm-up (5'), balance exercises (40') and cool-down (5')
Volume	Each session will have a volume of 8 physical work periods of 5 min (2 series of 4 repetitions each period) with a total work time of 40 min.	Each session will have a volume of 8 physical work periods of 5 min (2 series of 4 repetitions each period) with a total work time of 40 min.
Intensity or overload	Block A: separate exercises for each balance component; Block B: exercises for each component of balance + basic dual-task (DT) exercises; Block C: combined exercises of the balance components + increased demands of the DT exercises. The exercises started from a more stable position such as sitting or standing, then walking exercises progressing according to each block. The perception of effort will be controlled through the Borg scale, which should not exceed 17 points. Additionally, HB training will be performed at a progressive training intensity between 60 and 80% of the heart rate reserve (HCR) assessed with a heart rate monitor.	Gait Training groups will use a training intensity between 60 to 80% of reserve heart rate and a perceived effort of 13 to 17, according to the Borg scale. The indicated training intensity will be determined according to the theoretical maximum heart rate adjusted to age and the reserve heart rate, as proposed by Karvonen [27].

Table 3. Training progression program with HiBalance. The components of the balance are shown and organized by blocks for a 12-week progression.

Block	Weeks	Balance Components	Task
A	1	Stability limits - Motor agility	Single
	2	Stability limits - Motor agility	Single
	3	Anticipatory postural adjustments - Sensory integration	Single
B	4	Stability limits - Motor agility	DT cognitive
	5	Stability limits - Motor agility	DT cognitive
		Anticipatory postural adjustments - Sensory integration	DT motor
	6	Anticipatory postural adjustments - Sensory integration	DT motor
	7	Stability limits - Motor agility	DT cognitive
	8	Stability limits - Motor agility	DT cognitive
		Anticipatory postural adjustments - Sensory integration	DT motor
	9	Anticipatory postural adjustments - Sensory integration	DT motor
C	10	Stability limits - Motor agility - Anticipatory postural adjustments - Sensory integration	DT cognitive + motor
	11	Stability limits - Motor agility - Anticipatory postural adjustments - Sensory integration	DT cognitive + motor
	12	Stability limits - Motor agility - Anticipatory postural adjustments - Sensory integration	DT cognitive + motor

Abbreviation, DT: dual task

Table 4. Detail of the HiBalance training proposal. Each session will be worked on: 5' each workstation (20'' each exercise x 10'' rest and repeat until the time is complete) 2 laps of the circuit. The sessions of the last week (week 12) will work on only 2 stations with 10' each station, 2 laps of the circuit.

Block	Week/Session	Balance component	Workstation	Exercises
A	1/1	MA	W-1	Sitting simulate running with the feet Sitting, raise your arms widely and alternately
		SL	W-2	Standing with feet together, arms abducted at shoulder height, take foot forward, side, back, other side, trying to reach the furthest point and always returning to the center Change reach leg and repeat
		MA	W-3	Sitting, raise your knee to your chest and opposite arm, imitating walking with a wide movement and speed. Repeat
		SL	W-4	Stand with feet together with arms raised above your head. Move foot forward, side and back. The participant must coordinate bringing the arms to shoulder height when the foot makes a reach and bring them together when the foot returns to the center. Change reach leg and repeat
	1/2	MA	W-1	Sitting, raise your knee to your chest and opposite arm, imitating walking with a wide movement and speed. Repeat
		SL	W-2	Standing with feet together, arms abducted at shoulder height, bring foot from the center drawing a large crescent on the floor. Change reach leg and repeat
		MA	W-3	Standing with feet together, alternately raise one arm and then the other, fully extended above the head, favoring the range of movement with the trunk erect. Standing with feet together, alternately raise one knee to hip height and then the other alternately. It must accompany wide movement of the contralateral arm.
		SL	W-4	Standing with feet together, raise both arms in front of you trying to reach without taking your feet off, then bring your arms back in the same way.

			Standing with feet together, raise both arms in front of you, trying to reach by raising your heels, but avoiding taking the step. Then arms backwards, raising the front part of the foot, avoiding taking a step backwards.
2/3	MA	W-1	Walk forward, raising the opposite leg and arm widely. It must cross 10 lines on the floor with continuous walking. Walk backwards, emphasizing range and coordination of movement
	SL	W-2	Standing with feet together, raise both arms in front of you trying to reach without taking your feet off, then bring your arms back in the same way. Standing with feet together, raise both arms in front of you, trying to reach by raising your heels, but avoiding taking the step. Then arms backwards, raising the front part of the foot, avoiding taking a step backwards.
	MA	W-3	Walk forward, raising the opposite leg and arm widely. It must pass 5 hoops located in a line on the floor with continuous movement. Maintain rhythm during execution. Walk to the side, step by step, overcome 5 hoops located in a line on the floor, avoiding touching it.
	SL	W-4	Standing with feet together, raise the opposite arm and leg in a diagonal direction as wide as possible and alternately. Standing with feet together, raise your arm to the side at shoulder height and try to reach as far as possible to the same side, without taking your feet off. Return to the center and repeat with the other side.
2/4	SI	W-1	Multidirectional Walking: 5 steps forward, 5 steps back, 3 steps to the right, 3 steps to the left. Repeat with eyes closed (A) Repeat on tiptoe (A)
	APA	W-2	Walk forward with alternating long steps (10 each leg). Repeat raising and lowering both arms. Repeat with movement to the sides
	SI	W-3	Military walk on an unstable surface (mat) and then repeat walking with heels Walk on tiptoe on unstable surface and then repeat with tandem walking
	APA	W-4	Stand and sit 10 repetitions with hands crossed on the chest and then repeat with hands resting on the lower back

			Leaning on a chair, alternately touch one knee to the floor and return to a standing position 10 repetitions (or as low as you can).
3/5	SI	W-1	Standing, raise and lower your front step alternately (20 repetitions). Repeat with lateral step (10 repetitions per side) Repeat work with step backwards (20 repetitions)
	APA	W-2	Standing, take long steps backwards with the contralateral arm flexed (10 repetitions per side). Then repeat with ipsilateral arm in flexion (10 repetitions per side). Standing, perform front kicks alternately (10 repetitions per side) and then repeat with side kicks (10 repetitions per side)
	SI	W-3	On a low balance beam, walk forward and then back again (A) Walk with a tandem gait and return backwards (3 meters). Then, repeat with right eye closed and then with left eye closed (A)
	APA	W-4	Stand up from a chair and look back on the right side, when sitting down, touch the floor with your hands (10 repetitions). Repeat on the other side. Sitting with arms crossed and elbows resting on your knees, you must get up from the chair (10 repetitions)
3/6	SI	W-1	Standing, raise and lower your front step alternately (20 repetitions). Repeat with lateral step (10 repetitions per side) Repeat work with step backwards (20 repetitions)
	APA	W-2	Perform 5 jumps (or step as high and long as possible). Then repeat with momentum of the arms. Perform 5 jumps forward and then jump back (A)
	SI	W-3	Walk in tandem on an unstable surface and go back (3 meters). Then walk on a 3 meter line on tiptoe and go back. Walk with a tandem gait on an unstable surface with the right eye closed and return backwards (3 meters). Then, repeat with left eye closed.
	APA	W-4	Sitting on an unstable surface, carry a ball back and forth (10 repetitions). Then raise your feet alternately (10 repetitions) When standing, you must look behind you and sit down carefully (10 repetitions). Then repeat with the other side.

B	4/7	MA	W-1	MT: Walk forward, raising the contralateral leg and arm widely. Cross 10 lines on the floor that allow continuous walking. CT: when walking mention numbers 1-15 backwards. Return to start with reverse without cognitive task
		SL	W-2	MT: standing, bring both arms forward trying to reach, avoiding taking off your feet. Then bring your arms back, avoiding taking off your feet. CT: during the exercise subtract the number 15 from 2 by 2 Standing with feet together, raise heels and both arms in front of you trying to reach without taking a step. Then repeat backwards.
		MA	W-3	MT: Walk, lifting the contralateral arm and leg widely on 5 rings located in a line on the floor. CT: during the exercise mention the alphabet backwards (from z backwards) Walk to the side, step by step, overcome 5 hoops located in a line on the floor, avoiding touching it. Maintain rhythm during execution.
		SL	W-4	MT: Standing with feet together, raise the contralateral arm and leg diagonally trying to reach as much as you can. CT: during the exercise subtract the number 15 from 3 by 3 Standing with feet together, raise your arm to the side at shoulder height and try to reach as far as possible to the same side, without taking your feet off. Return to the center and repeat with the other side.
	4/8	MA	W-1	MT: standing next to hoops placed in a row on the floor, enter the hoop with one leg and then the other, leave the hoop in the same way and repeat until completing 5 hoops, maintaining the rhythm. CT: during the exercise you must mention words that start with A Repeat previous sequence with reverse gear.
		SL	W-2	MT: standing with feet together and a ball in your hands, bring both arms forward trying to reach without taking your feet off, bounce the ball and catch it. Then repeat backwards, avoiding taking your feet off. CT: during the exercise you must mention the alphabet backwards every time you bounce the ball. Standing with feet together, you must raise both heels, bringing both arms in front of you and you must bounce a ball. Then you must bring your arms back, raising the ball of your foot, avoiding taking a step backwards. Repeat.
		MA	W-3	MT: Standing in front of an agility ladder, walk back and forth step by step, as fast as you can CT: during the exercise you must mention words with E Tandem march on a line marked on the floor

	SL	W-4	MT: In pairs located 3 meters from the partner and in a tandem position, you must throw and receive a ball with the partner CT: during the exercise you must subtract the number 15 two by two
5/9	MA	W-1	MT: Standing in front of an agility ladder, walk laterally step by step, as fast as you can CT: during the exercise you must mention words with I Walking in tandem on a line marked on the floor
	SL	W-2	MT: In pairs, located 3 meters from your partner, perform a tandem march forward, throwing and receiving a ball with your partner. Repeat with reverse gear. CT: during the exercise you must subtract from the number 99 two by two
	MA	W-3	MT: standing in front of 5 hoops located in a row on the floor and with a ball in your hands, perform a forward march, bouncing the hoop without touching the hoops, as quickly as possible. CT: during the exercise you must mention words with O
	SL	W-4	MT: In pairs located 3 meters from the partner, in a tandem position and with a weight in both hands (2 kg). You should raise each dumbbell as instructed by your partner. CT: The partner will have a red sheet in one hand and a blue one in the other. He will randomly show one color or another to the partner. Make change after 2.5 min.
5/10	SI	W-1	Go up and down from the front with a step alternately while throwing and receiving a ball Walk around the entire circuit driving a ball with your feet
	APA	W-2	Long steps forward and back alternating leg while holding a tray with a ball Long steps back and forth alternating leg while holding a tray with a ball
	SI	W-3	Walk in tandem on a 3 m unstable surface while holding a tray with a ball. Walk on tiptoe on a 3 m unstable surface while holding a tray with a ball and walk backwards.
	APA	W-4	Stand and sit while holding weight in both hands (10 repetitions) Stand and sit while holding weight in right hand (10 repetitions) and then left hand (10 repetitions)
6/11	SI	W-1	Go up and down from the front with a step alternately while maintaining a layup with a ball (20 repetitions). Then repeat with lateral steps (10 repetitions per side). Alternately step up and down backwards while maintaining a layup with a ball (20 times).
	APA	W-2	Long steps forward and back alternating leg while throwing and receiving a ball Long steps back and back alternating legs while throwing and receiving a ball

	SI	W-3	Lateral walking on a low balance beam while throwing and receiving a ball Walk with a tandem gait and walk backwards (3 meters) while throwing and receiving a ball
	APA	W-4	Stand and sit while holding a tray with a ball (10 repetitions) Stand, take a step, come back and sit while holding a tray with a ball (10 repetitions). Repeat with the other leg
6/12	SI	W-1	Go up and down from the front with a step alternately while maintaining a layup with a ball (20 repetitions). Then repeat with lateral steps (10 repetitions per side). Alternately step up and down backwards while maintaining a layup with a ball (20 repetitions).
	APA	W-2	Long steps forward and back alternating leg while throwing and receiving a ball Long steps back and back alternating legs while throwing and receiving a ball
	SI	W-3	Lateral walking on a low balance beam while throwing and receiving a ball Walk with a tandem gait and walk backwards (3 meters) while throwing and receiving a ball
	APA	W-4	Stand and sit while holding a tray with a ball (10 repetitions) Stand, take a step, come back and sit while holding a tray with a ball (10 repetitions). Repeat with the other leg
7/13	MA	W-1	MT: standing in front of an agility ladder, walk forward-forward and then back-back, as fast as you can CT: during the exercise you must add 3 by 3 from the number 2 Walk over small and large obstacles interspersed without stopping and without CT
	SL	W-2	MT: In pairs located 3 meters from the partner, in a tandem position and with a weight in both hands (2 kg). He must raise each dumbbell according to the partner's instruction. CT: The partner will have a red sheet in one hand and a blue one in the other. He will randomly show one color or another to the partner. Make change after 2.5 min.
	MA	W-3	MT: walking over small obstacles forward while throwing and receiving a ball. CT: Before the walk you should look at a sequence of geometric figures and remember them. At the end of the walk, you must stand in front of a series of geometric figures placed on the floor. You must step with your feet on the sequence of figures according to what was presented at the beginning of the station.
	SL	W-4	MT: lateral walking on low height balance beam CT: during the exercise you must spell your name backwards

			Tandem walk backwards on a line marked on the floor
7/14	MA	W-1	MT: lateral walking on low balance beam while throwing and receiving a ball CT: during the exercise you must mention the alphabet backwards Walking around cones driving a ball with your feet
	SL	W-2	MT: walking forward with arms abducted at shoulder height on low balance beam CT: during the exercise you must mention your identity number backwards Walk with arms crossed over the chest. It stops at each cone to raise the leg to hip height and maintains it for 5 s, moving forward and changing the leg at the next cone.
	MA	W-3	MT: walk with dumbbells in your hands on rings arranged in a zig-zag pattern, advancing diagonally step by step and simultaneously abducting both shoulders. CT: during the exercise you must mention the ingredients of the food you consumed the previous day
	SL	W-4	MT: Stand, walk in tandem with arms crossed on chest on unstable surface, then climb onto a Swiss ball and hold. CT: while remaining on the Swiss ball you must count from the number 15 backwards by 3. Go down once you finish counting.
8/15	MA	W-1	MT: walk with dumbbells in your hands (2 kg) on hoops arranged in a zig-zag pattern, advancing diagonally step by step and bending both shoulders overhead simultaneously. CT: during the exercise you must mention as many words as possible that begin with C Walking around cones driving a ball with your feet
	SL	W-2	TM: tandem walking backwards with arms crossed on the chest on a low balance beam. With each step you must take off one foot from the beam, draw a large crescent in the air and lean back in tandem. CT: during the exercise you must mention trios of rhyming words without repeating Walk with arms crossed over the chest. Stop at each cone to raise leg to hip height and hold for 5 s. advance and in the next cone change the leg
	MA	W-3	TM: standing in front of an agility ladder, advance with small alternating jumps (scissors). CT: prior to the exercise, show him an image with objects. During the exercise you should mention the objects that you remember from the image.
	SL	W-4	MT: Stand, walk in tandem with arms crossed at the chest on an unstable surface, then climb onto a Swiss ball and throw a ball to a marked point in front of the wall. CT: while remaining on the Swiss ball you must count from the number 15 backwards by 3. Go down once you finish counting.

8/16	SI	W-1	Go up and down from the front with a step alternately while throwing and receiving a ball Walk around the entire circuit driving a ball with your feet
	APA	W-2	Long steps forward and back alternating leg while holding a tray with a ball Long steps back and forth alternating leg while holding a tray with a ball
	SI	W-3	Walk in tandem on a 3 m unstable surface while holding a tray with a ball. Walk on tiptoe on a 3 m unstable surface while holding a tray with a ball and walk backwards.
	APA	W-4	Stand and sit while holding weight in both hands (10 repetitions) Stand and sit while holding weight in right hand (10 repetitions) and then left hand (10 repetitions)
9/17	SI	W-1	Go up and down from the front with a step alternately while maintaining a layup with a ball (20 repetitions). Then repeat with lateral steps (10 repetitions per side). Alternately step up and down backwards while maintaining a layup with a ball (20 repetitions).
	APA	W-2	Long steps forward and back alternating leg while throwing and receiving a ball Long steps back and back alternating legs while throwing and receiving a ball
	SI	W-3	Lateral walking on a low balance beam while throwing and receiving a ball Walk in tandem and walk backwards (3 meters) while throwing and receiving a ball
	APA	W-4	Stand and sit while holding a tray with a ball (10 repetitions) Stand, take a step, come back and sit while holding a tray with a ball (10 repetitions). Repeat with the other leg
9/18	SI	W-1	Go up and down from the front with a step alternately while maintaining a layup with a ball (20 repetitions). Then repeat with lateral steps (10 repetitions per side). Alternately step up and down backwards while maintaining a layup with a ball (20 repetitions).
	APA	W-2	Long steps forward and back alternating leg while throwing and receiving a ball Long steps back and back alternating legs while throwing and receiving a ball
	SI	W-3	Lateral walking on a low balance beam while throwing and receiving a ball Walk with a tandem gait and walk backwards (3 meters) while throwing and receiving a ball
	APA	W-4	Stand and sit while holding a tray with a ball (10 repetitions)

				Stand, take a step, come back and sit while holding a tray with a ball (10 repetitions). Repeat with the other leg
C	10/19	MA	W-1	MT: stand, step over an obstacle, walk on an agility ladder with steps inside and outside the ladder, while carrying a tray with a ball without it falling. CT: during the exercise you must say out loud your identity number backwards
		SL	W-2	MT: Lateral walking on a low balance beam while throwing and receiving a ball with a basket. CT: during the exercise you must mention out loud words that begin with the letter C
		SI	W-3	MT: Walk in tandem on an unstable surface (mat) with your eyes closed and passing a ball from front to back while rolling your waist. CT: during the exercise you must add the number 8 by 3
		APA	W-4	MT: standing on a Swiss ball, you must throw a ball to a mark located in front of the wall and receive the ball (5 times) CT: during the exercise you must mention words that begin with the letter A
	10/20	MA	W-1	MT: standing in front of an agility ladder, walk with a forward-forward and then back-back step, as fast as you can and jumping a square, while passing a ball back and forth by rolling your waist. CT: during the exercise you must subtract 3 by 3 from the number 15
		SL	W-2	TM: walk forward on a low balance beam with knees raised to hip height, while transferring ping-pong balls between 2 cups. CT: during the exercise you must words that begin with the letter E
		SI	W-3	MT: Walking in tandem backwards on unstable surface (mat) with eyes closed while fastening buttons (A) CT: during the exercise you will be told a sequence of numbers that you must repeat in the same order.
		APA	W-4	MT: Walking over the center of hoops randomly placed on the ground quickly while throwing and receiving a ball from close range. CT: during the exercise you must mention words that begin with the letter D
	11/21	MA	W-1	MT: Walk around cones driving a ball with your feet. Then, he passes over obstacles of different heights located on the ground, while fastening and unfastening clothes. CT: during the exercise you must add 3 by 3 starting with the number 2
		SL	W-2	MT: Walk forward in tandem on a low balance beam, then cross an obstacle, then climb onto a Swiss ball and balance on one foot, while inserting coins into a piggy bank. CT: while remaining on the Swiss ball you must add up the inserted coins.
		SI	W-3	MT: standing with feet together on a trampoline, take one step forward and one step back with eyes open and then repeat with eyes closed. CT: during the exercise you must mention words that begin with the letter F

	APA	W-4	MT: walk on randomly demarcated colored lines on the floor according to instructions of the color to follow given by the handler, while receiving a ball in a basket in his hands.
11/22	MA + SL	W-1	MT: Walk through an obstacle course, then balance beam laterally and finish with a tandem walk, while carrying a tray with a ball. CT: During the exercise you must name as many kitchen appliances as possible.
	SI + APA	W-2	TM: stand and sit 10 repetitions, then walk forward with long steps, and then touch marks on the floor with your feet in a zig-zag pattern, while carrying a glass of water. CT: during the exercise you must name as many words as possible that begin with the letter M.
12/23	MA + SL	W-1	MT: stand and sit 10 repetitions, then walk forward on balance beam, then cross obstacles, then perform forward jumps, then walk in tandem, then touch marks on the floor with your feet in a zig-zag shape, and at the end perform 5 jumps in place. While performing the exercises, you must throw and receive a ball and in the walking phases you must drive a ball with your feet Then while doing the exercises, you should carry a tray with a plastic cup.
	SI + APA	W-2	MT: stand and sit 10 times, then walk forward on balance beam, then cross obstacles, then perform forward jumps, then walk in tandem, then touch marks on the floor with your feet in a zig-zag shape, and at the same time final perform 5 jumps in place. CT 1: While doing the exercises, you must memorize and repeat sequence of numbers CT 2: Then while doing the exercises, you must add 6 by 6
12/24	MA + SL	W-1	MT: stand and sit 10 repetitions, then walk forward on balance beam, then cross obstacles, then perform forward jumps, then walk in tandem, then touch marks on the floor with your feet in a zig-zag shape, and at the end perform 5 jumps in place. While performing the exercises, you must throw and receive a ball and in the walking phases you must drive a ball with your feet Then while doing the exercises, you should carry a tray with a plastic cup.

	SI + APA	W-2	MT: stand and sit 10 repetitions, then walk forward on balance beam, then cross obstacles, then perform forward jumps, then walk in tandem, then touch marks on the floor with your feet in a zig-zag shape, and at the same time final perform 5 jumps in place. CT 1: While doing the exercises, you must memorize and repeat sequence of numbers CT 2: Then while doing the exercises, you must add 6 by 6

(A): Assisted; MA: Motor agility; SL: Stability limits; SI: Sensory integration; APA: Anticipatory postural adjustments; MT: Motor Task; CT: Cognitive Task

The TIDieR (Template for Intervention Description and Replication) Checklist*:

Information to include when describing an intervention and the location of the information

Item number	Item	Where located **	
		Primary paper (page or appendix number)	Other † (details)
	BRIEF NAME		
1.	Provide the name or a phrase that describes the intervention.	___1, 3_____	_____
	WHY		
2.	Describe any rationale, theory, or goal of the elements essential to the intervention.	____4-5_____	_____
	WHAT		
3.	Materials: Describe any physical or informational materials used in the intervention, including those provided to participants or used in intervention delivery or in training of intervention providers. Provide information on where the materials can be accessed (e.g. online appendix, URL).	Table 1, 3 and 4	Conradsson D, Löfgren N, Ståhle A, Hagströmer M, Franzén E. A novel conceptual framework for balance training in Parkinson's disease-study protocol for a randomised controlled trial. BMC Neurol. 2012 Sep 27;12:111. doi: 10.1186/1471-2377-12-111. PMID: 23017069; PMCID: PMC3482553._
4.	Procedures: Describe each of the procedures, activities, and/or processes used in the intervention, including any enabling or support activities.	___7-10_____	_____

	WHO PROVIDED		
5.	For each category of intervention provider (e.g. psychologist, nursing assistant), describe their expertise, background and any specific training given.	___7-9_____	_____
	HOW		
6.	Describe the modes of delivery (e.g. face-to-face or by some other mechanism, such as internet or telephone) of the intervention and whether it was provided individually or in a group.	___7-9, Table 2	_____
	WHERE		
7.	Describe the type(s) of location(s) where the intervention occurred, including any necessary infrastructure or relevant features.	___6-7_____	_____
	WHEN and HOW MUCH		
8.	Describe the number of times the intervention was delivered and over what period of time including the number of sessions, their schedule, and their duration, intensity or dose.	__7-10, Table 2, 3 and 4_____	_____
	TAILORING		
9.	If the intervention was planned to be personalised, titrated or adapted, then describe what, why, when, and how.	___7-10, Table 4	_____
	MODIFICATIONS		
10.‡	If the intervention was modified during the course of the study, describe the changes (what, why, when, and how).	_____N/A_____	_____
	HOW WELL		
11.	Planned: If intervention adherence or fidelity was assessed, describe how and by whom, and if any strategies were used to maintain or improve fidelity, describe them.	_____8_____	_____

12.‡	Actual: If intervention adherence or fidelity was assessed, describe the extent to which the intervention was delivered as planned.	_____N/A____	_____

** **Authors** - use N/A if an item is not applicable for the intervention being described. **Reviewers** – use '?' if information about the element is not reported/not sufficiently reported.

† If the information is not provided in the primary paper, give details of where this information is available. This may include locations such as a published protocol or other published papers (provide citation details) or a website (provide the URL).

‡ If completing the TIDieR checklist for a protocol, these items are not relevant to the protocol and cannot be described until the study is complete.

* We strongly recommend using this checklist in conjunction with the TIDieR guide (see *BMJ* 2014;348:g1687) which contains an explanation and elaboration for each item.

* The focus of TIDieR is on reporting details of the intervention elements (and where relevant, comparison elements) of a study. Other elements and methodological features of studies are covered by other reporting statements and checklists and have not been duplicated as part of the TIDieR checklist. When a **randomised trial** is being reported, the TIDieR checklist should be used in conjunction with the CONSORT statement (see www.consort-statement.org) as an extension of **Item 5 of the CONSORT 2010 Statement.** When a **clinical trial protocol** is being reported, the TIDieR checklist should be used in conjunction with the SPIRIT statement as an extension of **Item 11 of the SPIRIT 2013 Statement** (see www.spirit-statement.org). For alternate study designs, TIDieR can be used in conjunction with the appropriate checklist for that study design (see www.equator-network.org).

5 CONCLUSÃO GERAL

O objetivo desta tese foi analisar a estratégia adaptativa da marcha com obstáculos em pessoas com DP, e fornecer um protocolo para futuro ensaio clínico randomizado de um treinamento de equilíbrio padronizado altamente desafiador. Em relação aos resultados do primeiro estudo, cujo objetivo específico foi comparar os parâmetros espaço-temporais da marcha entre indivíduos com e sem DP ao atravessar obstáculos, podemos concluir que pessoas com DP enfrentam os obstáculos por meio de adaptações motoras, mostrando uma estratégia de movimento mais conservadora com presença de menor comprimento de passo ao pousar após cruzar um obstáculo, menor velocidade de travessia e maior largura de passo. Esses achados fornecem informações sobre o controle motor e a adaptação de pessoas com DP ao cruzar obstáculos durante a caminhada.

Estes resultados permitiram-nos estabelecer uma nova hipótese baseada nas adaptação espaço-temporais apresentadas pelas pessoas com DP. Como mencionado, a estratégia conservadora apresentou menor comprimento do passo em relação ao obstáculo, menor velocidade de travessia e maior largura do passo, o que permitiria altura suficiente para superar a altura do obstáculo. Não obstante, essa estratégia implicaria passar mais tempo em apoio unipodal, o que aumentaria a demanda pelo controle do equilíbrio prejudicado pela doença, podendo aumentar o risco de tropeçar e cair.

Em relação aos resultados do segundo estudo, seu objetivo específico foi descrever detalhadamente uma intervenção *HiBalance* de três meses sobre parâmetros espaço-temporais da marcha com obstáculos e fatores de risco para quedas em pessoas com DP para um futuro ensaio clínico randomizado. Em relação a este protocolo podemos concluir que o ensaio clínico proposto é um dos primeiros estudos a investigar os efeitos do treinamento altamente desafiador ao caminhar sobre obstáculos em pessoas com DP. Também nos permitirá verificar os efeitos nos fatores de risco para quedas que estão comprometidos pela doença, como capacidade de equilíbrio, força e potência muscular e medo de cair. Dado que existe pouca informação sobre o comportamento da força e potência muscular no treino baseado nas

componentes do equilíbrio, esta informação permitirá estabelecer o alcance deste tipo de variáveis nas intervenções em pessoas com DP. Por outro lado, o desenho do treino de HB, embora estabeleça uma diretriz clara para a geração do programa de treino, os tipos de exercícios não são programados ou descritos, o que limita a possibilidade de comparação deste tipo de intervenção. Neste sentido, a nossa proposta estabelece uma série de exercícios previamente descritos que nos permitirão comparar os seus resultados com outros tipos de treino, bem como estabelecer um sistema de ajuste em cada um dos exercícios propostos.

Estamos confiantes de que os resultados desta proposta de ensaio clínico respondem à necessidade de implementar intervenções específicas de equilíbrio e marcha para problemas específicos que requerem a solução da tarefa motora de ultrapassar obstáculos em pessoas com DP. Da mesma forma, a instrumentalização de testes da marcha (sistema optoelétrico), equilíbrio postural (plataforma de força), força e potência muscular (transdutor de força), bem como mobilidade funcional através do *Timed Up and Go* (acelerômetro), para avaliar os efeitos do HB permitirá que obtenhamos dados mais fiáveis e robustos para uma análise adequada dos participantes intervencionados.

Os resultados esperados desta proposta de estudo clínico nos permitirão considerar esta modalidade de formação como uma potencial forma de intervenção que integra diferentes benefícios clínicos em programas de reabilitação e prevenção por parte de profissionais de saúde que participam com pessoas com DP. Com isso, acreditamos que esta tese tem potencial para contribuir com novas informações para melhor orientação e tomada de decisão na prescrição de exercícios, bem como em medidas de resultados relacionados a tarefas motoras deficientes em pessoas com DP.

6 IMPACTOS DO TRABALHO

Os impactos deste trabalho estão relacionados com a relevância da marcha com obstáculos como um cenário desafiador que permite analisar a capacidade de adaptação em pessoas com DP. Este tipo de análise proposta permite ampliar as opções na avaliação da marcha e poder realizar uma transferência clínica relacionada a ambientes de risco de queda. A compreensão das estratégias durante esse tipo de marcha nos permitirá propor diferentes formas de intervenção para contribuir na resolução complexa do risco de quedas apresentado pelas pessoas com DP. Além disso, a possibilidade de disponibilizar clinicamente mais estratégias terapêuticas permite-nos ter mais recursos para combater os problemas da doença, a deterioração progressiva que se desenvolve nestas pessoas e nas suas famílias, e retardar o aparecimento da incapacidade.

Num cenário incipiente no desenvolvimento da área da reabilitação, esta tese permite a implementação de uma linha de investigação em relação ao exercício em pessoas com doença de Parkinson, bem como em idosos com deficiência, na Universidade de Talca, Chile. O impacto do desenvolvimento de um ensaio clínico com estas características permitirá um espaço para pesquisas clínicas com a participação de acadêmicos e estudantes, e a transferência desses estudos e a possibilidade de implementação de um programa de reabilitação e prevenção para pessoas com DP. Sem dúvida, este tipo de transferência permite-me, como acadêmico, traduzir o meu interesse de investigação em aplicação clínica e, através da minha Instituição, ser capaz de responder às necessidades de saúde da minha comunidade.