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MARCOS RAPHAEL PEREIRA MONTEIRO

A COMPLEXIDADE DA TAREFA COMO VARIÁVEL DA DOSE DO EXERCÍCIO FÍSICO NA PROMOÇÃO DA FUNCIONALIDADE EM MULHERES IDOSAS: *BRAIN FUNCTIONAL TRAINING*

SÃO CRISTÓVÃO
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EPÍGRAFE

"Pra que caminhos para quem não tem pés para caminhar?"

(Exu Mirim).

RESUMO

A Complexidade da Tarefa como Variável da Dose do Exercício Físico na Promoção da Funcionalidade em Mulheres Idosas: *Brain Functional Training*. Marcos Raphael Pereira Monteiro, São Cristóvão, 2026.

O exercício físico é uma das práticas de saúde mais difundidas no mundo e, tradicionalmente, sua prescrição tem sido orientada por variáveis clássicas de dose, como volume e intensidade. Entretanto, a complexidade da tarefa tem emergido como um componente relevante tanto para a análise do movimento quanto para o treinamento físico, embora ainda careça de maior densidade teórica e empírica. Nesse cenário, um modelo de treinamento denominado *Brain Functional Training* (BFT) surge da premissa de aumentar o nível de complexidade da tarefa na intenção de favorecer um aumento da ativação de áreas cerebrais relacionadas ao planejamento do movimento. Nesse contexto, esta tese investigou os efeitos e os possíveis mecanismos da manipulação da complexidade da tarefa sobre a funcionalidade de mulheres idosas fisicamente independentes. No Estudo I, foi desenvolvido um arcabouço teórico, com base em revisão de literatura, para sustentar a complexidade como variável de dose do exercício físico. Foi formulada a hipótese de que o aumento da complexidade amplia as demandas de planejamento, eleva a carga cognitiva aguda e recruta, de forma mais intensa, regiões pré-frontais associadas às funções executivas, favorecendo adaptações funcionais quando aplicado de modo repetido. No Estudo II, examinou-se o efeito agudo de diferentes níveis de complexidade em uma tarefa de agachamento sobre marcadores de esforço cognitivo, desempenho físico e desempenho executivo em mulheres idosas. Observou-se aumento do esforço cognitivo nas condições mais complexas, especificamente quando a tarefa de agachamento foi combinada com cálculo mental ou apresentou predominância unilateral. Apesar do maior custo cognitivo, não foram identificadas diferenças imediatas entre as condições para desempenho executivo. Em contrapartida, o aumento da complexidade levou a maior tempo de execução, menor velocidade de movimento e, quando a complexidade foi predominantemente motora, menor amplitude de movimento. A percepção subjetiva de esforço não diferiu entre as condições. No Estudo III, investigaram-se os efeitos de 16 semanas de intervenção com BFT, treinamento funcional e intervenções corpo mente, bem como a retenção após 16 semanas de destreinamento, sobre funcionalidade, função executiva e composição corporal. Os três modelos promoveram melhora semelhante do desempenho funcional e executivo, com manutenção parcial após o destreinamento. O BFT apresentou vantagens específicas em movimentação sob dupla tarefa e em controle inibitório, sugerindo potencial superioridade em demandas cognitivas integradas ao movimento. Todos os grupos também aumentaram a massa magra apendicular no pós intervenção, com declínio parcial no período de destreinamento. Conclui-se que a complexidade da tarefa constitui uma variável promissora da dose do exercício físico, com impacto agudo sobre o esforço cognitivo e o desempenho motor, além de efeitos repetidos relevantes para a funcionalidade e a cognição em mulheres idosas.

Palavras-Chaves: Estado Funcional; Envelhecimento; Função Executiva; Neurofisiologia; Treinamento Cognitivo; Saúde.

ABSTRACT

Task Complexity as a Variable of Exercise Dose in the Promotion of Functionality in Older Women: Brain Functional Training. Marcos Raphael Pereira Monteiro, São Cristóvão, 2026.

Physical exercise is one of the most widespread health practices worldwide, and its prescription has traditionally been guided by classical dose variables such as volume and intensity. However, task complexity has emerged as a relevant component for both movement analysis and physical training, although it still lacks greater theoretical and empirical density. In this context, a training model known as Brain Functional Training (BFT) arises from the premise of increasing task complexity to enhance the activation of brain areas related to movement planning. Accordingly, this thesis investigated the effects and possible mechanisms of manipulating task complexity on the functionality of physically independent older women. In Study I, a theoretical framework was developed, based on a literature review, to support complexity as a variable of exercise dose. The hypothesis was that increasing complexity expands planning demands, elevates acute cognitive load, and more intensely recruits prefrontal regions associated with executive functions, thereby promoting functional adaptations when applied repeatedly. In Study II, the acute effects of different levels of complexity in a squat task were examined on markers of cognitive effort, physical performance, and executive performance in older women. An increase in cognitive effort was observed under more complex conditions, particularly when the squat task was combined with mental calculation or involved unilateral predominance. Despite the higher cognitive cost, no immediate differences were identified between conditions for executive performance. In contrast, increased complexity resulted in longer execution time, reduced movement velocity, and, when complexity was predominantly motor, reduced range of motion. Perceived exertion did not differ between conditions. In Study III, the effects of a 16-week intervention with BFT, functional training, and mind–body interventions were investigated, as well as retention after 16 weeks of detraining, on functionality, executive function, and body composition. All three models promoted similar improvements in functional and executive performance, with partial maintenance after detraining. BFT showed specific advantages in movement under dual-task conditions and inhibitory control, suggesting potential superiority in cognitive demands integrated with movement. All groups also increased appendicular lean mass post-intervention, with a partial decline during the detraining period. It is concluded that task complexity constitutes a promising variable of exercise dose, with acute effects on cognitive effort and motor performance, as well as relevant repeated effects on functionality and cognition in older women.

Keywords: Functional Status; Aging; Executive Function; Neurophysiology; Cognitive Training; Health.

RESUMO PARA A SOCIEDADE

A Complexidade da Tarefa como Variável da Dose do Exercício Físico na Promoção da Funcionalidade em Mulheres Idosas: *Brain Functional Training*. Marcos Raphael Pereira Monteiro, São Cristóvão, 2026.

O exercício físico é amplamente reconhecido como uma das principais estratégias para a promoção da saúde. Tradicionalmente, o exercício é prescrito com base em fatores como a carga externa e a quantidade de repetições. No entanto, um aspecto que vem ganhando atenção é a complexidade da tarefa, ou seja, o quão desafiador é o exercício não apenas para o corpo, mas também para o cérebro. Esta tese investigou como aumentar essa complexidade pode influenciar a saúde de mulheres idosas independentes. A ideia central foi que exercícios mais desafiadores, sejam aqueles que combinam movimento com tarefas mentais, ou aqueles que apresentam maior dificuldade técnica para realizar, podem estimular mais o cérebro e melhorar não só o desempenho físico, mas também a forma de realização de tarefas cotidianamente. Em um primeiro momento, foi desenvolvido um modelo teórico propondo que exercícios mais complexos exigem maior planejamento e aumentam o esforço mental, ativando regiões do cérebro ligadas ao controle e à organização das ações. Em seguida, foi testado o efeito imediato dessa complexidade durante exercícios de agachamento. Os resultados mostraram que tarefas mais desafiadoras, como agachar enquanto realiza cálculos mentais ou com apoio maior uma perna, aumentam o esforço mental. Apesar disso, o desempenho em testes cognitivos não mudou imediatamente. Por outro lado, os movimentos ficaram mais lentos, com menor amplitude e maior tempo de execução. Além disso, os erros durante as respostas aos cálculos mentais também aumentaram. Curiosamente, as participantes não perceberam essas tarefas como mais cansativas. Por fim, foi avaliado o efeito de diferentes tipos de treinamento, com maior e menor complexidade ao longo de 16 semanas. Todos os programas melhoraram a capacidade física e cognitiva das participantes. No entanto, o modelo com maior complexidade (Brain Functional Training) mostrou vantagens específicas em situações que exigem fazer duas coisas ao mesmo tempo e no controle da atenção. Parte desses ganhos se manteve mesmo após um período sem treinamento. De forma geral, os resultados indicam que tornar os exercícios mais desafiadores para o cérebro pode ser uma estratégia eficaz para melhorar tanto a função física quanto a cognitiva em mulheres idosas. Isso sugere que profissionais de saúde podem ir além de simplesmente aumentar a intensidade do exercício, incorporando também desafios mentais para potencializar os benefícios.

LISTA DE TABELAS E FIGURAS

LISTA DE ABREVIATURAS E SIGLAS

ACSM – American College of Sports Medicine

ALST – Appendicular Lean Soft Tissue

BDNF – Brain-Derived Neurotrophic Factor

BG – Basal Ganglia

BFT – Brain Functional Training

CF – Cognitive Flexibility

DETR – Moment after the detraining period (detraining)

DLPFC – Dorsolateral Prefrontal Cortex

fNIRS – Functional Near-Infrared Spectroscopy

FT – Functional Training

FTSTS – Five Times Sit-to-Stand Test

GJST – Gallon Jug Shelf Transfer

GLMM – Generalized Linear Mixed Model

HIIT – High-Intensity Interval Training

IC – Inhibitory Control

LC-NA – Locus Coeruleus–Noradrenaline System

M1 – Primary Motor Cortex

MBI – Mind–Body Interventions

MEDT – Medicine Ball Throw Test

MeSH – Medical Subject Headings

OMS – Organização Mundial da Saúde

PFC – Prefrontal Cortex

PhA – Phase Angle

PM – Premotor Cortex

POST – Moment after the training period (post-intervention)

PRE – Moment before the beginning of the training period (pre-intervention)

PTS – Put On and Take Off a T-shirt

R – Resistance

RPP – Rising from the Prone Position

RT – Response Time

S1 – Primary Somatosensory Cortex

SDNN – Standard Deviation of Normal-to-Normal Intervals

SMA – Supplementary Motor Area
SQ – Squat Task
SQCog – Squat with Cognitive Task
SQCogMot – Squat with Cognitive and Motor Task
SQMot – Squat with Motor Task
SWCT – Stroop Word-Color Task
TF – Treinamento Funcional
TUG – Timed Up and Go
TUGc – Timed Up and Go with Additional Cognitive Task
TUGm – Timed Up and Go with Additional Motor Task
Vigitel – Sistema de Vigilância de Fatores de Risco e Proteção para Doenças Crônicas por Inquérito Telefônico
W10M – 10-Meter Walk Test
W6Min – 6-Minute Walk Test
WM – Working Memory
Xc – Reactance

SUMÁRIO

1 INTRODUÇÃO

A prática sistematizada de atividade física tem sido amplamente incorporada por diferentes populações em escala global como um comportamento associado à promoção de saúde. Esse evento possivelmente ocorre em função da consolidação do exercício físico, um tipo de atividade física planejado, estruturado e repetitivo que busca promover ou aumentar um ou mais componentes da aptidão física (Caspersen; Powell; Christenson, 1985), como uma estratégia não farmacológica para a prevenção e o manejo de diferentes condições de saúde (Thompson et al., 2020). No contexto do Brasil, dados do Sistema de Vigilância de Fatores de Risco e Proteção para Doenças Crônicas por Inquérito Telefônico (VIGITEL) de 2023 indicam que entre 36,9% e 53,3% dos adultos atingem, no tempo livre, níveis de atividade física equivalentes a pelo menos 150 minutos semanais de intensidade moderada (Brasil, 2024), sendo esse o mínimo recomendado pela Organização Mundial da Saúde (OMS) (Bull et al., 2020).

Em particular, o exercício físico é amplamente indicado para pessoas idosas devido a sua capacidade de mitigar os efeitos deletérios associados à senescência (Bull et al., 2020; Izquierdo; Singh, 2023). Nesse contexto, o *American College of Sports Medicine* (ACSM), aponta que programas de exercícios físicos para pessoas idosas estão em segundo lugar nas tendências *fitness* para o ano de 2026 (R. McAvoy et al., 2025), mantendo-se de forma consistentes entre três primeiras colocações nos últimos três anos (Newsome et al., 2024, 2025). Especificamente no Brasil, apenas cerca de 26,9% dos indivíduos com 65 anos ou mais atingem os níveis recomendados pela OMS de atividade física no tempo livre (Brasil, 2024).

Compreender o exercício físico como estratégia de promoção da saúde, frequentemente descrita por analogia a um "medicamento" (Li; Qiu; Li, 2023; Thompson et al., 2020), requer o entendimento da sua dose. De acordo com Wasfy e Baggish, especialmente no contexto da prática clínica, devem ser consideradas as seguintes variáveis: duração da sessão, que reflete o tempo de uma única sessão de treinamento; frequência, que também se relaciona ao tempo, porém considerando múltiplas sessões em um determinado período; e, por fim, a intensidade, que reflete o desempenho no exercício em relação a um percentual da capacidade máxima ou ao custo metabólico da tarefa (Wasfy; Baggish, 2016).

Por outro lado, uma aproximação com maior número de variáveis, proposta pela ACSM, para o controle da dose do exercício físico envolve o modelo FITT (VP), que é o acrônimo para frequência (F), intensidade (I) e duração da sessão (T, *time*) já apresentadas anteriormente, e acrescenta, tipo (T) que corresponde à natureza do exercício aplicado, volume (V) que representa a quantidade de trabalho mecânico realizado, comumente quantificado como séries e repetições, e progressão (P) que se refere ao ajuste gradual e planejado das variáveis ao longo do tempo para determinar o avanço dos programas de exercício físico (Bishop et al., 2025)

As alterações nas variáveis da dose do exercício físico podem fornecer diferentes impactos na saúde e funcionalidade da pessoa idosa, sendo essa última associada à capacidade de realizar tarefas físicas e cognitivas básicas necessárias para as atividades de vida diária (Dhammi; Kumar, 2014; Izquierdo et al., 2025). Como exemplo, a revisão sistemática com metanálise de Steib e colaboradores aponta que, para o aumento da força máxima, a alta intensidade é mais favorável quando comparada à baixa ou moderada intensidade no treinamento de força, contudo, o estudo não encontra diferenças no tocante à funcionalidade (Steib; Schoene; Pfeifer, 2010). Quando analisada a função cognitiva de pessoas idosas, uma metanálise com modelo de *network* bayesiano aponta que para intensidades moderadas a recomendação mínima semanalmente de exercício de *endurance* é de 70 minutos, enquanto, quando o exercício é realizado de forma vigorosa, essa recomendação passa a ser de 35 minutos (Gallardo-Gómez et al., 2022). Nesse cenário, o Consenso Global sobre Recomendações Ideais de Exercício para Promover a Longevidade Saudável em Pessoas Idosas fornece recomendações específicas para treinamento resistido, treinamento de *endurance* e treinamento de equilíbrio, contemplando frequência, volume, intensidade, exemplos de exercícios e até orientações de segurança, além de discorrer sobre a necessidade de especificidade dos exercícios adotados e de abordagens multicomponentes (Izquierdo et al., 2025).

Na intenção de discutir melhor os efeitos das variáveis que compõem a dose do exercício físico, La Scala Teixeira e colaboradores em 2019 sugerem o uso da complexidade enquanto mais uma variável da dose do exercício físico, esta seria definida como a “dificuldade técnica do movimento, variabilidade nos padrões de movimento ou incerteza das ações a serem performadas”. Apesar de ser sugerida como variável da dose no exercício físico somente em 2019, a modulação da complexidade da tarefa já era utilizada anteriormente na neurociência aplicada ao movimento, com estudos mostrando maior necessidade de atenção e redução de performance quando é aumentada a complexidade de uma tarefa (Shumway-Cook; Brauer; Woollacott, 2000; Shumway-Cook; Woollacott, 2000). Nessa perspectiva, a complexidade da tarefa pode ser compreendida como uma variável de natureza híbrida, atuando tanto como componente independente da dose do exercício quanto como moduladora das respostas ao estímulo, ao influenciar simultaneamente as demandas motoras e cognitivas associadas à execução do movimento.

Alinhado a isto, em 2024, Da Silva-Grigoletto e colaboradores apresentaram um modelo de treinamento cuja premissa central é o uso da complexidade da tarefa na modulação da dose do exercício físico: o *Brain Functional Training* (BFT). O BFT surge da premissa de aumentar o nível de complexidade da tarefa, com o objetivo de favorecer maior ativação de áreas cognitivas relacionadas ao planejamento do movimento, especialmente regiões pré-frontais, buscando promover ganhos em saúde e funcionalidade como efeito dos estímulos repetidos. Esse primeiro trabalho é um artigo de perspectiva, voltado à aplicação do BFT em pessoas idosas (Da Silva-Grigoletto et al., 2024). Apesar de seu caráter inovador, o estudo inicial ainda pode se beneficiar de um maior aprofundamento nos mecanismos fisiológicos associados à prática do BFT, apresentando interpretações preliminares acerca dos fenômenos envolvidos. Nesse sentido, observa-se uma oportunidade, na literatura científica, para o desenvolvimento de hipóteses mais robustas e teoricamente fundamentadas.

Nesse cenário, apesar de teoricamente plausível, ainda é pouco compreendido como a modulação da complexidade da tarefa realizada durante o exercício físico pode impactar na performance do exercício de forma aguda. Por fim, além dos efeitos agudos, torna-se necessário investigar também os efeitos repetidos da modulação da complexidade em programas de exercício físico com maior complexidade quando comparados a de menor complexidade sobre variáveis relacionadas à saúde e funcionalidade da pessoa idosa.

2 OBJETIVOS E HIPÓTESE

2.1 OBJETIVO GERAL

Investigar os possíveis efeitos e mecanismos das modulações na complexidade da tarefa, enquanto variável de dose do exercício físico, sobre a funcionalidade e saúde de mulheres idosas fisicamente independentes.

2.2 OBJETIVOS ESPECÍFICOS

1. Apresentar um arcabouço teórico que sustente o uso da complexidade como variável de dose para a melhoria da funcionalidade no contexto da saúde, com ênfase particular nos aspectos cognitivos, conforme empregado no BFT (Estudo I – publicado na revista *Acta Psychologica*).

2. Investigar o impacto de diferentes níveis de complexidade da tarefa de agachamento sobre marcadores fisiológicos de esforço cognitivo (dilatação pupilar e frequência de piscadas), desempenho físico (variáveis cinemáticas) e desempenho executivo (tempo de resposta e acurácia) em mulheres idosas (Estudo II – a ser submetido na revista *Psychology of Sport and Exercise*)

3. Verificar os efeitos de treinamento e retenção após 16 semanas de intervenção com BFT, Treinamento Funcional (TF) e Intervenções Corpo-Mente sobre o estado funcional e a composição corporal em mulheres idosas (Estudo III – submetido na revista *Archives of Geriatrics and Gerontology*).

2.2 HIPÓTESES

1. A compreensão da complexidade da tarefa é um fator-chave na aplicação do exercício físico voltado à melhora da funcionalidade.

2. Tarefas com maior nível de complexidade resultarão em maior esforço cognitivo e também levarão a maiores reduções no desempenho físico e executivo, quando comparadas a tarefas com menor nível de complexidade.

3. Os três modelos de intervenção (BFT, TF e Intervenções Corpo-Mente) promoverão ganhos no estado funcional e na massa magra em mulheres na pós-menopausa, sendo que o BFT e o TF apresentarão efeitos semelhantes em testes de

desempenho, porém o BFT será superior ao TF e às Intervenções Corpo-Mente em testes de função executiva. Adicionalmente, acreditamos que as Intervenções Corpo-Mente apresentarão efeitos menores sobre aspectos da aptidão funcional e da massa magra.

3 DESENVOLVIMENTO

A presente tese foi elaborada em formato alternativo, em consonância com modelos internacionalmente utilizados, conforme previsto na INSTRUÇÃO NORMATIVA Nº 03/2023/PROCFIS. Alinhado a isto, para responder os objetivos propostos, foram realizados três estudos. O estudo I foi publicado na revista *Acta Psychologica* (Anexo A), o estudo II será submetido para avaliação na revista *Psychology of Sport and Exercise,* e o estudo III foi submetido para avaliação na revista *Geriatrics and Gerontology International* (Anexo B). O desenho experimental geral dos três estudos pode ser contemplado na Figura 1

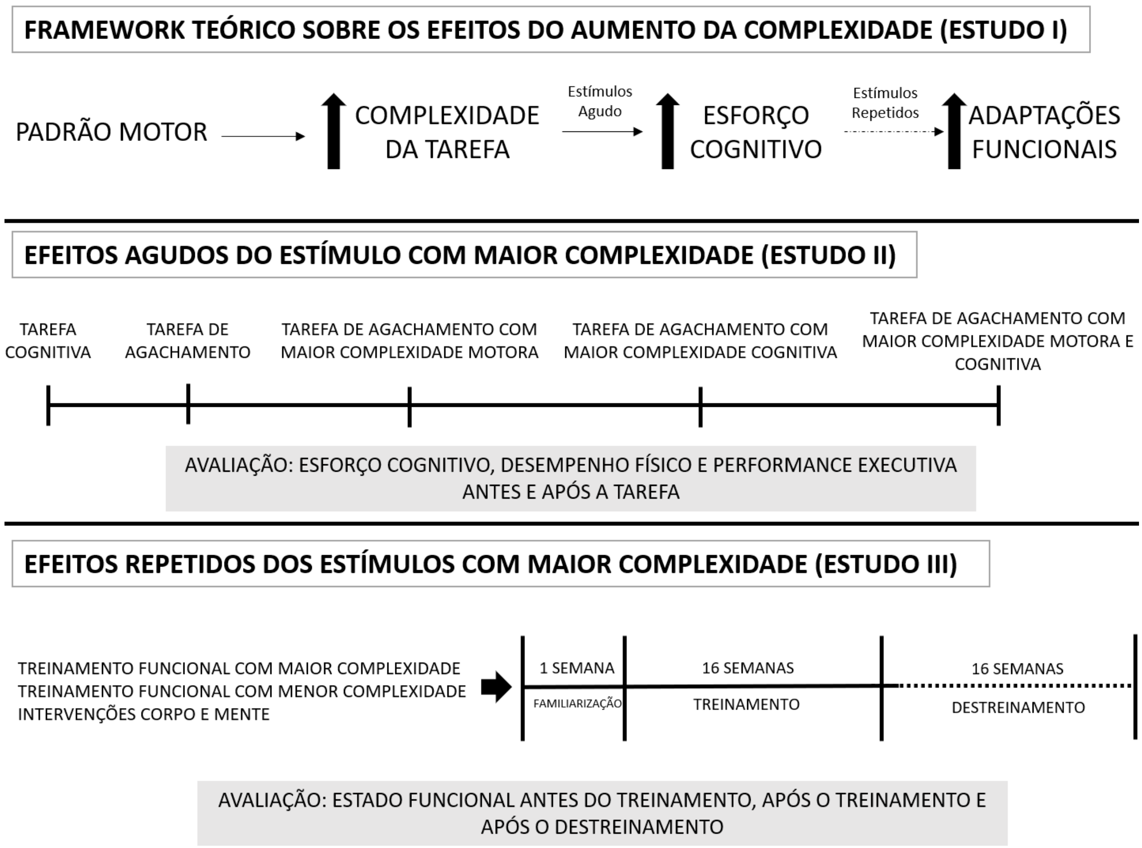

Figura 1. Desenho experimental geral dos três estudos que compõem a tese.

4 ESTUDO I – UM NOVO ARCABOUÇO SOBRE EXERCÍCIO, FUNCIONALIDADE E SAÚDE: *BRAIN FUNCTIONAL TRAINING*

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4.1 INTRODUCTION

The effects of physical exercise on cognition are well established in the scientific literature, involving modifications in the morphology and function of the central nervous system, especially improving white matter integrity, promoting neuroplasticity, and enhancing executive functions (De Sousa Fernandes et al., 2020; Xiong et al., 2021; Zhang; Zhou; Chen, 2023). From this perspective, planning can be considered one of the core executive functions, defined as the ability to conceive, organize, and execute a sequence of actions toward a goal (Diamond, 2013; Lezak, 2004). This executive function may be more or less demanded according to the level of movement automatization, since tasks that are still being learned and are considered more complex require greater cortical engagement (Wu; Hallett, 2005).

The proper functioning of the executive functions is an essential part of functionality according to the Functional Status concept described in the Medical Subject Headings (MeSH): "Ability regarding basic physical and cognitive activities such as walking or reaching, focusing attention, and communicating, as well as the routine activities of daily living, including eating, bathing, dressing, transferring, and toileting [...]" (Dhammi; Kumar, 2014).

In this scenario, Functional Training stands out because its main objective is to improve functionality (Da Silva-Grigoletto; Resende-Neto; Teixeira, 2020), with some recent articles showing its positive long-term effects on executive functions (Martinez-Navarro et al., 2021; Pantoja-Cardoso et al., 2023a). From the perspective of prioritizing the effects on planning ability as a result of the interaction between core executive functions, the possibility arises of employing cognitive dual-task paradigms specifically designed to enhance these executive functions, as has been implemented in another training model known as Brain Endurance Training (Dallaway; Lucas; Ring, 2021; De Lima-Junior et al., 2023; Díaz-García et al., 2023; Staiano et al., 2023). In this regard, Brain Endurance Training emerges as a training approach that utilizes acute mental fatigue as a stimulus to induce chronic reductions in fatigue during physical and/or cognitive tasks, thereby leading to improved performance (Staiano et al., 2023; Staiano; Merlini; Marcora, 2015). This approach primarily induces mental fatigue through tasks that increase cognitive load, defined by Sweller (1988) as the mental effort required to process multiple elements of a problem simultaneously, and the relationships between them, which are closely linked to working memory capacity (Sweller, 1988).

Additionally, another strategy to increase planning demands involves increasing movement variability, thereby promoting motor learning and mechanisms of brain plasticity (Maier et al., 2019). Huber's model already integrates aspects of complexity within rehabilitation, although his taxonomy is more focused on task-related motor conditions, specifically on environmental and action contexts (Huber; Manser; De Bruin, 2024). Changes in motor patterns, as well as the inclusion of cognitive dual tasks, are understood in Functional Training as modulation of task complexity (La Scala Teixeira et al., 2019).

From this perspective, Da Silva-Grigoletto et al. (2024) proposed a greater focus on changes in complexity during Functional Training as the main variable to promote adaptations in executive functions. This alternative proposal for Functional Training is called "Brain Functional Training". We believe that this modality has great potential for broad dissemination, as it presents itself as an alternative way to implement the "Functional Training" and, thanks to its health adaptations, also fits to aligns with the "Exercise is Medicine" initiative. Both modalities have been highlighted in the last five years among the world's top 20 fitness trends according to the American College of Sports Medicine (Newsome et al., 2024; Thompson, 2019, 2021, 2022, 2023).

However, although promising, the study by Da Silva-Grigoletto et al. (2024) on Brain Functional Training has focused on its application in older adults without explicitly detailing the main neural systems underlying the approach. The study proposes improved connectivity between brain regions as the primary hypothesis supporting the framework, yet it does not provide in-depth substantiation of this hypothesis. Furthermore, it lacks a thorough discussion of how modalities aimed at enhancing cognitive aspects influence the nervous system, or how Brain Functional Training integrates key contributions from these modalities alongside those from Functional Training itself. Due to its dynamic nature and broad applicability, Brain Functional Training can be adapted for different populations, especially when the pursuit of improvements in functionality and executive function modulated by intensity and frequency represent a challenge. In this sense, it is important to clarify that increases in complexity should be different and modulated according to each individual's functional profile, following the principles of biological individuality and understanding the premise of "Functional for what and for whom?" (Da Silva-Grigoletto; Brito; Heredia, 2014).

In this sense, the theoretical basis by which increased cognitive load resulting from greater complexity in Brain Functional Training may promote adaptations in executive functions and functionality is still unclear, thereby characterizing a gap in the current literature regarding the next step in the application of Brain Functional Training models. Our hypothesis is that understanding task complexity is a key factor in the application of physical exercise aimed at enhancing functionality. We propose that this understanding should integrate both motor and cognitive aspects related to task planning. Accordingly, the objective of this paper is to present a theoretical framework underlying the use of complexity as a dose variable to improve functionality within the health context, with a particular focus on cognitive aspects, as employed in Brain Functional Training. Along these lines, the application of Brain Functional Training will aim to promote chronic improvements in functionality and acute increases in activation of cortical regions related to task planning.

4.2 THE BRAIN AND HOW IT MODULATES EXERCISE

Considering the extensive intricacy of motor control, it is important to briefly summarize the main mechanisms involved in the neurological circuitry that controls movement. Human movement is coordinated primarily by the corticospinal tracts, which originate primarily in the frontal and parietal lobes and descend through the spinal cord to innervate the distal portions of the limbs (Jang, 2014). The primary motor cortex (M1), the supplementary motor area (SMA), the premotor area (PM), the somatosensory cortex (S1), cerebellum, basal ganglia (BG), and the prefrontal cortex (PFC) have been identified as being involved in motor performance (Figure 1) (Rhee; Mehta, 2018; Shitara et al., 2013).

The M1 region is located in the posterior part of the precentral gyrus of the frontal lobe. It is known as the main cortical area for motor commands. This area plays a crucial role in descending motor pathways, as seen in its projection of axons through these pathways (Sato et al., 2021). Furthermore, M1 is the source of a significant number of corticospinal and corticobulbar tract fibers, which are essential for controlling voluntary muscle movements. While M1 does not directly participate in planning sequential muscle movements, it does regulate specific aspects of movement such as direction, velocity, acceleration, and strength (Teka et al., 2017). Additionally, M1, in coordination with S1, directly influences motor output and descending drive. M1 is responsible for managing motor output, while S1 modulates motor output through sensory feedback. As the complexity of the task increases, the involvement of SMA and PM in motor planning becomes more prominent, emphasizing their role in complex motor functions (Hoshi; Tanji, 2007).

Another important center for movement, the cerebellum, is located in the posterior parts of the brainstem (Shitara et al., 2013). The cerebellum is primarily implicated in motor (equilibrium, motor learning, and coordination for muscle movements) and non-motor (cognition and language) functions participating in planning and motor gesture correction (Marvel; Morgan; Kronemer, 2019). Consequently, the cerebellum plays an inhibitory role in modulating and inhibiting inappropriate motor actions (Shitara et al., 2013). In turn, the BG is a grey mass structure located at the base of the brain. It includes the central base of the amygdala, putamen, caudate nucleus, and globus pallidus (Rhee; Mehta, 2018). The BG connects to the thalamus, and this, in turn, connects to the superior motor areas (M1, SMA, and PM) (Hoshi; Tanji, 2007). The BG is involved in different cortical circuits, from motor planning to executive functions (which will be more detailed shortly) (Lin et al., 2022; Marvel; Morgan; Kronemer, 2019; Taylor et al., 2016; Teka et al., 2017).

The PFC is believed to play a role in planning, initiating, facilitating, and inhibiting movements, contributing to motor control (Friedman; Robbins, 2022; Lee; Choi; Martin, 2020; Lin et al., 2022). In this scenario, it is important to highlight the action of the PFC in carrying out daily tasks. This region is responsible for executive functions, which are processes controlled by cognition that are necessary for non-automatic or instinctive actions (Diamond, 2013). The executive functions can be divided into low and high order. The low-order functions are working memory (ability to keep information in mind and be able to manipulate this data mentally during another task), inhibitory control (ability to inhibit information, irrelevant stimuli or unwanted behavior), and cognitive flexibility (ability to switch between two or more activities, behaviors, or ways of thinking). These low-order functions directly influence the performance of the high-order executive functions, including planning (Diamond, 2013).

These executive functions determine the planning required for movement execution, such as the need to recall sequences necessary for effective movement or to inhibit distracting environmental information. Recognizing that these executive functions are components of cognition which are directly related to movement generation, movement emerges as the result of interacting factors related to the environment, the task, and the individual (Shumway-Cook; Woollacott, 2007).

The relationship between the executive functions determined by the PFC and other important components of the motor control system is so intimate that we can mention the interaction between the PFC and the BG for the proper activation of working memory, with the BG playing the role of gatekeepers to adjust the inhibition of the thalamocortical loops, thus allowing working memory not to be affected by a new stimulus (Frank; Loughry; O'Reilly, 2001). When an activity is reward-based, subregions of the BG, particularly the nucleus accumbens, play an active role in the process through the dorsolateral pathway. The dorsolateral part of PFC (DLPFC) has neural connections with the BG, more specifically with the caudate nucleus. Consequently, the caudate nucleus also appears to be involved in decision-making during motor actions (Milosevic et al., 2020).

In this scenario, although the PFC is primarily involved in executive functions (Miller; Cohen, 2001), its activity is also associated with the development of neuromuscular fatigue (Tyagi; Mehta, 2021). Specifically, DLPFC stimulation has the potential to increase time to exhaustion during an endurance task, as well as improve performance in inhibitory control tasks (Angius et al., 2019). In this sense, the PFC play as a key role in the regulation and termination of whole-body endurance exercise, a process mediated by cerebral cortex oxygenation (De Wachter et al., 2021). Accordingly, it is suggested that changes in PFC activity can impact motor areas and muscle oxygenation when individuals experience central neuromuscular fatigue (Berchicci et al., 2013; Hou et al., 2016; Jiang et al., 2012).

It is important to point out that the most classic position in the literature points to a sequential activation pattern among the areas mentioned above, as observed in ballistic movements where there is no time for the cerebellum to adjust the movement due to the speed at which it is performed (Albuquerque; De Sousa Fortes; Lage, 2023).

In addition, it is also worth noting that cognitive variations in motor execution can occur in a parallel or serial format. If serial, the cognitive variation determines the planning of the action, meaning that the motor sequence we develop depends on solving the cognitive challenge. If parallel, the motor execution is already chosen and does not depend on solving cognitive challenges.

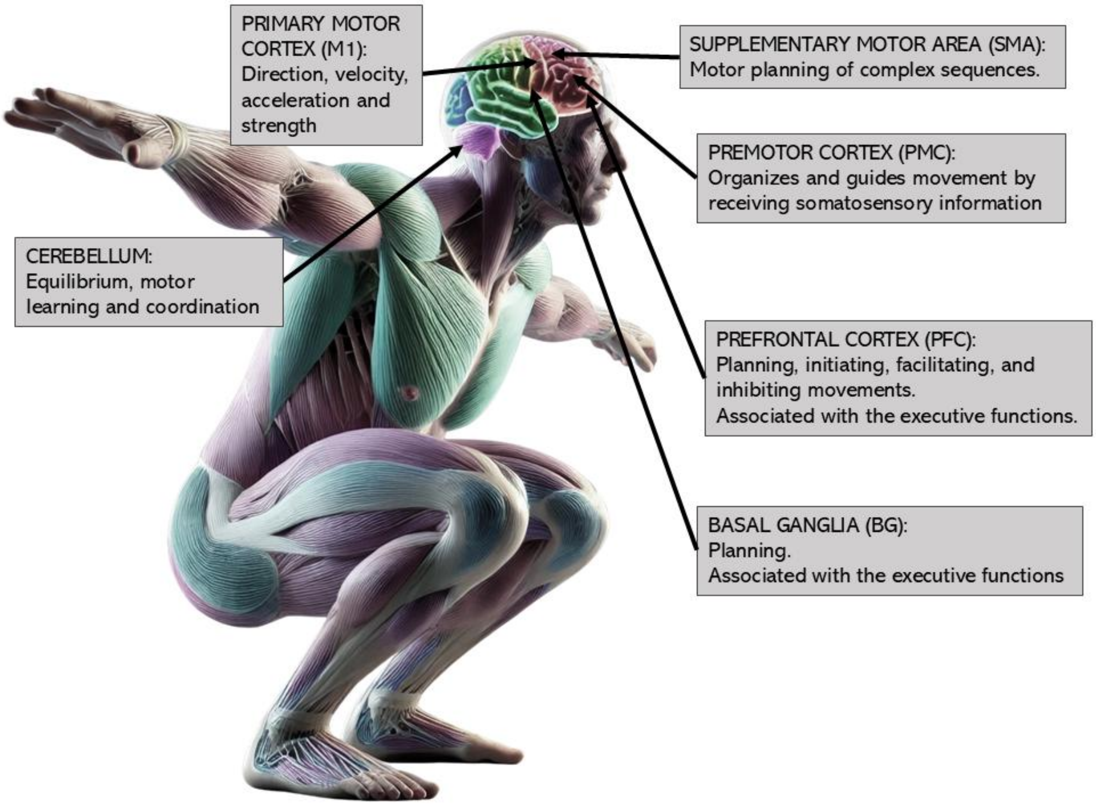

Figure 1. Motor areas involved in movement planning

Note: Regarding motor areas, PFC, PM, and SMA are involved in movement planning, contributing to the generation of command sequences that produce voluntary movements. In contrast, M1 acts as the executor, sending the preplanned commands to skeletal muscles, a process that can be supported by S1 through its participation in the descending motor drive. Finally, BG and the cerebellum function as controllers, ensuring movement accuracy and contributing to movement correction.

4.3 THE EXERCISE AND HOW IT MODULATES THE BRAIN

Understanding that movement is directly modulated by different parts of the nervous system, it follows that the stimuli needed to maintain healthy motor control involve adaptations across multiple neural regions. The molecular mechanisms responsible for the cognitive improvements promoted by physical exercise are closely related to the release of brain-derived neurotrophic factor (BDNF) and its increase at central nervous system, the improve of mitochondrial health, changes in cytokines capable of crossing the blood-brain barrier, increased brain metabolism and regulation of gut microbiota (Lu et al., 2023). Thanks to technological advances that allow us to measure neural responses and adaptations in human studies, it is now possible to investigate the influence of physical exercise on areas of the nervous system involved in motor control. In this sense, a positive relationship has been observed between cardiorespiratory capacity and greater functional brain connectivity in the medial region of the PFC, although cardiorespiratory capacity is not associated with greater connectivity between the DLPFC and other brain structures (Moore et al., 2022). Similarly, higher levels of cardiorespiratory capacity are also associated with greater gray matter volume of PFC (Erickson; Leckie; Weinstein, 2014). Regarding cerebral metabolism, techniques such as the functional near-infrared spectroscopy (fNIRS) enable real-time assessment of cerebral oxygenation, reflecting neural activity. Studies in humans have shown that moderate- to vigorous- intensity whole-body endurance training increases cerebral oxygenation in the PFC during cognitive tasks, both acutely and chronically (Shen et al., 2024). Meanwhile, there is also a link between greater endurance capacity and better performance in cognitive tasks during physical movements (Liu et al., 2023). This increased oxygenation resulting from enhanced cerebral blood flow can improve cognitive aspects in patients with cerebral hypoperfusion, although this does not occur in patients with neuronal damage (Renke et al., 2022).

4.3.1 Role of Exercise Volume and Intensity

In general, changes related to exercise intensity seem to modulate important aspects of the infraspinal pathway; however, the effects related to intracortical communication do not show a positive association with the proposed level of intensity (Latella et al., 2017). Interestingly, during cycling, as exercise intensity increases, a reduction in PFC activation has been observed (Fontes et al., 2020). The authors suggest that one possible explanation for this phenomenon could be the redistribution of blood flow to prioritize energy resources in motor-related brain areas, at the expense of regions crucial for cognitive functioning. However, in the cited study, no increase in blood flow was observed in other motor areas, which is only partially consistent with the Transient Hypofrontality Hypothesis (Dietrich, 2006).

On the other hand, blood concentrations of BDNF appear to increase under conditions of higher task intensity, both during resistance training (Borges Junior et al., 2024) and endurance training (Rodríguez-Gutiérrez et al., 2024). However, it is important to note that sample collections in human studies reflect circulating BDNF in the blood and do not necessarily represent its concentrations in the cerebrospinal fluid (Laske et al., 2007; Pillai et al., 2012). Furthermore, regarding training volume specifically, the study by Flanagan et al (2012) demonstrated increased activity in the motor cortex among individuals who performed a training volume three times higher in number of repetitions compared to the strength training group.

Despite these considerations, some studies in the scientific literature have already reported positive effects of high-intensity interval training (HIIT) protocols on post-exercise cognitive performance, primarily mediated by blood lactate levels, with particular emphasis on protocols involving moderate session volumes (5 to 15 minutes) (Jacob et al., 2023).

From a chronic perspective, a systematic review indicates that intensity appears to be a key training variable, being directly associated with greater neuroplastic adaptations. These neuroplastic adaptations seem to influence motor aspects such as maximal oxygen uptake, maximal strength, maximal voluntary isometric force, and muscle power, but not cognitive function. Among the unaltered domains are key components involved in movement planning, including executive function and processing speed. Moreover, this neuroplastic adaptation effect does not seem to occur in healthy older adults or individuals with neurological conditions (Hortobágyi et al., 2022). Similarly, the systematic review by Zhang et al. (2023) reported that neither session duration (volume) nor session intensity moderated the adaptations related to executive functions. However, the authors noted that low training frequency and a moderate intervention length (both considered indicators of training volume) appear to be dose adjustments that contribute to improvements in executive functions (Zhang et al., 2023).

4.3.2 Role of Exercise Complexity

In addition to volume and intensity of physical exercise, another important component of the task that can influence the activation of superior brain centers is complexity, which is related to the technical difficulty of the exercise, variability in execution patterns, and uncertainty in the actions to be performed (La Scala Teixeira et al., 2019). In this sense, the study by Kimura et al (2022), showed an increase in PFC activity when performing a dual cognitive task for moderate and high intensity whole-body endurance exercise; however, only at moderate intensity did the PFC remain highly activated (Kimura et al., 2022). The studies by Lee et al (2024) and Mirelman et al (2014) also indicate that increases in complexity during walking generate higher levels of activity in the frontal lobe of the brain (Lee et al., 2024; Mirelman et al., 2014).

Regarding resistance exercises, the study by Claußen and Heidelbach (2024) compared a classic squat exercise with a squat performed on an unstable platform, finding greater mental effort (represented by an increase in pupil dilation) in the more complex condition (Claußen; Heidelbach, 2024). In line with this, increments in complexity also increase the demands on the corticospinal pathways due to the need to adjust the frequency and synchronization of motor plate activation (Flanagan et al., 2012).

From a chronic perspective, Rosso et al. (2024) demonstrated that a 12-week intervention involving dual-task walking activities did not alter PFC activation but led to positive adaptations in walking speed, an important indicator of cognitive health (Rosso et al., 2024). Conversely, according to a systematic review published in 2021, combined physical and cognitive training (which we will refer as Cognitive-Motor Training) was significantly more effective for cognitive function than physical exercise alone, particularly in domains related to movement planning such as executive function and processing speed (Gavelin et al., 2021). Moreover, these training modalities showed similar efficacy to single-task physical exercise in promoting gains in physical function. In addition, the greater complexity of motor tasks appears to potentiate adaptations in functionality in different contexts (Díaz-García et al., 2023; Díaz-García; García-Calvo; Ring, 2025; Staiano et al., 2023).

4.3.3 Doses Variables on Brain Functional Training

In the same context, Netz (2019) highlights the importance of changes in task complexity for exercises considered "motor." According to the author, training models focused on strength and aerobic aspects are primarily modulated by intensity to promote cognitive effects. This occurs due to cardiovascular physiological adaptations derived from the metabolic demands imposed by these exercises, benefiting the brain's bioenergetic aspects. Meanwhile, balance and coordination exercises are primarily modulated by task complexity to promote cognitive effects, occurring due to the neuromuscular demands imposed and acting on neuroplasticity specific to the task (Netz, 2019).

Specifically in the context of Brain Functional Training, this scientific context highlights the need for approaches that consider task complexity as a central element in acutely activating cortical areas associated with task planning, with chronic transfer to improved performance (Da Silva-Grigoletto et al., 2024). It is believed that stimulating the PFC through motor and cognitive approaches promotes chronic adaptations that can be transferred to functionality.

4.4 COGNITIVE APPROACHS IN THE EXERCISE

The relationship between movement and cognitive aspects has been highlighted for many years, dating back to the 19th century, when William James addressed this relationship in his book "*Principles of Psychology*" (James et al., 1890). In fact, the first vision training applied to sports dates back to the end of the 19th century, particularly in baseball in the United States. During both World War I and World War II, fighter pilots were trained using specific visual (peripheral) and vestibular exercises (Sloan, 1946).

In this sense, it is common for this relationship to be further explored in the sporting context, where cognitive-motor approaches are necessary to develop tactical aspects of sport performance. This relationship was already being explored in manuscripts dating back to the 1970s, such as the book "*Psycho-Motor Behaviour in Education and Sport*" by Bryant Cratty in 1974 (Cratty, 1974). On the other hand, one of the pioneers in exploring cognitive demands during training was Professor Carmello Pittera, who has been presenting practical proposals for integrating physical exercise and cognitive tasks since the 1980s. In this regard, we highlight the book "*El Sistema PSI.CO.M.*" (Pittera, 2017). Additionally, two other authors who stand out are Mario Di Santo and Frans Bosch, who propose a greater emphasis on the cognitive aspects of training during physical exercise.

These approaches received different names over time, and most sought to promote the development of perceptual-cognitive skills, combining physical capabilities with cognitive tasks involving environmental perception (Fooken et al., 2018; Milazzo; Farrow; Fournier, 2016; Soltani Kouhbanani et al., 2020). Interventions that use this premise have shown effects on corticomotor reorganization, involving greater connectivity between different brain areas required for planning and solving tasks involving multiple levels of complexity (Cavaleri et al., 2020; Hülsdünker; Strüder; Mierau, 2018; Hung et al., 2013). Unpublished pilot studies conducted by our research group also show that 30 minutes of Cognitive-Motor Training lead to greater activation of the PFC, PMC and cortico-cerebellar pathways.

Over time, these training models have been increasingly proposed in the context of health. In 2000, Shumway-Cook's study showed that greater cognitive demand, applied as a dual cognitive task, could lead to alterations in the balance of older people

(Shumway-Cook; Woollacott, 2000). In this scenario, the use of dual tasks as a strategy to increase cognitive demand in order to improve health grew over the first two decades of the 21st century (Schaefer; Schumacher, 2011; Thom; Clare, 2011). Recent training proposals aimed at promoting the health of older people already involve cognitive-motor approaches that explore the performance of mathematical, semantic, and memory tasks in a complementary way to physical exercise (Rondão; Mota; Esteves, 2022).

It is interesting to note the expansion of Cognitive-Motor training beyond the traditional applications in older adults and sports performance. Today it is increasingly applied in rehabilitation settings, as well as among healthy adults and children.

This scenario reflects the scientific literature's need for a better understanding of the effects of Cognitive-Motor Training, which has led to the development of approaches involving dual tasks. In this context, cognitive dual tasks are increasingly being explored, specifically targeting cortical areas of interest. The study by Dallaway et al. (2021) demonstrated greater immediate improvements in PFC oxygenation for protocols involving cognitive dual tasks compared to those without such tasks. However, this study involved handgrip movement training, which does not present global motor patterns aligned with human movement (Dallaway; Lucas; Ring, 2021).

Nevertheless, tasks that stimulate executive functions while being associated with motor components have been shown to improve sports performance (De Lima-Junior et al., 2023; Díaz-García et al., 2023; Staiano et al., 2023). In this context, the study by Díaz-García et al. (2025) is notable, as it applied Brain Endurance Training with tasks designed to overload executive function in order to promote functionality and health in older adults. However, this study employed tests that may not accurately reflect older adults' functional abilities, such as the 30-second arm curl and 30-second sit-to-stand. Although these tests simulate daily activities, they do not adequately capture power-related demands, which are closely linked to functional independence in activities of daily living (Simpkins; Yang, 2022). From a similar perspective, but aiming for greater transfer to functionality in a health context, Brain Functional Training has emerged as a promising approach (Da Silva-Grigoletto et al., 2024).

Extended realities are also becoming increasingly common in rehabilitation environments. Studies using virtual reality for rehabilitation highlight the importance of variable practice to promote better retention and enhanced generalization of motor skills (Maier et al., 2019). In this sense, the manipulation of complexity and the use of different motor patterns involved in Brain Functional Training aim to improve motor learning retention while simultaneously engaging cognitive domains that are integral to functionality, with a particular focus on executive functions. This approach operates similarly to neurocognitive training models using extended realities for chronic pain management and injury prevention (Guerra-Armas et al., 2025; Hamoongard; Letafatkar; Thomas, 2024).

Furthermore, considering environments that stimulate interaction between cognitive and motor aspects during task performance, a systematic review reported that Cognitive Motor Training performed simultaneously with cognitive and motor stimuli appears to promote more effective adaptations in overall cognitive function than exergaming, which also utilizes extended reality systems (Gavelin et al., 2021).

In this context, an increasing number of studies have focused on examining the effects of greater cognitive processing demands during physical exercise. However, to maximize the benefits of this cognitive overload, it is essential to consider training modalities that also impose meaningful physical demands necessary for maintaining and improving the individual's functionality. Within this framework, Functional Training emerges as a particularly relevant approach.

4.5 FUNCTIONAL TRAINING

The search for functionality has always marked our culture. At the beginning of the 20th century, this pursuit contributed to the popularization of physiotherapy as a profession, being associated with the rehabilitation of soldiers involved in the First World War and patients affected by polio (Shaik; Shemjaz, 2014).

Based on the principle of specificity in sports training, it is understood that the task the trained task must be similar to the task one intends to improve (Kasper, 2019). In this sense, at the beginning of the 21st century, the work of Manini et al. (2007) was notable for demonstrating how to improve older adults' functionality through the practice of movements that simulate activities of daily living; this program was called "task-specific training" (Manini et al., 2007). To simulate everyday activities, these movements need to be integrated and multiplanar, requiring elements that promote changes in acceleration and the demands for dynamic stabilization (Da Silva-Grigoletto; Brito; Heredia, 2014). It is worth pointing out that for these exercises to be considered specific for daily life, we must not only take into account the characteristics of the exercise, but also the characteristics of the individual (Da Silva-Grigoletto; Brito; Heredia, 2014). However, it is not enough just to mimic the movements performed; it is also necessary to integrate the physical capacities required to perform the task, an approach commonly characterized as multicomponent training (La Scala Teixeira et al., 2017). Therefore, to stimulate functionality in the best possible way, it is necessary to understand the components of the physical exercise dose that are involved in stimulating different physical capacities, such as coordination, agility, balance, and strength.

In this sense, the definition of Functional Training is proposed as a systematization of training that "aims the synergistic, integrated and balanced improvement of different physical capacities in order to guarantee efficiency and safety during the performance of daily tasks, work and/or sports, being based on the biological and methodological principles of training, notably the principle of specificity" (Da Silva-Grigoletto; Resende-Neto; Teixeira, 2020). Understanding that all training seeks to improve performance at some point along the functionality continuum, terminological confusion has emerged, which some proposals suggesting the use of multicomponent or multimodal training as synonyms for Functional Training (Da Silva-Grigoletto; Resende-Neto; Teixeira, 2020), and even publications arguing for the non-existence of Functional Training (Ide et al., 2022). However, it is important to emphasize that this nomenclature is not intended to implement a new training model, but rather to characterize an approach focused on optimizing training efficiency in the pursuit of functionality.

An example of the appropriate use of this terminology is the article by Pelicioni et al. (2016). The study compares the effects of a rehabilitation approach called "functional", in which the use of exercises is based on aspects of motor control and resembles activities of daily living, against an approach called "non-functional", which does not follow these principles (Pelicioni et al., 2016). In this way, we emphasize that the term "functional" refers to the pursuit of "functionality", described in the Oxford dictionary as "the state or quality of being functional; the quality of being suitable to serve a purpose" (Dictionary, 1989), which is conceptually aligned with the previously described description of Functional Status.

Regarding this, over the last few years, various training protocols have been proposed that present characteristics consistent with Functional Training (although they were not always given this nomenclature), demonstrating positive effects on the Functional Status of adults (Da Silva-Grigoletto et al., 2021, 2022; Wilke; Mohr, 2020), older people (Aragão-Santos et al., 2021; Liu et al., 2014; Vasconcelos et al., 2020), children (Gonzalez et al., 2023), and athletes (Bashir et al., 2022; Xiao et al., 2021).

4.5.1 Functional Training limitations

Although Functional Training has shown effects in different populations, it has primarily focused on promoting improvements through motor stimuli, often overlooking the need for cognitive stimulation. In this context, we highlight two studies that report the effects of training models resembling what is understood as Functional Training on executive function, both applied to older women. However, both interventions employed moderate- to high-intensity levels, which are not always appealing or feasible (Martinez-Navarro et al., 2021; Pantoja-Cardoso et al., 2023b).

Moreover, understanding that cognitive adaptations are essential for achieving functionality, specific stimuli also represent a viable approach—making it possible to emphasize adaptations driven by task complexity rather than by increasing volume or intensity to high levels. Among the strategies to enhance task complexity, the use of dual tasks targeting executive functions stands out. In this regard, the incorporation of dual tasks as a means to increase complexity has already been proposed in an article from our research group (La Scala Teixeira et al., 2017) and tested in a different context with older adults (Pantoja-Cardoso et al., 2023b)

However, studies employing cognitive dual tasks often fail to specifically align them with executive function stimuli, lacking a direct connection with aspects of planning. The perspective that changes in motor patterns are also characterized as increases in task complexity and are possible tools for increasing the cognitive load associated with task planning is also not explored in traditional Functional Training protocols. Within this framework, and in pursuit of stimulating the cognitive skills necessary for maintaining Functional Status, an alternative to Functional Training has been proposed: Brain Functional Training (Da Silva-Grigoletto et al., 2024).

4.6 BRAIN FUNCTIONAL TRAINING

Brain Functional Training is an alternative approach to applying Functional Training, while still being characterized as a multi-component method that emphasizes the synergistic, integrated, and balanced improvement of various physical capacities through multi-joint and multi-planar exercises that mimic patterns observed in daily activities. However, it incorporates specific stimuli aimed at promoting movement planning adaptations by increasing movement complexity, both through the greater difficulty of the motor pattern and through the inclusion of cognitive tasks that stimulate executive functions. It is based on the search for greater adaptations in functionality resulting from greater planning capacity (Da Silva-Grigoletto et al., 2024). Understanding planning as a higher-order executive function, resulting from the interaction between low-order executive functions, we propose increasing cognitive load throughout of Functional Training through task complexity, including motor or cognitive tasks that challenge inhibitory control, working memory, and cognitive flexibility. It is important to understand that the ability assessed in executive function tasks is closely related to the variability of movement and daily life tasks (Diamond, 2013; Hausdorff et al., 2005). In addition, the prior performance of a mental task that challenges executive functions can increase the local oxygenation of the PFC, favoring its better functioning (Dallaway et al., 2023).

An initial strategy to increase planning demands involves enhancing the motor complexity of the exercise. Motor variability is considered essential for task learning, as it supports reinforcement learning processes (Tumer; Brainard, 2007). Consequently, it is important to challenge motor variability across different movement patterns representative of daily life activities (Ranganathan; Newell, 2013). The modulation of complexity across different motor patterns will allow the individual to experience varying levels of motor variability in the diverse patterns employed in daily activities. This approach facilitates a greater mastery of the movements used in everyday tasks, thereby enhancing the individual’s ability to perform these activities with improved efficiency (Figure 2). In line with this, Gentile's Taxonomy, later expanded by Huber, provides important insights into the handling of complexity by dividing it into categories according to the characteristics of the environmental context (e.g. stationary or in motion) and the action function (e.g. no object manipulation or object manipulation) (Huber; Manser; De

Bruin, 2024). Modifications such as changes in the base of support and an increase in the number of planes used are well discussed in the article by La Scala Teixeira et al. (2019) (Figure 3).

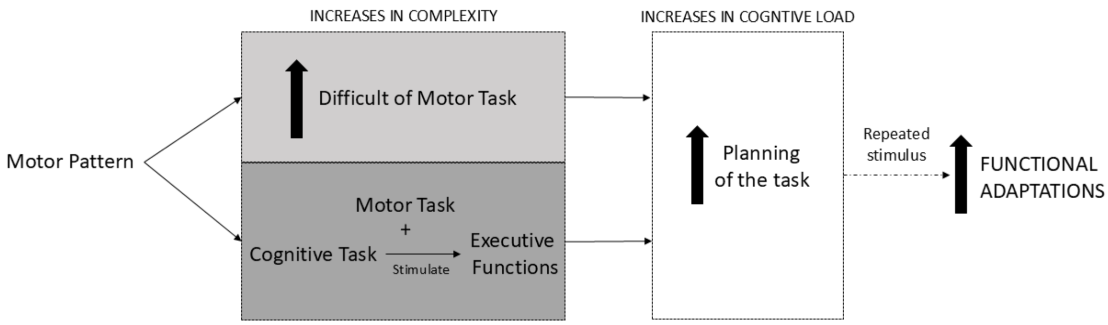

Figure 2. Practical framework illustrating how increased task complexity can generate greater cognitive load and, through repeated exposure, lead to functional adaptations.

A second way to improve task complexity in the pursuit of better planning is by considering cognitive tasks to generate cognitive paradigms in order to stimulate the low-order executive functions, specifically inhibitory control and working memory (Figure 2). A widely used example is the application of mathematical tasks while performing the movement; this type of cognitive task primarily makes use of working memory to provide answers (Diamond, 2013) (Figure 3).

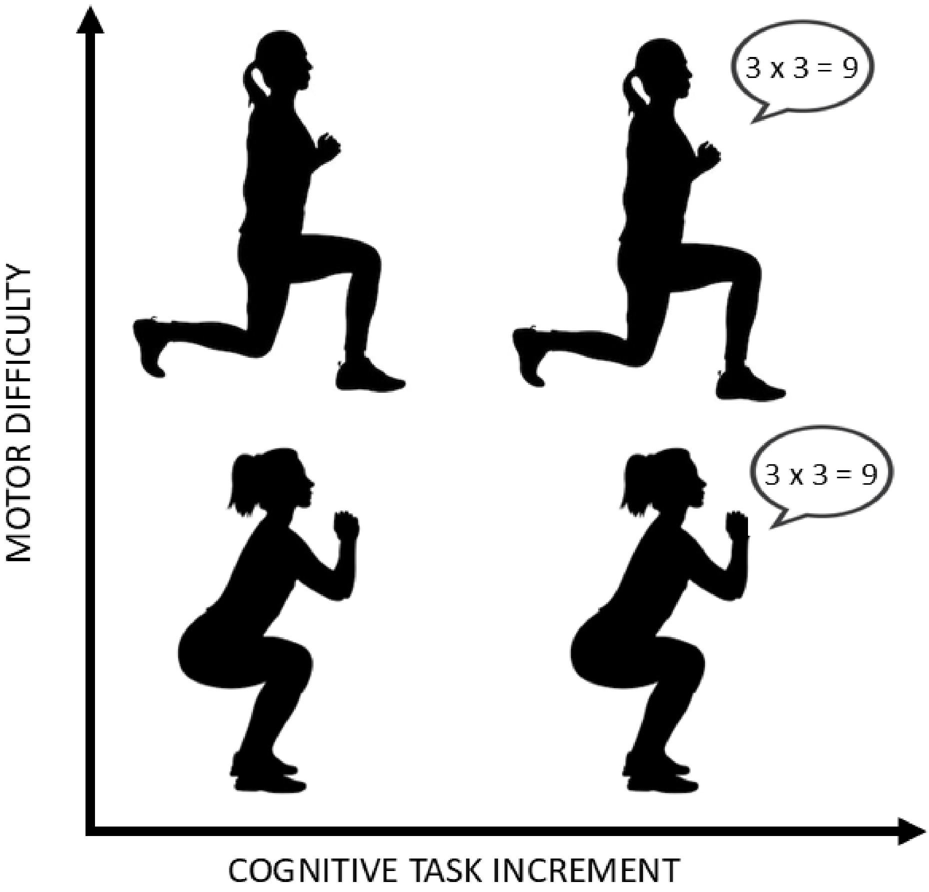

Figure 3. Possible pathways for increasing the complexity of the same task, in this case the squatting task. Note: The complexity can be increased through the motor pathway, by reducing the base of support and thereby increasing the difficulty of execution, or through the cognitive pathway, by adding an arithmetic operation task that stimulates working memory.

In this way, when analyzing how to include cognitive tasks within a training protocol, we can opt for the simultaneous approach (performed concurrently with another task) or the sequential approach (performed separately from another task) (Tait et al., 2017). We believe that the simultaneous approach is the best option due to its greater ability to generate neuroplasticity and to be closer to simulating activities of daily living (Herold et al., 2018; Tait et al., 2017). Moreover, when a task is simultaneous, it is also essential to determine whether it will be serial or parallel. Manser et al. (2024) conducted an analysis of effectiveness moderators in exergaming training models and revealed a greater effect for embedded simultaneous tasks (serial) compared to additional simultaneous tasks (parallel) (Manser; Herold; De Bruin, 2024). It is important to highlight that in both approaches, there is a modification in task complexity, which is therefore proposed as a means to increase cognitive demand in a specific motor task (Figure 2).

Once the concept of Brain Functional Training is presented, Table 1 positions this approach among other training modalities and approaches.

Table 1. Training Modalities and Approaches

Modality/Approach	Definition
Functional Training	A systematization of training that “aims at the synergistic, integrated, and balanced improvement of different physical capacities in order to ensure efficiency and safety during the performance of daily, occupational, and/or sports activities, based on the biological and methodological principles of training, notably the principle of specificity” (Da Silva-Grigoletto et al., 2020)
Brain Functional Training	An alternative approach to applying Functional Training, while maintaining its multi-component nature that emphasizes the synergistic, integrated, and balanced improvement of multiple physical capacities through multi-joint and multi-planar exercises replicating patterns observed in daily activities, focuses on the use of complexity-based strategies to induce cognitive overload related to planning, ultimately aiming to enhance functionality through improved planning capacity.
Brain Endurance Training	A training method that employs acute mental fatigue as a stimulus to induce chronic reductions in perceived fatigue during both physical and cognitive tasks, aiming to inoculate individuals against mental fatigue and thereby enhance endurance exercise performance (Staiano et al., 2023; Staiano; Merlini; Marcora, 2015).
Cognitive-Motor Training	Training interventions that require the simultaneous execution of mental and physical tasks (Wollesen et al., 2020).

4.6.1 Structure and Application of a Brain Functional Training Protocol

To present a practical example of Brain Functional Training, we adopted a previously widely used structural model for organizing Functional Training sessions (Da Silva-Grigoletto; Resende-Neto; Teixeira, 2020). In this model, the session is divided into three parts, with Part 1 aimed at preparing for movement, Part 2 for strength exercises in basic patterns, and Part 3 aimed at cardiometabolic conditioning.

In Part 1, traditional Functional Training models typically include coordinative exercises during the movement preparation phase, which directly involve cognitive aspects such as reaction time and changes in direction. We suggest that Brain Functional Training protocols should maintain this approach (Aragão-Santos et al., 2024; Pantoja-Cardoso et al., 2023b).

In Part 2, where strength exercises based on basic movement patterns are performed with high specificity and a multisystemic perspective, exercise selection should follow the principle of complexity, adapting to each participant’s individual context. According to the proposed framework (Figure 2), exercises can generate cognitive load due to their motor and technical difficulty, such as by reducing the base of support, introducing dual motor tasks, or increasing instability. Table 2 illustrates how strength exercises based on fundamental movement patterns can be incorporated into a Brain Functional Training session, considering either cognitive or motor complexity increments. These cognitive commands should preferably be performed in a simultaneous and serial manner.

Table 2. Examples of increased complexity induced by cognitive commands targeting executive functions during exercises that simulate motor patterns used in activities of daily living.

MOTOR PATTERN	**MOTOR TASK**	**COGNITIVE COMMANDS**
Carry	Farmer Walk	The task is performed under the mediation of inverse commands. When the participant hears "stop," they should begin walking; when they hear "continue," they should stop walking. Commands are delivered randomly while the participant follows a predetermined route (Supplementary video material).
Squat	Front Squat	The task is performed while simultaneously engaging in an immediate recall task for a list of words, in which one new word is added, and one previous word is omitted on each trial (Supplementary video material).
Pull	Low Rowing	The task is performed while simultaneously engaging in Stroop tasks, which are presented and responded to orally.
Push	Push up	The task is performed while simultaneously engaging in simple arithmetic operations.
Squat	Squat + Lunge	The task is performed under the guidance of commands corresponding to odd or even numbers, following a specific pre-determined pattern. For example, odd numbers cue a squat and even numbers cue a lunge. The commands alternate randomly, following the participant's natural squatting rhythm (Supplementary video material).

Note: In the last example, complexity is further increased both by the cognitive command and by the alteration of the motor pattern.

Finally, Part 3 of the training protocol may include cognitive tasks associated with motor activities such as cycling or running, ideally performed simultaneously with paradigms like the Flanker task or Go/No-Go task. This final component draws from Brain Endurance Training protocols, following the same rationale of inducing greater mental fatigue to promote relevant cardiometabolic conditioning adaptations (Staiano et al., 2023).

It is also important to emphasize that, just as exercises involving motor patterns not yet mastered by the participant may result in biomechanical alterations and improper execution, cognitive tasks should also be monitored to ensure they are being performed correctly, with continuous attention to task accuracy.

We point out that a balance should always be sought between the cognitive demands provided through summative cognitive tasks and the cognitive demands provided through greater motor complexity, requiring greater motor coordination. This cognitive load demand provided by complexity needs to be measured, as well as the need to control other internal and external loads generated by physical exercise (Impellizzeri; Marcora; Coutts, 2019). In this sense, for practical application, we can point to the use of scales to verify cognitive load (Ouwehand et al., 2021) or the accuracy of the task performed. In addition, the cognitive demand provided by physical exercise must be always be dosed so that it promotes the need for learning, thus constantly requiring interaction between diffuse brain areas (Doyon; Penhune; Ungerleider, 2003).

4.7 CONCLUSIONS AND PERSPECTIVES

This article is the first to theorize about the neurophysiological mechanisms involved in the use of Functional Training and Brain Functional Training, showing the perspectives of this training model in the search for functionality with greater emphasis on cognitive adaptations. In addition, Brain Functional Training is in line with the most recent positions on physical exercise for the older adults, which emphasize to the search for functionality.

4.7.1 Limitations and Practical Implications

We highlight that the implementation of Brain Functional Training depends on the educational background of practitioners, requiring movement professionals to adapt cognitive stimuli according to each participant's reality. Another limitation is the presence of auditory distractors in training environments, such as gyms or training studios, which often have background music. Depending on the situation, these auditory distractors may already impose demands on participants' inhibitory control, becoming an additional factor for professionals to consider. Furthermore, these auditory distractors can hinder the delivery of auditory external cues, making it necessary to use visual commands.

It is also worth noting that Brain Functional Training is a versatile approach that can be applied across various contexts. In public health, it can serve as a tool for promoting well-being among older adults, aligning with recent consensus on training strategies for this population (Izquierdo et al., 2021). Beyond its effects on functionality, the use of stimuli targeting executive functions may also help mitigate age-related declines in these domains (Ferguson; Brunsdon; Bradford, 2021). In this sense, Brain Functional Training aims to improve functionality through basic patterns that can be assessed with simple tests such as the Five Times Sit To Stand Test (Goldberg et al., 2012) or Timed Up and Go test (Podsiadlo; Richardson, 1991). Ensuring safety in this population is essential, as exercises commonly classified as highly complex may not be feasible for all participants. This type of approach can be delivered either in group settings or individually.

Within the health perspective, this model is particularly relevant for populations with neurological conditions, in which increases in training intensity may not be feasible or may be insufficient to produce the necessary neuroplastic effects, such as in women with breast cancer or individuals with attention-deficit/hyperactivity disorder (Garland et al., 2024; Willcutt et al., 2005).

In rehabilitation settings, functionality should remain the primary target (Pelicioni et al., 2016). In this context, Brain Functional Training represents an alternative for increasing training intensity in situations where morphological adaptations are not sufficient to allow further progression of external load. This may apply, for example, to young athletes with preserved cognitive function who, after traumatic injuries and prolonged periods of rest, experience morphological losses such as reduced muscle mass and perceptual deficits resulting from damage to ligamentous structures. For these groups, it is particularly relevant to consider basic patterns assessed through tests like the neurocognitive single-leg hop test, which overlays neurocognitive demands onto traditional functional performance testing to quantify both physical and cognitive/visual-motor capabilities, which are essential in sport-specific environments (Millikan et al., 2019).

Regarding safety, it is always necessary to ensure that the complexity of the applied tasks does not exceed the morphological readiness of the structures involved, such as the premature inclusion of change-of-direction exercises in patients recovering from anterior cruciate ligament reconstruction.

Additionally, Brain Functional Training is well-suited for training and rehabilitation in individuals with cognitive impairments, due to its emphasis on cognitive processes and the stimulation of executive functions.

4.7.2 Future Research Directions

We highlight the need for experimental studies applying Brain Functional Training across different populations, such as older adults and individuals in rehabilitation settings, to evaluate its effects on functionality within a health context. In this scenario, it is particularly important to conduct randomized clinical trials comparing more complex models (Brain Functional Training protocols) with less complex ones (traditional Functional Training protocols).

We emphasize the importance of assessing functional outcomes in studies with repeated-measures designs using assessments that closely reflect daily-life functionality.

Such measures include the five-repetition sit-to-stand test, which is widely recognized for its relevance to health and as a determinant of sarcopenia (Cruz-Jentoft et al., 2019; Goldberg et al., 2012); the Timed Up and Go test, which evaluates balance and is associated with fall risk (Montgomery et al., 2020; Podsiadlo; Richardson, 1991); and the 10-meter walk test, which reflects key aspects of an individual's cognitive health (Grande et al., 2019). Moreover, it is also relevant to include subjective assessments that reflect the patient's real-life context, such as the Patient-Specific Functional Scale (PSFS) (Pathak; Sharma, 2023), in which the patient identifies activities that are personally meaningful yet difficult to perform and provides an objective rating for each on a scale from 0 to 10. This type of assessment has a personalized and subjective nature, reflecting the individual's own perception of functionality in specific tasks.

In addition, it is necessary to clearly understand the neural mechanisms involved in increased complexity, and in this sense, we highlight the need for studies that verify the acute responses to Brain Functional Training protocols. In these studies of acute response, we suggest using equipment to measure activity in the prefrontal region, such as neuroimaging and fNIRS scans, as well as indicators of mental fatigue, using ocular measurements.

5 ESTUDO II – IMPACTO DE DIFERENTES NÍVEIS DE COMPLEXIDADE DURANTE A TAREFA DE AGACHAMENTO SOBRE O ESFORÇO COGNITIVO E O DESEMPENHO FÍSICO EM MULHERES IDOSAS

Título: *Impact of Different Levels of Complexity During the Squat Task on Cognitive Effort and Physical Performance in Older Women*

Idioma: Inglês

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5.1 BACKGROUND

Task complexity is a fundamental concept in movement neuroscience, defined as the dynamic interaction among motor, sensory, and cognitive components involved in the execution of an action (Shumway-Cook; Woollacott, 2007). This interaction is critical because it determines the level of planning, postural control, and attentional demand required for efficient movement performance (Shumway-Cook; Woollacott, 2000). Routine motor tasks, such as walking in predictable environments, are highly automated, relying predominantly on subcortical circuit activation and requiring minimal cognitive control. In contrast, tasks of greater complexity such as dual-task performance (e.g., walking while conversing) demand more robust sensorimotor integration and greater cortical activation, resulting in greater cognitive exertion (Ross et al., 2021; Shumway-Cook; Woollacott, 2000).

The increase in task complexity is intrinsically linked to higher demands on motor and cognitive planning, which consequently elevates mental load of the task and the subsequent cognitive effort of the subject (Kunasegaran et al., 2023; Westbrook; Braver, 2015). In such scenarios, there is greater recruitment of cortical regions such as the prefrontal cortex, premotor cortex, and supplementary motor area structures closely associated with executive functions (Albuquerque; De Sousa Fortes; Lage, 2023; Diamond, 2013; Lee et al., 2024). Executive function can be defined as a collection of top-down control processes that are engaged when automatic responses or reliance on instinct or intuition are ill-advised, insufficient, or impossible (Diamond, 2013). In this context, planning is conceptualized as a higher-order executive function that emerges from the coordinated operation of core executive functions, including working memory, inhibitory control, and cognitive flexibility, thereby supporting goal-directed behavior. Nevertheless, comparisons between performance on the Tower of Hanoi task, a classic measure of planning, and the Operation Span Task, a classic measure of working memory, suggest a close association between planning-related and working memory-related scores (Ferguson; Brunsdon; Bradford, 2021).

Indeed, Marvel et al. (2019) highlight the close interplay between cognition and motor control, showing that motor regions traditionally considered secondary for movement execution, including the premotor cortex and the supplementary motor area, also contribute to working memory, thereby supporting action planning and preparation. This mechanism may confer an advantage through the generation of motor traces that strengthen internal representations of information, suggesting that complex motor task execution relies not only on biomechanical control but also on executive processes critical for action adjustment and monitoring (Oliveira et al., 2018).

Aligned with this perspective, the study by Lee et al. compared four walking conditions (straight walking, curved walking, straight walking with a concurrent cognitive task, and curved walking with a concurrent cognitive task) and showed that, during locomotor tasks performed concurrently with cognitive demands (dual-task conditions), there is a significant increase in prefrontal cortex activation compared with single-task performance (Lee et al., 2024). These findings suggest that increasing motor complexity and adding cognitive components to dynamic tasks reduce motor automatization and require greater engagement of neural networks responsible for planning, attention, and executive control (Van Ruitenbeek et al., 2022).

The immediate cortical responses observed under conditions of higher motor complexity provide the neurophysiological basis for the adaptive processes triggered by functional and cognitive training programs (Hülsdünker et al., 2025). In this context, the framework proposed by Pereira-Monteiro et al. (2026) posits that increasing task complexity directly amplifies planning demands and subsequent cognitive effort, promoting, in repeated effects, adaptations in functionality. This model suggests that both motor and cognitive pathways can be modulated by the level of challenge imposed, thereby enhancing neural mechanisms underlying coordination and attentional control.

Such cortical demands are reflected in measurable physiological and behavioral responses. Specifically, mental load can be assessed through subjective questionnaires, attention-based tests, reductions in task performance, and physiological measurements (Bafna; Hansen, 2021). Among physiological indicators, pupillometry has emerged as a noninvasive tool for assessing pupillary changes that directly reflect mental load associated with task demands (Bafna; Hansen, 2021; Bauer et al., 2022). Transient pupil dilation, linked to activation of the locus coeruleus-noradrenaline system (LC-NA), is a robust indicator of increased cognitive effort (Zou et al., 2023). Conversely, blink rate has also been identified in the literature as an important indicator of cognitive effort, being associated with alertness level and serving as a proxy for the status of the dopaminergic system (Arezes et al., 2015; Zou et al., 2023). Additionally, cognitive effort can be assessed through behavioral indicators such as response time and accuracy widely used in neuropsychological testing to reflect executive performance (Rubio-Morales et al., 2022).

Particularly, with advancing age, a gradual and significant decline in executive functioning occurs, particularly after early adulthood (Ferguson; Brunsdon; Bradford, 2021). In older women, this decline may be exacerbated by reduced estrogen levels, a hormone with neuroprotective and cognition-modulating roles (Martino et al., 2022). The decreased efficiency of executive function compromises the ability to plan and adapt motor behavior to more challenged contexts, especially in tasks requiring divided attention and simultaneous postural control (Seidler et al., 2010). Indeed, in tasks designed to assess three-dimensional working memory, both in a reaching-based format using the classical Corsi Block-Tapping Test and in a locomotor format using the Walking Corsi Test, age emerged as the only factor associated with performance when the confounding variables of sex and physical activity level were controlled (Pereira-Monteiro et al., 2026a).

Given this bidirectional relationship between cognition and movement, analyzing functional motor tasks represents a relevant strategy for understanding how increased cognitive complexity impacts motor control in older women. Among such tasks, squatting stands out because it involves multiple body segments and requires dynamic postural control. It is widely used in both clinical contexts and resistance training programs for older women (Aragão-Santos et al., 2024; Izquierdo et al., 2025; Resende-Silva et al., 2025).

Manipulating the complexity of the squat task by introducing simultaneous motor or cognitive demands (dual-task conditions) allows for controlled observation of how additional cognitive challenges affect physical performance, cognitive outcomes, and cognitive effort in older women. It has been suggested that the squatting task, even under low-load conditions, requires cognitive resources, negatively impacting accuracy and the total number of responses in a mental arithmetic task when compared with a standing condition (Herold et al., 2020). Therefore, the dual-task squat represents an appropriate experimental model for investigating the interaction between motor and cognitive demands in older women.

Despite advances in understanding the interaction between motor and cognitive demands, it remains unclear how different levels of cognitive complexity modulate physical performance and cognitive effort during functional tasks such as squatting. Although experimental research has largely focused on gait or balance tasks under dual-task conditions (Akizuki et al., 2025; Jardim et al., 2021) investigations of other functional patterns such as the squat, which has high transferability to daily activities and constitutes a fundamental movement pattern in resistance training for older women remain scarce. Therefore, the aim of the present study was to investigate the impact of different levels of squat task complexity on physiological markers of cognitive effort (pupil dilation and blinks frequency), physical performance (kinematic variables) and executive performance (reaction time and accuracy) in older women. Our hypothesis is that tasks with a higher level of complexity will result in a greater level of cognitive effort and will also lead to greater reductions in both physical and executive performance when compared to tasks with a lower level of complexity.

5.2 METHODS

5.2.1 Experimental Design

This was an experimental, cross-over, and randomized clinical trial investigated the acute-effects of different levels of task complexity during squatting. The protocol involved manipulating a cognitive task based on mathematical subtraction and a motor task represented by biomechanical variations of the squatting movement. The conditions included squat task (SQ), isolated cognitive task (Cog), squat with cognitive task (SQCog), lunge task (SQMot), and lunge with cognitive task (SQCogMot). Outcomes were cognitive effort, assessed through pupil dilation, blink frequency, and Stroop Word-Color Task (SWCT) performance, and movement kinematics, evaluated by movement velocity and range of motion.

Each participant completed two preliminary visits prior to the experimental sessions. The first visit was dedicated to exercise familiarization and anchoring of the OMNI-GSE scale, while the second focused on learning the SWCT in accordance with the procedures described by Farias et al. (2024). The overall flow of the experiment is illustrated in Figure 4.

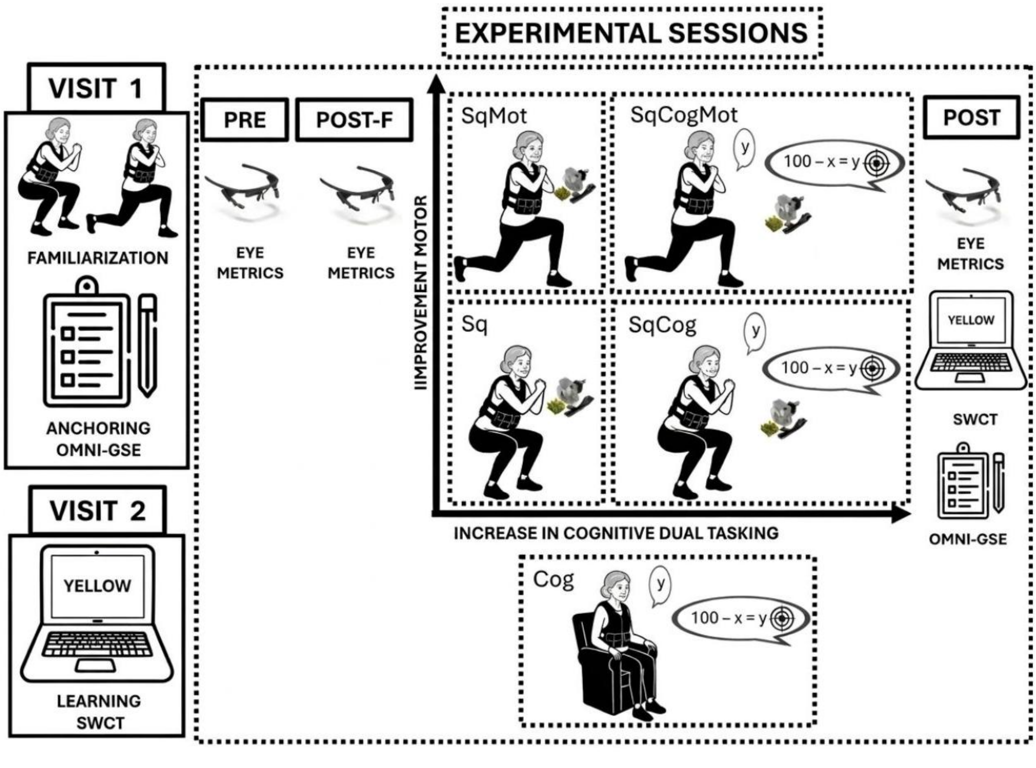

Figure 4. Experimental Design

5.2.2 Sample

The sample size calculation was based on the results of the average pupil size from the study by Claußen and Heidelbach (2024) (Claußen; Heidelbach, 2024). Considering a statistical power of 0.80, a significance level of 0.05, and an effect size f of 0.30, 15 individuals were deemed necessary, considering one group and five measures, to detect differences within factors. Participants were recruited from city in Brazil. Inclusion criteria were: female sex, age between 60 and 75 years, absence of menstrual bleeding in the past 12 months, absence of color blindness, ability to read, no musculoskeletal or cardiovascular contraindications to exercise, and a minimum score of 24 on the Montreal Cognitive Assessment (MoCA). Exclusion criteria included the presence of symptoms or conditions that could prevent the safe performance of the prescribed exercises.

Participants were instructed to abstain from vigorous exercise and alcohol consumption for 24 hours prior to testing and to avoid caffeine intake within 12 hours of their laboratory visits. All participants received detailed information regarding the study objectives, procedures, risks, and benefits, and provided written informed consent (Appendicle A). The protocol was approved by the local Research Ethics Committee (protocol number: 5.877.029) and conducted in accordance with the Declaration of Helsinki. After expressing interest, volunteers underwent an interview and completed a registration form to collect personal information.

5.2.3 Procedures

All experimental sessions were conducted in a room with controlled artificial lighting, no external light, and no ambient noise, with a temperature of 22°C, in order to avoid variations in luminosity and temperature that could interfere with the pupillary metrics. To ensure correct performance during the tasks, all protocols were supervised by a physiotherapist and a physical education professional. To reduce the potential influence of pre-assessment factors, such as physical activity during transportation to the laboratory or traffic-related stress, participants were allowed a resting period before each evaluation protocol. Assessments were initiated only after participants reported feeling calm and approaching their habitual resting condition. Given that outcome measures were obtained after completion of the eight-set protocol, the observed responses represent the cumulative effect of the exercise session.

5.2.3.1 Task protocol

Before each task, participants performed four sets of 30 seconds of lower-limb stretching, which served as a standardized preparatory phase before task execution. During this period, instructions regarding the upcoming exercise were provided, functioning as a familiarization moment with the movement to be performed on that day (POST-F). In the sessions involving Sq variations (Sq, SqCog, SqMot, and SqCogMot), the exercises were performed with an external load equivalent to 10–20% of body mass, applied using a weighted vest, and consisted of eight sets of 10 repetitions in maximal velocity. To ensure standardization during SqMot and SqCogMot, a tape was used to fix foot positioning and maintain the same stance across all sets.

The cognitive tasks (Cog, SqCog, and SqCogMot) consisted of ten mathematical subtraction operations starting from 100. The subtraction interval varied according to the series: in series 1 and 5, participants subtracted by 3; in series 2 and 6, by 4; in series 3 and 7, by 5; and in series 4 and 8, by 6. Accuracy was recorded at the end of each serie.

5.2.3.2 Evaluation Protocols

All the assessments were performed in a silent room with no external auditory stimuli, thereby minimizing potential environmental influences on visual attention. To ensure standardization of ocular measurements in moments PRE, POST-F and POST, during eye-tracking data acquisition, participants were seated comfortably and instructed to maintain their gaze on a blank white target positioned on the wall at eye level.

Cognitive effort was monitored using the Pupil Lab Core device (Berlin, Germany) recording at a frequency of 200Hz. Pupil diameter of the left eye was recorded for 10 seconds and blink frequency for 2 minutes, both assessed at three time points: before the task (PRE), after the preparation and familiarization with movement (POST-F), and immediately after the task (POST). Raw data were processed using the Pupil Player software, version 3.5.1.

During data processing, pupillary signals were analyzed at the same sampling frequency at which they were collected. From the pupillometry data, both peak pupil dilation and mean pupil diameter were extracted, considering raw values as well as values corrected relative to baseline. The baseline was defined based on the pre-measurement period.

Specifically, preprocessing procedures were implemented following established approaches described in the literature (Mathôt; Vilotijević, 2022).

The preprocessing pipeline included: (i) masking samples with low tracking confidence (confidence < 0.7); (ii) identification of time windows contaminated by blinks, excluding intervals with margins of 50 ms before and 150 ms after each blink; (iii) detection of remaining outlier samples using a MAD criterion (Leys et al., 2013); (iv) linear interpolation of signal gaps up to 1000 ms; (v) smoothing of the signal using a 4 Hz Butterworth low-pass filter; and (vi) temporal downsampling of the preprocessed pupil time series to 100 Hz to standardize the temporal resolution across recordings and reduce data redundancy. This step was omitted when the native sampling rate was already sufficiently close to 100 Hz. In addition, potentially extreme data points were visually inspected. For peak pupil diameter, minimal preprocessing was preferred, as aggressive filtering and smoothing may attenuate transient maxima and underestimate peak amplitude.

To ensure data quality, a minimum threshold of 70% valid signal per sample was established. The proportion of interpolated data was also recorded and is reported in the results.

Blink frequency was determined by counting all instances in which pupil diameter dropped below 0.15 mm with a duration shorter than 1000 ms (O'Connor; Petruzzello, 1992).

Executive performance was assessed at the end of each intervention by measuring response time in congruent and incongruent trials of the SWCT. The test was presented on a 15-inch computer screen displaying color words that could be congruent (semantic content = word color) or incongruent (semantic content ≠ word color). Participants were instructed to identify the color of the word while ignoring its semantic meaning. The test included 44 incongruent trials and 18 congruent trials. Accuracy (percentage) and response time (milliseconds) were recorded using PsychoPy software version 2024.2.4 (PsychoPy, Oxford, United Kingdom) (Faria et al., 2024).

The kinematic variables were recorded using a linear encoder attached to the participants' waist with a belt. The recorded parameters were execution velocity (m/s), range of motion (cm), and total time to complete each series. The data were processed using the Chronojump software (Sydney, Australia).

Perceived exertion was recorded at the end of each session using the OMNI-GSE scale, ranging from 0 to 10 (Da Silva Grigoletto, 2013). Task preference was assessed immediately after all experimental sessions by asking participants to select their preferred task among the performed conditions through the following question: "Which of these exercises would you prefer to perform in a training program?".

5.2.4 Statistical Analysis

For the analysis of pupillometric and blink-related variables, a generalized linear mixed model (GLMM) was employed, including participant as a clustering variable, with a gamma distribution and an identity link function. Fixed effects were specified as Condition (Sq, Cog, SqMot, SqCog, and SqCogMot) and Time (PRE, POST-F, and POST), as well as their interaction (Condition × Time). A random intercept was included for each participant. The equation model adopted was: $[\text{DEPENDENT VARIABLE}] \sim 1 + \text{CONDITION} + \text{TIME} + \text{CONDITION:TIME} + (1 \mid \text{PARTICIPANT})$.

A similar analytical approach, including only the Condition factor, was applied to examine kinematic variables (velocity and range of motion). Condition was also the sole factor considered for comparisons between experimental sessions and the baseline session for the following outcomes: congruent and incongruent response times in the SWCT, perceived exertion, velocity and range of motion, and accuracy. The equation model adopted was: $[\text{DEPENDENT VARIABLE}] \sim 1 + \text{CONDITION} + (1 \mid \text{PARTICIPANT})$. Bonferroni-adjusted post hoc tests were conducted to examine significant effects of Condition.

In addition, a sensitivity analysis was conducted for pupillometric, blink-related, and SWCT outcomes by restricting the sample to participants with MoCA scores ≥ 27. This analysis aimed to determine whether the observed findings were maintained among individuals with higher cognitive performance.

To verify whether there was a difference in the frequency of preference among the experimental conditions, a chi-square goodness-of-fit test was performed.

All statistical analyses were conducted using jamovi (Jamovi, 2022; The jamovi project, 2024), and graphical representations were generated using GraphPad Prism and RStudio. The level of statistical significance was set at $p < 0.05$.

5.3 RESULTS

A total of 15 women were assessed, with a mean age of 67.5 ± 4.9 years and a median MoCA score of 27, with a minimum of 24 and a maximum of 30. Regarding the pupil response, a significant session*time interaction effect was found for peak pupil dilation ($\chi^2(8) = 16.50$; $p = .036$). No significant differences were observed between the PRE and POST-F moments ($p > .05$) for any comparison. However, when comparing the PRE to POST moments, increases were observed relative to the Sq condition: 0.606 mm ($p = .037$) in the SqCog condition, and 0.836 mm ($p = .008$) in the SqMot condition (Figure 5 and 6). The intercept value was 2.70 mm. The interpolation rate averaged 9,4% with a standard deviation of 8.1%.

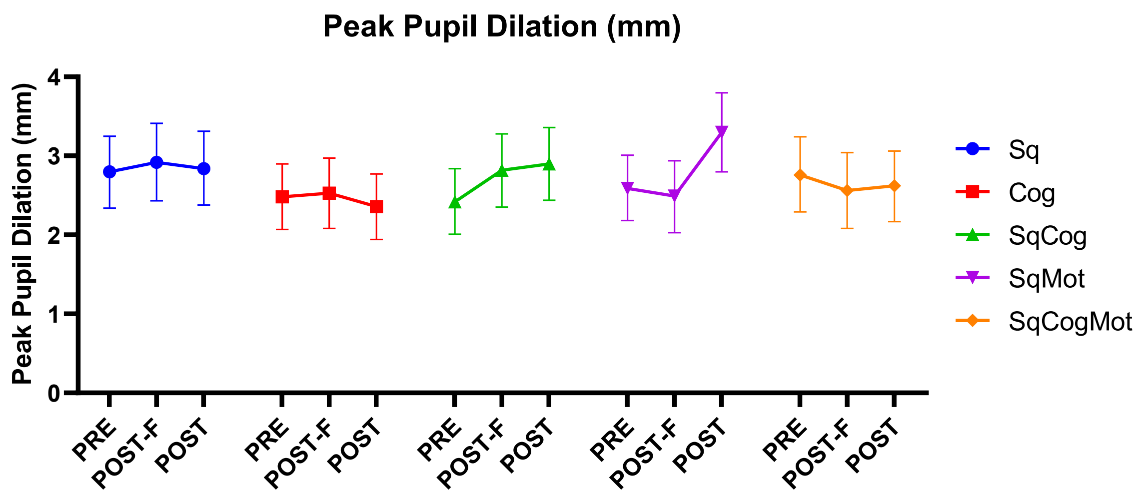

Figure 5. Descriptive Peak Pupil Dilation data

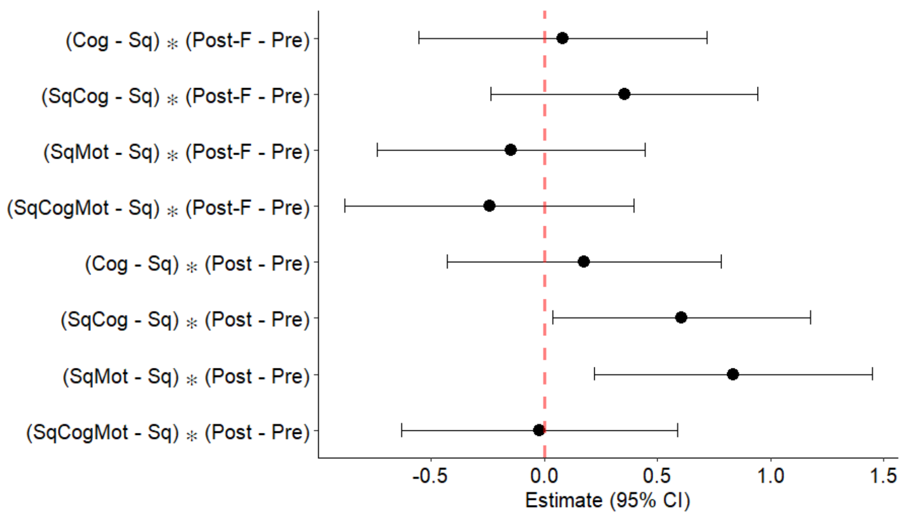

Figure 6. Peak Pupil Dilation interactions of GLMM

In the sensitivity analysis, which included 11 participants with MoCA scores ≥ 27, a significant session*time interaction effect was found for peak pupil dilation ($\chi^2(8)$ = 17.64; p = .024).. Similar to the findings in the full sample, no significant differences were observed between the PRE and POST-F moments (p > .05) for any comparison. However, when comparing the PRE to POST moments, an increase of 0.726 mm (p = .038) was observed in the SqMot condition relative to the Sq condition, but not was noted an increase in the SqCog condition relative to the Sq condition. The intercept value was 2.64 mm. The interpolation rate averaged 8.1% with a standard deviation of 7.1%.

On the other hand, there was no significant session*time interaction effect for mean pupil size (F(8) = 0.89; p = .524) or delta pupil size (F(8) = 0.96; p = .473), in this case, the interpolation rate averaged 11,8% with a standard deviation of 7.9%. No significant effects were observed for blinks in the session*time interaction ($\chi^2(8)$ = 4.93; p = .765) or for the main effect of time ($\chi^2(2)$ = 1.52; p = .765). In the sensitivity analysis, no significant interaction effects were observed for mean pupil size (p = .235) blinks (p = .801)

Regarding the SWCT, no significant effects were found for response time in the congruent condition ($\chi^2(5)$ = 2.95; p = .708) or the incongruent condition ($\chi^2(5)$ = 1.75; p = .882). No significant effect was found for the Stroop effect either ($\chi^2(5)$ = 5.37; p = .372) (Table 3). The sensitivity analysis showed no significant effects on response time in the congruent condition (p = .673), the incongruent condition (p = .853), or the Stroop effect (p = .158).

Table 3. SWCT results after the protocol of task.

SESSION	BASAL	Sq	Cog	SqCog	SqMot	SqCogMot
Congruent Accuracy (%)	100 ± 0	100 ± 0	99.6 ± 1.48	100 ± 0	99.6 ± 1.43	100 ± 0
Incongruent Accuracy (%)	99.8 ± 0.58	99.2 ± 1.85	99 ± 3.05	99.8 ± 0.58	100 ± 0	99.8 ± 0.63
Congruent RT (ms)	897.7 ± 157.56	898.2 ± 126.76	914.5 ± 132.76	905.6 ± 130.74	942 ± 200.14	916.9 ± 208.54
Incongruent RT (ms)	976.2 ± 157.42	950.4 ± 168.05	982.3 ± 162.23	957.5 ± 153.94	972.9 ± 202.23	961.1 ± 171.09
Stroop Effect (ms)	78.5 ± 63.65	52.2 ± 60.32	67.8 ± 62.74	51.9 ± 62.53	30.9 ± 62.84	44.2 ± 76.41

About the execution time, when considering the eight series and examining the session effect across them, significant differences were found, $\chi^2(4)$ = 98.40, p < .001. Based on model estimates, compared with the Sq condition, the Cog condition showed an increase of 18.46 s ($p < .001$), the SqCog condition showed an increase of 18.88 s ($p < .001$), the SqMot condition showed an increase of 1.95 s ($p = .230$), and the SqCogMot condition showed an increase of 16.81 s ($p < .001$). Post hoc comparisons revealed that SqMot differed from Cog ($p < .01$), SqCog ($p < .001$), and SqCogMot ($p < .001$) (Table 4).

In respect of the velocity of motion, no significant differences were found among the different conditions, $F(3) = 2.02$, $p < .126$. On the other hand, the range of motion showed significant differences between conditions, $\chi^2(3) = 132.00$, $p < .001$. Based on model estimates, compared with the Sq condition, the SqMot condition showed a reduction of 11.72 cm, and the SqCogMot condition showed a reduction of 11.75 cm, both with $p < .05$. Post hoc analyses revealed differences between SqMot and SqCog ($p < .001$) and between SqCog and SqCogMot ($p < .001$), but not between SqMot and SqCogMot ($p = 1.000$) (Table 4).

Regarding accuracy, $\chi^2(2) = 15.1$, $p < .001$, model estimates indicated significant differences for the Cog condition SqCogMot (-0.715, $p < .001$). Regarding PSE, no significant effects were observed ($p = .280$).

Finally, no statistically significant differences were found in task preference ($\chi^2(2) = 0{,}400$, $p = 0{,}819$.), with 6 participants (40%) preferring the Sq condition, 4 participants (26%) preferring the SqCog condition, and 5 participants (33%) preferring the SqMot condition (Table 4).

Table 4. Kinematic variables, accuracy, perceived exertion and preference regarding different tasks.

	Sq	Cog	SqCog	SqMot	SqCogMot
Time (s)	17.32 ± 2.92 †#§	39.6 ± 20.2*$	38.76 ± 13.38*$	19.37 ± 3.96 †#§	38.39 ± 14.16*$
Velocity (m/s)	0.55 ± 0.15	NA	0.29 ± 0.06	0.32 ± 0.06	0.43 ± 0.69
Range (cm)	34.83 ± 5.23 $§	NA	33.35 ± 6.47 $§	23.8 ± 4.2 *#	23.1 ± 5.87 *#
Accuracy (%)	NA	82.1 ± 19.0 §	76.7 ± 18.4	NA	75.9 ± 22.0 †
Exertion	4.73 ± 1.09	4.42 ± 1.65	5.00 ± 1.30	4.60 ± 1.12	5.23 ± 1.42
Preference	6 (40%)	0 (0%)	4 (26.7%)	5 (33.3%)	0 (0%)

Note: NA: Not Applicable. *: Difference relative to the Sq condition, based on the model interaction analysis; †: Difference relative to the Cog condition, based on Bonferroni post hoc analysis; #: Difference relative to the SqCog condition, based on Bonferroni post hoc analysis; $: Difference relative to the SqMot condition, based on Bonferroni post hoc analysis; §: Difference relative to the SqCogMot condition, based on Bonferroni post hoc analysis.

5.4 DISCUSSION

The present study demonstrated a significant increase in cognitive effort during the performance of more complex squatting conditions (squatting combined with mental arithmetic, squatting with single-limb predominance) when compared with the traditional Sq, with the exception of the combined condition (squatting with single-limb predominance and mental arithmetic). Despite the higher cognitive demand associated with increased task complexity, no differences were identified between the different levels of complexity in immediate executive performance. Regarding physical performance, increasing task complexity through a cognitive pathway resulted in longer task execution time and did not alter movement velocity. Notably, when complexity was increased through a predominantly motor demand, a reduction in range of motion was also observed. In this context, no differences were found in perceived exertion across the evaluated conditions.

The increase in peak pupil dilation under more complex conditions (SqCog and SqMot), compared to Sq, supports the sensitivity of pupillometry as a real-time marker of increased cognitive load in older adults (Piquado; Isaacowitz; Wingfield, 2010). Pupil dilation is modulated by the LC-NA, which is activated proportionally to the demands for executive control and selective attention (Van der Wel; Van Steenbergen, 2018). In particular, this system responds to cognitive effort by increasing activity in the pupillary dilator muscle and inhibiting the Edinger–Westphal complex of the oculomotor nucleus, leading to relaxation of the sphincter muscle (Granholm; Steinhauer, 2004). In this sense, our findings suggest that both the inclusion of an arithmetic task, which predominantly relies on working memory, and the transition to a more unstable motor pattern require a more robust recruitment of cortical resources, likely involving the prefrontal cortex and supplementary motor areas to maintain task stability and accuracy (Lee et al., 2024; Marvel; Morgan; Kronemer, 2019).

Interestingly, the task with the highest level of both cognitive and motor complexity (SqCogMot) did not differ from the simplest condition (Sq). One possible explanation lies in the study design itself, as during each visit a prior explanation of the task to be performed that day was provided to the participants. This may have influenced LC-NA activation due to an initial cognitive effort required to learn the movement, potentially altering baseline levels and affecting subsequent changes (Bicalho et al., 2019; Van der

Wel; Van Steenbergen, 2018). Another possibility relates to task execution. In this condition, the movement pattern clearly involves a reduced range of motion compared to a traditional squat, as well as lower accuracy compared to an isolated cognitive task. This may reflect a level of technical difficulty that prevents effective task performance. This interpretation is further supported by the fact that none of the participants selected this condition as their preferred task.

On the other hand, mean pupil size did not differ across conditions. These findings are consistent with the work of Albuquerque et al., who showed that exercising closer to the aerobic threshold did not change average pupil size (Albuquerque et al., 2023). Additionally, we did not observe an increase in delta pupil size, which has been reported under a similar stimulus when the squat task was performed on an unstable base compared with a stable base (Claußen; Heidelbach, 2024). One possible explanation lies in the characteristics of the population, as older adults may present chronic hyperactivation of the LC-NA system, leading them to exhibit smaller evoked pupil responses during active tasks. This may hinder the detection of differences in mean or delta pupil values (Kim et al., 2026; Piquado; Isaacowitz; Wingfield, 2010).

Similarly, blink rate did not show significant variations across conditions. Although blink frequency is often associated with dopaminergic activity and levels of alertness, and changes have been reported in the context of repetitive practice during motor learning (Bicalho et al., 2019), its sensitivity may be reduced in tasks that require continuous visual fixation, as in the present study, in which participants were instructed to fix their gaze on a sheet of paper (Mahanama et al., 2022).

The sensitivity analysis suggests the presence of subtle differences between individuals with lower and higher cognitive performance regarding cognitive effort. Specifically, when the analysis was restricted to participants with higher cognitive status (MoCA $\geq$ 27), only the increase in motor complexity was associated with a significant increase in cognitive workload, as reflected by peak pupil dilation. In contrast, the cognitive and combined conditions no longer differed significantly from the reference condition. One possible explanation is that the level of difficulty imposed by the cognitive task was insufficient to elicit substantial cognitive effort among participants with higher cognitive performance. As a result, the cognitive demands of the task may have remained below the threshold necessary to produce detectable changes in pupillary responses. Conversely, the increased motor complexity may have represented a more salient challenge, requiring greater attentional and executive resources even among cognitively preserved individuals (Lee et al., 2015).

It is noteworthy that, despite the increase in cognitive effort immediately after performing the more complex tasks, there were no significant effects on SWCT performance. This suggests that the protocols used in this study were not sufficient to induce a state of heightened cognitive activation, as observed in studies with young and patients with breast cancer. (Albuquerque et al., 2023; Salerno et al., 2020). It is also important to note that the task protocol did not increase SWCT scores, indicating that it was not sufficient to induce a state of mental fatigue (Bafna; Hansen, 2021). This last finding may be explained by the participants' high baseline cognitive level (minimum MoCA = 24), indicating preserved cognitive reserve (Stern, 2009).

The reduction in range of motion under conditions of greater motor complexity, as well as the decrease in accuracy in more complex cognitive tasks, can be explained by capacity-sharing theory, which posits that the human brain has finite resources for information processing. When two tasks compete for these resources, a decline occurs in one or both performances (Tombu; Jolicœur, 2003; Wu; Wang, 2024). In the present study, participants appeared to adopt a posture-first strategy, reducing velocity and range of motion to ensure balance and accuracy in the arithmetic task (Shumway-Cook; Woollacott, 2000). The more pronounced reduction in range of motion in conditions with greater motor complexity (SqMot and SqCogMot) suggests that the biomechanical demands of the lunge impose a higher motor planning load than the traditional squat. Similarly, increasing complexity through a motor pathway impacted accuracy in the same cognitive task (SqCogMot compared with Cog). This greater need for sensorimotor integration to manage a reduced base of support likely consumes resources that would otherwise be allocated to movement efficiency or to performance in the cognitive paradigm (Wu; Wang, 2024).

A relevant point of discussion is the dissociation between physiological markers and perceived exertion. Although pupillary metrics indicated a higher mental load, participants did not perceive the more complex tasks as more exhausting. This discrepancy suggests that RPE may be more strongly influenced by peripheral metabolic and mechanical load than by the demands of cerebral processing in short-duration tasks.

These findings are not fully aligned with those reported by Marcora et al. (2009), who demonstrated that increased mental exertion can elevate perceived effort during subsequent physical performance (Marcora; Staiano; Manning, 2009). From a clinical perspective, this implies that movement professionals should not rely exclusively on subjective reports from older women to monitor the cognitive load of an exercise session.

The main limitation of the present study is that eye-tracking metrics were collected only immediately before and after exercise, making it impossible to assess cognitive load during movement execution. Given the transient nature of pupillary responses, important fluctuations in cognitive demand may have occurred during task performance and remained undetected by our assessment protocol. Furthermore, pupillary measures in older adults should be interpreted with caution, as aging is associated with a chronically elevated tonic activity of the locus coeruleus–noradrenergic (LC–NA) system, as well as age-related changes in ocular health that may reduce pupil responsiveness and limit the sensitivity of pupillometry to detect exercise-induced effects (Kim et al., 2026). Nevertheless, significant changes in peak pupil diameter were still observed despite these methodological and physiological constraints, suggesting that pupillometry retained sufficient sensitivity to detect exercise-related effects in this sample. Future studies employing mobile eye-tracking systems capable of recording ocular metrics during movement may provide a more sensitive and ecologically valid approach for characterizing cognitive load throughout exercise execution.

Taken together, the findings of the present study indicate that the manipulation of task complexity was able to alter the internal cognitive–motor load of exercise, even in the absence of substantial changes in external load or perceived exertion. This pattern suggests that complexity acts as a qualitative modulator of the stimulus, redistributing attentional resources, reorganizing movement strategies, and imposing additional demands on motor planning.

5.5 CONCLUSION

Increasing squat task complexity elevated physiological markers of cognitive effort, particularly peak pupil dilation, but did not translate into changes in mean pupil size, blink rate or immediate executive performance. Furthermore, greater complexity led to measurable kinematic adaptations, including increased execution time when a cognitive task was added and reduced range of motion when complexity was increased through a motor pathway, while movement velocity remained unchanged. Overall, task complexity during exercise modulated cognitive load and motor behavior in older women without affecting perceived exertion.

6 ESTUDO III – EFEITOS REPETIDOS DO *BRAIN FUNCTIONAL TRAINING* SOBRE O ESTADO FUNCIONAL E A COMPOSIÇÃO CORPORAL DE MULHERES NA PÓS-MENOPAUSA: UM ENSAIO CLÍNICO RANDOMIZADO

Título: *Repeated Effect of Brain Functional Training on Functional Status and Body Composition of Postmenopausal Women: A Randomized Controlled Trial*

Idioma: Inglês

Estado atual: Submetido (Anexo – B)

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6.1 BACKGROUND

Recently, it has been highlighted by the scientific literature that there is widespread evidence of the use of physical exercise to improve the health of older people (Garatachea et al., 2015). This age group is widely affected by various declines in physical fitness and physiological systems, including harmful changes in body composition (e.g., marked by the significant reduction in lean mass with women showing less lean mass in the upper limbs compared to men) (Janssen, 2004), strength (Dodds et al., 2014), and cognitive skills over time (Ferguson; Brunsdon; Bradford, 2021). Among the non-pharmacological strategies to mitigate the deleterious effects of aging, physical exercise stands out, particularly Functional Training (FT), which has emerged as a fitness trend over the past six years according to the American College of Sports Medicine (Newsome et al., 2024, 2025; R. McAvoy et al., 2025; Thompson, 2019, 2021, 2022, 2023).

The FT is characterized as a multicomponent training method, utilizing multi-joint and multiplanar exercises, aiming to enhance performance in daily tasks (Da Silva-Grigoletto; Resende-Neto; Teixeira, 2020; La Scala Teixeira et al., 2017). This type of training aligns with the latest scientific literature, aiming to promote adaptations in the functional status of older adults (Fragala et al., 2019; Izquierdo et al., 2021). The definition of Functional Status in Medical Subject Headings involves the association between physical and cognitive abilities for successful performance of daily living activities (Dhammi; Kumar, 2014). Along these lines, studies have demonstrated effects on the motor aspects of Functional Status with different FT protocols, including increases in muscular strength, power output, and movement quality (De Resende-Neto et al., 2021; Vasconcelos et al., 2020). Furthermore, it is also common in the scientific literature to use tests that simulate activities of daily living. In this scenario, the study by Aragão-Santos et al. (2024) stands out, which reported improvements in tests simulating activities of daily living — such as standing up from a chair, walking around the house, and transferring objects — after 16 weeks of a 50-minute FT protocol in older women. These effects were retained after 12 weeks of detraining, preventing a return to baseline levels (Aragão-Santos et al., 2024). Regarding the physical aspects promoted by FT with respect to body composition, it has been shown that FT increases muscle mass in postmenopausal women after eight weeks of training and reduces fat mass after 12 weeks (Pereira-Monteiro et al., 2024).

Understanding, then, that besides tests focused on physical capabilities, cognitive adaptations are also important, we highlight the study by Pantoja-Cardoso et al. (2023). This study investigated the effects of FT on executive function, due to its intrinsic association with human movement (Diamond, 2013; Marvel; Morgan; Kronemer, 2019), and showed that FT reduced response time in the incongruent condition of the Stroop Word-Color Task (SWCT) (Pantoja-Cardoso et al., 2023b). This indicates an impact on executive functioning, particularly on inhibitory control, understood as the ability to inhibit irrelevant information and control impulsive behavior in daily life. No effects were found, however, in specific tests of working memory, defined as the ability to recall and manipulate recent information for a given task, or cognitive flexibility, understood as the capacity to shift a previously adopted line of reasoning for a specific purpose (Diamond, 2013)

Beyond FT, Mind Body Interventions (MBI) strategies are also pointed to as an important non-pharmacological alternative, demonstrating significant effects on the health indicators of postmenopausal women (Xu et al., 2024). Among these, Tai Chi Chuan and Qigong, both Chinese practices, are widely used to improve health in older adults, with significant effects on balance (Bertolini et al., 2024; Carcelén-Fraile et al., 2021), strength (Carcelén-Fraile et al., 2021), and cognitive performance (Guazzarini et al., 2024). On the other hand, these mind-body practices lack stimuli aimed at improving muscle strength and power output, considered essential factors for enhancing functionality. So, it is important to go through some training methods that could stimulate both physical (e.g., strength, power output) and cognitive (e.g., executive functions) skills simultaneously.

In this context, with the growing demand for cognitive adaptations alongside physical adaptations, Brain Functional Training (BFT) was proposed in 2024 (Da Silva-Grigoletto et al., 2024), offering an alternative perspective for traditional FT. BFT places greater emphasis on the cognitive load administered to participants and introduces options for adjusting the dosage to stimulate planning, a high-order executive function (Pereira-Monteiro et al., 2026b). These dosage adjustments are primarily based on modulating task complexity, with one of the key methods for increasing complexity being the use of dual-task cognitive challenges focused on stimuli for lower-order executive functions, specifically working memory, inhibitory control, and cognitive flexibility (La Scala Teixeira et al., 2019).

In particular, the use of dual-task exercises may generate an effect known as interference, due to the nervous system's concurrent need to allocate attentional resources to both a motor and a cognitive task simultaneously. This can result in prioritizing one task over the other or failing to provide sufficient attentional resources for the successful execution of both (Plummer et al., 2013). In this context, the study by Wisniowska et al. (2023) highlighted a greater need for planning time and a higher number of errors during dual-task training compared to single-task training in older adults. However, the study also indicated that, over time, both planning time and the number of errors decreased during the course of dual-task training (Wiśniowska et al., 2023). In this regard, it remains unclear how the interference effect might hinder the motor adaptations provided by BFT when compared to classical models like FT or other cognitive-motor training approaches such as MBI. Moreover, it is still uncertain whether the increased mental load, driven by a greater focus on planning in BFT, will indeed lead to superior adaptations in executive function when compared to FT.

It is also known that these training strategies, which involve greater cognitive overload, aim to reduce mental fatigue, improving performance in the trained actions with equal or less cognitive load (Staiano et al., 2023). To assess this mental effort, we can use subjective questionnaires, attention tests, reduced task performance, and physiological measurements (Bafna; Hansen, 2021). Neuropsychological tests such as the SWCT stand out in this scenario. This test has been validated for older people and is an important marker of mental fatigue (Faria et al., 2024). In addition to these, physiological markers can also be used, in particular heart rate variability (Forte; Favieri; Casagrande, 2019) during cognitive effort, which indicates the use of time and frequency indicators related to greater overload.

Additionally, other approaches that assess cognitive performance in conjunction with physical performance can be applied in a dual-task format (Li; Verghese; Holtzer, 2014). Specifically, the Timed Up and Go (TUG) test, which primarily involves standing up and walking, is recognized as a key indicator of functionality. Variations of this test are included in different batteries designed to assess functional performance, such as the GDLAM protocol and the Senior Fitness Test (Martin Dantas; Gomes De Souza Vale, 2004; Rikli; Jones, 2013). Furthermore, the TUG is recommended as an assessment tool for functional impairment in patients with sarcopenia, as indicated in the European

Sarcopenia Consensus (Cruz-Jentoft et al., 2019). In this regard, modified versions of the TUG test have been proposed, incorporating either an additional motor task (TUGm) or a cognitive task (TUGc) (Vance et al., 2015).

Since BFT is still a relatively new proposal, there is a lack of studies in the scientific literature that demonstrate the behavior of exertion and cognitive load required by the more complex tasks within the BFT model. Given that BFT is an innovative approach that has yet to produce experimental studies, this study aimed to verify the training and retention effects of 16 weeks of BFT, FT, and MBI on functional status and body composition in postmenopausal women. We believe that all three models of intervention will promote gains in functional status and lean mass in postmenopausal women, with BFT and FT presenting similar effects in performance tests, but BFT being superior to FT and MBI in executive function tests. Additionally, we believe that MBI will present smaller effects on aspects of functional fitness and lean mass.

6.2 METHODS

6.2.1 Experimental design

This was a randomized clinical trial with parallel groups (between-subject) and repeated measures (within-subject), in which postmenopausal women underwent three different training models — specifically BFT, FT, and MBI (independent variables) — over 16 weeks, followed by an additional 16-week period without exercise (e.g., follow-up). The participants were evaluated before the beginning of the training period (PRE), after the training period (POST), and after the detraining period (DETR), with measurements taken on functional status and body composition (dependent variables).

The entire protocol was conducted at the Department of Physical Education of the Federal University of Sergipe in Brazil between January and September 2025. Physical education professionals and physiotherapists with at least two years of experience in FT and functional and cognitive assessment coordinated all data collection and physical training procedures. These professionals were supported by undergraduate students from both fields, all of whom had at least six months of experience with physical exercise and functional and cognitive assessment.

We followed the CONSORT 2025 checklist. The study was approved by the Research Ethics Committee of the Federal University of Sergipe under protocol number 8.508.178. All the procedures were conducted in accordance with the Declaration of Helsinki. All participants received detailed information regarding the study objectives, procedures, risks, and benefits, and provided written informed consent (Appendicle B).

6.2.2 Sample

The sample size calculation was based on the results of the Gallon Jug Shelf Transfer Task test from the study by Aragão-Santos et al. (2024) (Aragão-Santos et al., 2024). Considering a statistical power of 0.95, a significance level of 0.05, and an effect size f of 0.259, 51 individuals were deemed necessary, considering three groups and three measures, to detect differences between groups, within factors (time), and in interactions (groups x time). Considering the detraining period and to account for potential sample attrition, an additional 50% was added to the final sample size, resulting in a total of 77 participants. To address possible initial sample losses due to failure to meet the established inclusion criteria, we attempted to contact 100 postmenopausal women.

The sample was selected, adopting a non-probabilistic strategy, through social media dissemination and leaflet distribution. The inclusion criteria were as follows: being between 60 and 75 years of age, having been postmenopausal for at least twelve months, being able to read, not having participated in training programs in the past three months, and having no history of uncontrolled hypertension or medical contraindications for physical exercise.

Thus, postmenopausal women were included in the program and randomized into training groups based on block randomization, based on a score of functional test values, where data were organized from the best to the worst value, and group distribution followed this order to ensure homogeneity among them. An independent researcher conducted the allocation procedures to ensure the impartiality of the process. The exclusion criteria were: attendance below 30% of the training sessions (Figure 7). This percentage was selected to ensure a minimum presence, considering that adherence will later be included in the statistical analysis.

6.2.3 Experimental intervention

The training period was 16 weeks for all groups, with sessions three times per week on non-consecutive days (Monday, Wednesday, and Friday) and a duration of 45 minutes per session. BFT and FT training sessions were conducted in a multi-sport gymnasium between 6:00 and 7:30 a.m. in sequential time slots, while the MBI group trained outdoors on a grassy area near the gym. All groups were supervised by trained and experienced professionals.

Each intervention consisted of three parts. The first parts, common to all training modalities, included five minutes of movement preparation, incorporating joint mobility and stability exercises targeting the main joints that need mobility, based on the Joint by Joint concept (cervical, shoulder, hip, and ankle) (Cook, 2011). This was followed by three minutes of a standardized warm-up, which included squats, jumping jacks, and stationary running. After this warm-up, each group proceeded with its specific training.

In FT and BFT, parts two and three shared the same setup of number and sequence of exercises, density (work/rest ratio), load, and progressions (Table 5). However, while FT used basic exercises, BFT performed 50% of these exercises as dual-task activities, combining physical exercise with a simultaneous cognitive action. In MBI, parts two and three had different configurations from those in FT and BFT, featuring specific movement sequences and focusing on different physical capacities.

6.2.3.1 Functional Training

Blocks two and three of the FT were composed of six exercises organized in a circuit format, with two rounds completed. Block two had a density ratio of 1:2 (20 seconds of work / 40 seconds of rest), focusing on muscular power, speed, agility, and coordination, with a predominance of exercises targeting the lower limbs (4 out of 6 exercises). In block three, the focus was on muscular strength and endurance in basic movement patterns, such as squatting, pushing, pulling, and carrying, with a density of 1:1 (30 seconds of work / 30 seconds of rest), maintaining an equal number of exercises for lower and upper limbs (Table 5).

For both blocks, the eight-week intervention training progression was based on motor complexity, incorporating more challenging biomechanical variations of the movement patterns applied in each exercise (e.g., transitioning from symmetrical to asymmetrical movements) (La Scala Teixeira et al., 2019). Additionally, participants received continuous guidance during the sessions to perform the concentric phase of the movement at maximum possible speed.

Table 5. Training program and progressions BFT and TF.

	Weeks - 1 to 8 Exercises	Weeks - 9 to 16 Exercises
PART 2 Round - 2 Density - 1/2 Time - 20’’:40’’	Medball Wall Throw	Medball Wall Throw + asymmetrical base
	Step up	Side steps up
	Frontal Agility Ladder Drill	Lateral Agility Ladder Drill
	Rope Alternating Waves (a rope for both hands)	Rope alternating waves (a rope for each hand)
	Crossing the Line (1 track)	Crossing the Line (2 track)
	Zig zag frontal run	Zig zag side run
PART 3 Round - 2 Density - 1/1 Time - 30’’:30’’	Farmer Walk	Farmer walk unilateral
	Suspension Strap Row with neutral shoulder	Suspension Strap Row with shoulders at 45-degree abduction
	Sit and Stand	Goblet Squat
	Push up in a Box	Push up in a Box + touching the other hand
	Resistance Band Row	Resistance Band Row one leg
	Deadlift with Kettlebell	Deadlift with Kettlebell + leg adduction

6.2.3.2 Brain Functional Training

The BFT training was identical to FT in terms of the number and order of exercises, density (work/rest ratio), intensity-load, and biomechanical progressions (Table 1). However, 50% of the exercises in each circuit were performed with an increment of the complexity of the task using a dual cognitive task, meaning that the execution of the exercises included an additional executive function-specific task (inhibitory control, cognitive flexibility, or working memory). Due to the adaptability and learning involved in cognitive tasks, additional progressions were implemented in this component, with one modification every four weeks (Table 6). These modifications were always based on the initial task. Thus, three exercises from the second and third blocks were performed with the dual cognitive task, as follows:

1. Medball Wall Throw with Inhibitory Control Task: In this exercise, participants, positioned two meters away from the wall, threw the implement at symbols drawn on the wall, each featuring different shapes and colors (e.g., square, circle, green, blue). The instructor verbalized a command (e.g., green square), and the participant was required to throw the implement at any symbol except the one that was verbalized. The progression involved increasing the number of symbols or verbal commands (Table 6).
2. Crossing the Line with Cognitive Flexibility Task: In this exercise, participants were tasked with crossing a line marked on the floor as quickly as possible, always with one step forward and one step backward. During the movement, the instructor verbalized the direction to initiate the movement (e.g., left or right), maintaining random commands throughout the exercise. The progression involved assigning different commands to represent the sides (e.g., even numbers for right, odd numbers for left) (Table 6).
3. Agility Ladder with Working Memory Task: In this exercise, participants performed a predetermined coordinated pattern on the ladder. At the end of the ladder, a table was placed with cones in three colors (blue, red, and yellow). Before starting the ladder exercise, the instructor verbalized a random sequence of colors, which the participant was required to replicate by placing the cones on the table in the specified order after completing the ladder passage. Each participant had a different sequence. The progression involved increasing the number of cones, modifying the characteristics of the cones (e.g., large or small) or modify the final order (Table 6).
4. Farmer Walk with Inhibitory Control Task: In this exercise, participants performed the movement of carrying weights while the instructor verbalized the commands "stop" and "go." However, the participant was required to do the opposite of the verbalized command, meaning they had to continue walking on the "stop" command and stop on the "go" command. Progression was achieved by

adding more actions (e.g., "step to the left," "step to the right") that had to be executed following the same logic (Table 6).

5. Sit and Stand with Cognitive Flexibility Task: In this exercise, participants performed the action of sitting and standing from a bench, with the commands "dead" or "alive" corresponding to sitting and standing, respectively. The goal was to complete the movement as quickly as possible in response to the instructor's verbal command. The progression involved using codes representing the same actions, such as an odd number for sitting and an even number for standing (Table 6).
6. Resistance Band Row with Working Memory Task: In this exercise, participants performed resistance band rows while simultaneously engaging in a memorization task (1 word with 1 category). The instructor initially verbalized a word (e.g., color or fruit). The next participant had to repeat the word and add another from the same category (e.g., color or fruit). Following this logic, each participant repeated the last word spoken and added a new one, continuing this process until the end of the allotted time. The progression involved adding more categories at once, as well as increasing the number of words to be repeated by each participant (Table 6).

Table 6. Cognitive dual tasks and progressions of BFT.

	Weeks - 1 to 4	Weeks - 5 to 8	Weeks - 9 to 12	Weeks - 12 to 16
Part 2				
Medball Wall Throw **(IC)**	2 elements and 2 colors	3 elements and 2 colors shuffled	3 elements and 3 colors shuffled	4 elements 3 colors and shuffled
Agility Ladder **(WM)**	left and right	even or odd (1 to 10)	even or odd (11 to 1000)	sum = left - odd and right - even
Crossing the Line **(CF)**	3 colors with 3 cones	3 colors with 4 cones	4 colors with 3 small cones and 1 large cone	3 colors with 3 inverted cones
Part 3				
Farmer walk **(IC)**	stop and follow (verbal)	stop and go + left and right	stop and go + switching hand + right left	stop and go + switching hand + right left + down and up
Sit and Stand **(CF)**	alive dead	odd or even (1 to 10)	odd or even (11 to 100)	sum = left - odd and right - even
Resistance Band Row **(WM)**	1 back and 1 category	2 back and 2 categories	1 back and 2 categories	3 back and 1 category

Note: Brain Functional Training – BFT; inhibitory control – IC; cognitive flexibility – CF; working memory – WM.

6.2.3.3 Mind Body Intervention (MBI)

This intervention consisted of practicing a core set of Tai Chi Chuan and Qigong movements that emphasized breathing techniques synchronized with coordinated movements. These included weight transfer, unipodal support, alignment, and rotation of the head, shoulders, and trunk, as well as coordinated movements of the eyes and hands. The intervention began with the Eight Pieces of Brocade (Baduanjin) sequence, followed by additional exercises derived from Qigong and Tai Chi Chuan. Over time, three modifications were made to the movement sequence (every four weeks), either by altering previously applied patterns or incorporating new actions. Each movement was performed for eight seconds and repeated eight times (Appendicle C).

6.2.4 Data Collection

The evaluators were blinded to the type of intervention to which the volunteers would be subjected, and the same evaluators were responsible for conducting all tests at every assessment time point. The volunteers were also blinded to the intervention until its commencement and were instructed to refrain from engaging in strenuous physical activities before data collection. During all performance tests, participants received standardized verbal encouragement to achieve their maximum performance.

The assessment was conducted in three stages. The first stage consisted of the cognitive assessment and was performed individually over the course of one week. The second stage involved the individual assessment of body composition. Finally, the third stage was conducted over two separate days. During this stage, all functional tests were administered on the same day, with the exception of the Six-Minute Walk Test (6MWT), which was performed on a separate day to avoid potential fatigue effects on participants' performance.

The functional tests were administered by the same evaluators who had previously conducted a pilot assessment with 50 participants one week earlier to determine the intraclass correlation coefficient (ICC), using a two-way mixed-effects model, absolute agreement, single measurement approach (Koo & Li, 2016). Regarding the scales adopted throughout the intervention, these were administered at the end of each training session.

6.2.4.1 Perceptual Scales

To quantify the Cognitive Load generated in each training session, a nine-point Likert scale (1–9) was used, represented with emoticons ranging from a relaxed expression, depicted by a blue emoticon, to a stressed/excited expression, depicted by a red emoticon. This representation is based on the propositions of Shenhav et al., who indicate that affect can be a direct reflection of Cognitive Load, aiming to support participants' understanding of the question (Shenhav et al., 2017)). At the end of each session, participants were individually asked: "How difficult was it to perform the tasks in your session today?".

On the other hand, the perceived exertion of each participant was recorded individually at the end of each training session. A modified version of the OMNI-GSE scale, validated for postmenopausal women, was employed for this purpose (Da Silva-Grigoletto et al., 2013). This scale ranges from 0 to 10, where 0 indicates no exertion and 10 represents maximum exertion. The scale was presented verbally to the participants, accompanied by a visual representation to facilitate their response.

6.2.4.2 Functional Assessment

6.2.4.2.1 Medicine Ball Throw Test (MEDT)

The test aimed to estimate upper limb power in a pushing pattern, participants were positioned on a chair placed against a wall, with a measuring tape extended on the floor from the front edge of the chair to a distance of 10 m. Participants sat with their backs supported by the chair and their feet firmly on the floor. To account for variations in arm length, participants held the ball with both hands, with arms fully extended, and released it directly onto the measuring tape, adjusted so that this point marked zero. Three practice trials were conducted, during which participants pushed the ball from the center of the chest in a motion similar to a basketball chest pass, aiming to achieve the greatest possible distance. The ball used weighed three kilograms. A rest interval of at least 90 seconds was maintained between each attempt, and the best result, measured in meters, was recorded for analysis. The ICC value obtained was 0.776. (Harris et al., 2011).

6.2.4.2.2 Five Times Sit to Stand Test (FTSTS)

The objective of this test was to estimate lower-limb power. Participants used a chair positioned against the wall, with a seat height of approximately 45 cm, and were instructed to complete five sit-to-stand cycles as rapidly as possible. The time required to perform the sequence was recorded. Three trials were conducted, with a minimum rest period of 30 seconds between attempts, and the best performance, expressed in meters, was retained for analysis. An ICC value of 0.731 was obtained. (Goldberg et al., 2012).

6.2.4.2.3 Gallon Jug Shelf Transfer (GJST)

The participant stood next to a cabinet containing several racks, where five water jugs (±3.99 kg each) were placed on the rack at knee height. Upon the evaluator's signal, the participant was required to transfer the jugs, one at a time, to the rack at shoulder height. To ensure procedural standardization, participants used only their dominant hand on the jug's handle and their non-dominant hand on the side. The shortest time recorded, in seconds, was used for analysis. The ICC was 0.818. (Signorile et al., 2007).

6.2.4.2.4 Put on and Take off a T-shirt (PTS)

The PTS test involves performing a daily task commonly found in the routine of postmenopausal adults, with the name of the test directly reflecting this activity. The evaluator records the total time required to complete the task. The participant must stand with their arms at their sides, holding a size 'G' t-shirt (Hering, Brazil) in their dominant hand. Upon the command "go," the participant must put on the t-shirt and, immediately after completing this step, remove it, returning to the initial position. The stopwatch is started simultaneously with the evaluator's command and stopped when the participant returns to the initial position, with the t-shirt in hand and the arm extended at their side. For analysis, the shortest time, in seconds, between two attempts will be considered. The calculated ICC was 0.808.

6.2.4.2.5 Rising from the Prone Position (RPP)

The test aimed to assess the ability to stand up from the ground in the shortest time possible. For its execution, a mat measuring two meters in length by one meter in width was used. Participants were required to position themselves in a prone position, with their hands placed alongside their bodies and their feet outside the mat. Upon receiving authorization, they had to stand up quickly and remain standing without losing balance. The test was monitored by a qualified evaluator responsible for recording the time in seconds and assessing the performance. Each participant performed three attempts to achieve their best possible result. The resulting ICC was 0.903. (Santana et al., 2021).

6.2.4.2.6 Ten Meters Walk (W10M)

Upon the evaluator's signal, the participant was instructed to walk as quickly as possible over a total distance of 14 meters. The initial two meters and the final two meters were used to mitigate the influence of the acceleration and deceleration phases, respectively. The time required to cover the central ten meters was recorded by an evaluator positioned at the end of this section, using a stopwatch for precise time measurement. Two attempts were performed, with a two-minute interval between them. The shortest time, measured in seconds, was considered for the analysis of the results. (Martin Dantas; Gomes De Souza Vale, 2004). The reliability assessment resulted in an ICC value 0.679.

6.2.4.2.7 Six-minute Walking Test (W6Min)

The test was conducted in a gymnasium, where a 40-meter course was marked, with intervals every five meters. Upon completing one full lap, the participant covered a distance of 80 meters. During the six-minute test, the participant was required to complete as many laps as possible. At the end of the test duration, the total number of laps completed, along with the additional distance from the unfinished lap, was recorded to determine the total distance traveled. This test was performed only once (Agarwala; Salzman, 2020; “ATS Statement”, 2002).

6.2.4.2.8 Timed Up and Go (TUG) Variations

For the assessment of functional performance, the TUG test and its variations were administered. Specifically, the classic TUG consists of standing up from a chair, walking three meters to a cone, and returning to the starting point. The participant initiates the movement upon receiving the evaluator's command, "Go." Performance on the test is determined by the timed interval between the initiation of movement and the moment the participant returns to the chair. Reliability analysis demonstrated an ICC of 0.720. In addition to the classic version, two variations of the TUG were applied: the TUG with a motor dual task (TUGm) and the TUG with a cognitive dual task (TUGc). In the TUGm, the participant completed the course while holding a cup containing 200 mL of water filled halfway, whereas in the TUGc, the same trajectory was performed while reciting the days of the week in reverse order. Three attempts were conducted for each condition and the lower time was recorded to analysis (Vance et al., 2015). Additionally, motor and cognitive dual-task costs were calculated by subtracting the performance score of each respective dual-task condition from the score obtained in the classic version of the TUG test.

6.2.4.3 Executive Function Assessment

To assess executive function performance, a digital version of the SWCT was employed, following the protocol described by Pantoja-Cardoso et al. (2020) (Pantoja-Cardoso et al., 2023a). In this test, the participant was exposed to colored words that represent the names of colors, namely blue, yellow, green, and red, and which can be congruent, i.e. the word displayed corresponds to the same color in which it is painted (example: word - "blue"; color displayed - blue); or incongruent, i.e. the word displayed is different from the color in which it is presented (example: word - "red"; color displayed - green).

In the protocol used, the participant must be seated on a chair without wheels in front of the screen (17 inches), and a keyboard with four keys painted with the color corresponding to that expected by the program. The test begins with 12 trials of familiarization, where the evaluator instructs the participant to press the corresponding button for each color as quickly and correctly as possible. At each attempt, display feedback for correct or incorrect answers. After this stage, 60 congruent words and colors and 60 incongruent words and colors were randomly applied, totaling 120 trials (one trial every 500 ms), applied randomly without feedback for the answer. The average RT for all congruent and incongruent tasks was considered for analysis (Pantoja-Cardoso et al., 2023; Scarpina & Tagini, 2017). Specifically for the analysis, only tests with greater than 70% accuracy in both conditions and a maximum response time of 2000 ms were included.

Participants were instructed to refrain from caffeine consumption on the day of testing and from engaging in strenuous physical activity or consuming alcoholic beverages during the 24 hours preceding the assessment. They were also instructed to maintain their usual dietary and fluid intake habits. All samples were collected between 6.00 a.m. and 10:00 a.m.

From the perspective of assessing the mental effort exerted during the execution of the SWCT, participants used a Polar H10 heart rate monitor for five minutes before the test to assess heart rate variability. They continued wearing the monitor during the test and for one minute immediately after completing the task. For each moment, "Before," "During," and "After" the Stroop Task, the Standard Deviation of Normal-to-Normal intervals (SDNN) parameter was analyzed (Forte; Favieri; Casagrande, 2019). It is important to note that this heart rate monitor assessment was conducted only at the PRE and POST time points and was not performed in the DETR moment.

6.2.4.4 Body composition

A tetrapolar bioimpedance system (BIA AnalyzerTM®, Rushford, USA) operating at an electrical frequency of 50 kHz was used to measure the raw BIA variables: resistance (R), reactance (Xc), and phase angle (PhA). R and Xc values were recorded in ohms, while PhA was calculated as the arctangent of the Xc/R ratio, expressed in degrees. Participants were instructed to fast for at least six hours before the assessment, refrain from exercise the day prior, avoid caffeinated or diuretic beverages for up to 24 hours before the evaluation, and maintain normal hydration. The assessment was conducted only after verifying compliance with all recommendations. If adherence to the protocol was not confirmed, the session was rescheduled for the following day. During the measurement, participants remained in a supine position, and four electrodes were placed: two on the upper right limb (wrist and palm) and two on the lower right limb (ankle and foot) (Khalil; Mohktar; Ibrahim, 2014). Bioimpedance data were used to estimate appendicular lean soft tissue (ALST) based on a previously validated equation and were subsequently included in the analysis (Toselli et al., 2021).

6.2.5 Statistical Analysis

About the characterization of the sample, data were presented as mean and standard deviation. One-way ANOVA was conducted to compare these variables between parallel groups for the continuous variables, and a chi-square test was used for the analysis of education level, given its categorical nature.

Regarding the analysis of outcome variables, a mixed linear model was employed, given its advantages over more traditional methods for comparing means (Yu et al., 2022). The model incorporated group and time as fixed factors to assess changes in the dependent variables. Adherence and age were included as covariates to account for the effects of training attendance and senescence, respectively. To account for the variability in the average behavior of each subject, we included "subject" as a clustered variable in the model, treating it as a random effect on the intercept. Regarding the distribution of the data, Gaussian or Gamma models were selected based on the Akaike Information Criterion, with the best-fitting distribution determined for each variable. The identity link function was employed for the analyses.

Factor coding was defined as *simple* for the time and group factor. The intercept was established at the PRE time point, allowing the estimation of contrasts between PRE vs. POST and PRE vs. DETR conditions. For the group factor, the reference level was set to BFT, enabling the interpretation of pairwise comparisons for FT and MBI relative to BFT. The equation model adopted was: $[\text{DEPENDENT VARIABLE}] \sim 1 + \text{TIME} + \text{GROUP} + \text{ADHERENCE} + \text{AGE} + \text{TIME: GROUP} + (1 \mid \text{PARTICIPANT})$.

Additionally, effect sizes (Cohen's d) were calculated, and the following values were considered for interpretation: values between 0.2 and 0.5 were considered small, between 0.5 and 0.8 were considered moderate, and greater than 0.8 were considered large (Durlak, 2009).

For the analysis of exertion and mental load scales, the mixed linear model was also utilized. In this specific case, due to the large number of interactions, we opted to present only the post-hoc comparisons (with Bonferroni correction) between different groups at the same time point. A significance level of $p < 0.05$ was established for all statistical analyses. All analyses were conducted using Jamovi software version 2.6 (Gallucci, 2019; R Core Team, 2024; The jamovi project, 2024). Figures were created using GraphPad Prism version 8 and RStudio version 2024.04.2+764.

6.3 RESULTS

6.3.1 Baseline characteristics variables

Figure 7 illustrates the flow of participants throughout the study. Of the 100 individuals assessed for eligibility, 93 were randomized into the BFT, FT, and MBI groups. After accounting for losses to follow-up, 76 participants completed the study and were included in the final analyses. No adverse events or intervention-related harms were reported during the study

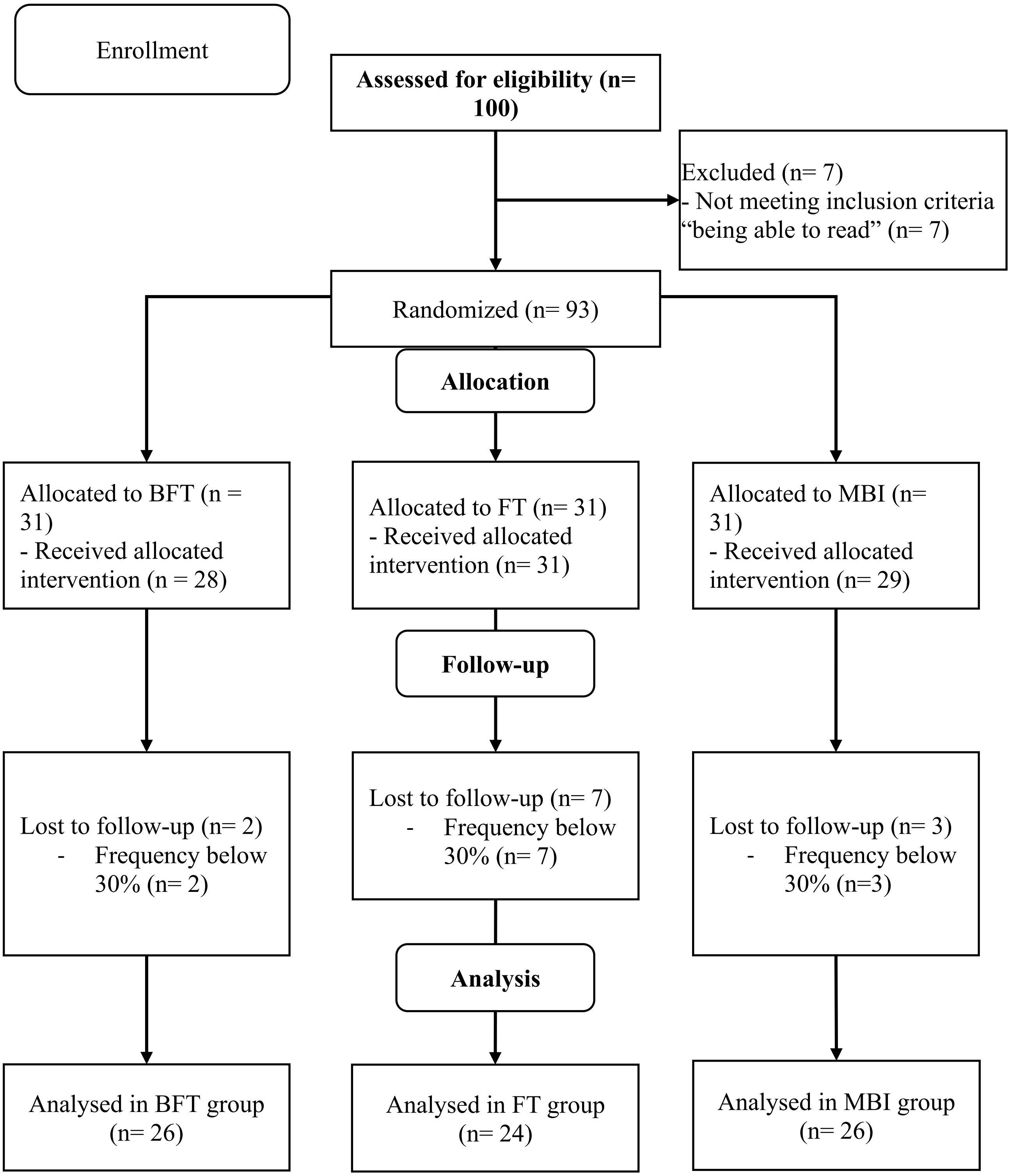

Figure 7. Flow diagram

When analyzing age, stature, body mass, body mass index, and education level, no baseline differences were identified for the study participants (Table 7). However, differences in the training protocol adherence were observed between groups ($p<0.003$).

Post-hoc comparisons revealed that BFT (80% [76.6; 83.5]) showed a significant difference (p<0.009) when compared to FT (72.8% [69.5; 76.0]) and MBI (73.3% [70.1; 76.4]). Conversely, no differences were found between FT and MBI.

Table 7. Characteristics of the sample

	BFT	FT	MBI	P value
Age (Years)	67.62 ± 4.66	66.25 ± 4.21	65.5 ± 4.14	0.236
Stature (M)	1.52 ± 0.08	1.53 ± 0.07	1.50 ± 0.07	0.348
Body mass (Kg)	65.78 ± 10.36	67.02 ± 13.54	63.97 ± 13.01	0.728
Body Mass Index	28.57 ± 4.13	28.64 ± 5.65	28.21 ± 4.22	0.937
EDUCATIONAL LEVEL	Absolute Frequency (Relative Frequency)			
Elementary Incomplete	12 (46.2)	12 (50.0)	12 (46.2)	0.882
Elementary Complete	3 (11.5)	3 (12.5)	2 (7.7)	
High School Complete	10 (38.5)	8 (33.3)	11 (42.3)	
Bachelor	0 (0)	1 (4.2)	0 (0)	
Postgraduate	1 (3.8)	0 (0)	1 (3.8)	

6.3.2 Perceptual variables

Throughout the experiment, significant differences were identified in Exertion and Cognitive Load levels over time (p<0.001), between groups (p<0.001), and in the time*group interaction for Exertion (p<0.001) and Cognitive Load (p=0.037). Regarding Exertion, it was observed that BFT and FT exhibited higher levels throughout most of the period, except in weeks 5 and 8 for BFT, and in weeks 8, 15, and 16 for FT. Concerning Cognitive Load, in comparisons between groups at the same time points, the BFT group showed higher Cognitive Load starting from week 12, maintaining this difference until week 16, without other significant differences between the groups (Figure 8).

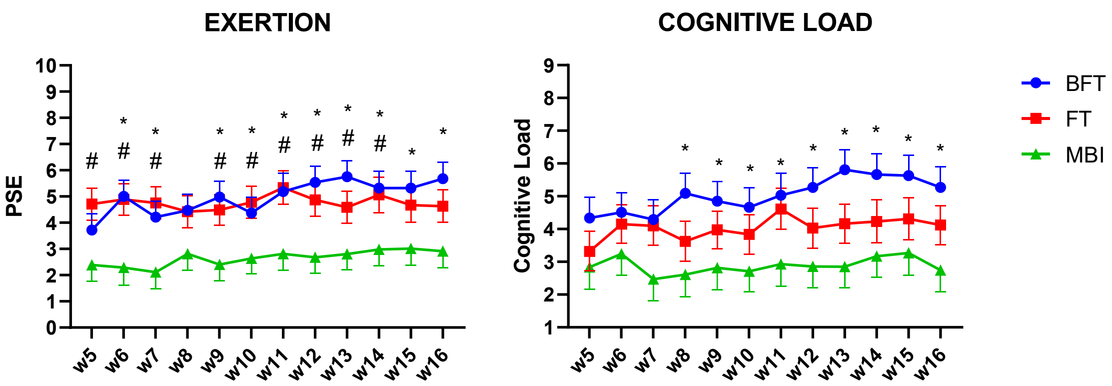

Figure 8. PSE and Cognitive Load across 16 weeks of BFT, FT and MBI.
Note: *: differences between BFT and MBI; #: differences between FT and MBI.

6.3.3 Functional variables

All functional tests demonstrated significant main effects over time ($p < 0.001$). Improvements from PRE to POST were observed in TUG, TUGm, MEDT, GJST, SPP, as well as in both the congruent and incongruent response times of the SWCT. Several of these gains were preserved after the detraining period, with maintained differences between PRE and DETR for TUGm, MEDT, GJST, and both congruent and incongruent SWCT response times. In contrast, despite the initial improvements from PRE to POST, a decline in performance from PRE to DETR was observed in TUG, MEDT, and SPP, indicating loss of training-induced benefits for these outcomes (Table 8).

Some outcomes showed distinct PRE to DETR changes regardless of POST behavior. A reduction in performance was identified for FTSTS from PRE to DETR ($p < 0.007$), whereas improvements at DETR were maintained for PTS, W10M, and W6Min (Table 8).

Significant interaction effects were detected for TUGc ($p < 0.006$), MEDT ($p = 0.037$), and for both congruent and incongruent response times in the SWCT ($p<0.001$, for both). These interactions indicate that the magnitude of change across the three time points differed among the training modalities. Specifically, interaction effects between PRE and POST showed that BFT demonstrated better performance than MBI for TUGc ($p < 0.001$) and MEDT ($p = 0.012$) but attenuated performance for both congruent and incongruent SWCT response times ($p < 0.001$). In addition, BFT outperformed FT between PRE and POST for the incongruent SWCT response time ($p = 0.003$). Regarding the PRE to DETR comparison, BFT also showed better performance than FT for the congruent SWCT response time ($p = 0.047$) but decreased performance than to MBI ($p < 0.001$) for both congruent and incongruent SWCT response times (Table 8).

Table 8. Effects of BFT, FT and MBI on functional status tests and body composition after 16 weeks of training and 16 weeks of detraining.

		PRE (Mean ± SD)	POST (Mean ± SD) d related to PRE	DETR (Mean ± SD) d related to PRE	PRE * POST Estimate [CI 95%] p time	PRE * DETR Estimate [CI 95%] p time	p interaction
MEDT	BFT	225 ± 22.5	242 ± 27.9	221 ± 26.8	**9.97**	**-12.42**	**0.037**
					[5.19; 14.75]	**[-17.38; -7.46]**	
			d = 0.756	d = - 0.178			
	FT	224 ± 32.8	244 ± 31.6	207 ± 33	**<.001**	**<.001**	
			d = 0.61	d = - 0.52			
	MBI	221 ± 37.5	**219 ± 33.4 ***	205 ± 30.5			
			d = - 0.05	d = - 0.43			
FTSTS	BFT	6.93 ± 1.64	6.79 ± 1.63	7.48 ± 1.64	-0.14	**0.39**	0.768
					[-0.40; 0.13]	**[0.11;0.67]**	
			d = - 0.09	d = 0.34			
	FT	8.1 ± 1.75	7.64 ± 1.53	8.82 ± 1.97	0.299	**0.007**	
			d = - 0.26	d = 0.41			
	MBI	7.94 ± 1.74	8.07 ± 2.38	8.43 ± 2.37			
			d = 0.07	d = 0.28			
GJST	BFT	10.76 ± 1.20	9.55 ± 1.07	9.97 ± 1.15	**-0.95**	**-0.461**	0.492
					[-1.15; -0.76]	**[-0.66; -0.26]**	
			d = - 1.00	d = - 0.65			
	FT	10.69 ± 1.16	9.7 ± 0.87	10.54 ± 1.25	**<.001**	**<.001**	
			d = - 0.85	d = - 0.13			
	MBI	10.68 ± 0.83	9.87 ± 0.99	10.41 ± 1.23			
			d = - 0.97	d = - 0.32			
PTS	BFT	14.2 ± 2.79	13.4 ± 2.31	12.9 ± 1.97	-0.42	**-0.98**	0.738
					[-0.91; 0.07]	**[-1.47; -0.49]**	
			d = - 0.28	d = - 0.47			
	FT	14.2 ± 2.23	13.6 ± 2.24	13.4 ± 2.35	.092	**<.001**	
			d = - 0.27	d = - 0.36			
	MBI	14.4 ± 2.71	14 ± 2.31	13 ± 1.58			
			d = - 0.14	d = - 0.52			
SPP	BFT	3.51 ± 0.93	3.39 ± 0.94	3.73 ± 0.96	**-0.17**	**0.24**	0.579
					[-0.34; -0.01]	**[0.07; 0.41]**	

			d = - 0.13	d = 0.23			
	FT	3.82 ± 0.86	3.55 ± 0.68	4.02 ± 0.84	**.046**	**.006**	
			d = - 0.31	d = 0.23			
	MBI	3.75 ± 0.84	3.8 ± 1.20	4.23 ± 1.12			
			d = 0.06	d = 0.57			
W10M	BFT	5.38 ± 0.69	5.3 ± 0.68	5.14 ± 0.63	0.04	**-0.29**	0.827
					[-0.10; 0.18]	**[-0.45; -0.13]**	
			d = - 0.12	d = - 0.34			
	FT	5.4 ± 0.68	5.49 ± 0.55	5.03 ± 0.49	0.570	**<0.001**	
			d = 0.13	d = - 0.55			
	MBI	5.54 ± 0.82	5.66 ± 0.89	5.29 ± 0.53			
			d = 0.15	d = - 0.30			
W6Min	BFT	559 ± 50.9	578 ± 63.8	489 ± 75.6	12.27	**-80.08**	0.803
					[-0.58; 25.13]	**[-92.72; -67.44]**	
			d = 0.37	d = - 1.37			
	FT	552 ± 47.5	561 ± 51.1	467 ± 53.2	0.061	**<.001**	
			d = 0.19	d = - 1.79			
	MBI	543 ± 69.9	555 ± 68.9	469 ± 64.3			
			d = 0.17	d = - 1.05			
TUG	BFT	7.42 ± 0.67	6.64 ± 0.76	7.18 ± 0.61	**3.45**	**-0.66**	0.273
					[3.26; 3.63]	**[-0.79; -0.52]**	
			d = - 1.15	d = - 0.35			
	FT	7.39 ± 0.75	7.01 ± 0.79	7.48 ± 0.86	**<.001**	**<.001**	
			d = - 0.51	d = 0.12			
	MBI	7.48 ± 1.12	7.02 ± 0.95	7.39 ± 0.87			
			d = - 0.41	d = - 0.08			
TUGc	BFT	8.4 ± 1.02	7.53 ± 0.91	8.17 ± 1.03	0.33	0.51	**0.006**
					[-0.44; 1.11]	[-0.24; 1.26]	
			d = - 0.85	d = - 0.22			
	FT	8.36 ± 1.02	7.59 ± 0.87	8.44 ± 1.64	0.398	0.18	
			d = - 0.75	d = 0.07			
	MBI	8.18 ± 1.26	**8.09 ± 1.01 ***	8.52 ± 1.41			
			d = - 0.07	d = 0.27			
TUGm	BFT	8.38 ± 0.93	6.57 ± 0.76	7.25 ± 0.91	**-1.68**	**-1.34**	0.420
					[-1.87; -1.49]	**[-1.55; -1.14]**	

			d = - 1.94	d = - 1.21			
	FT	8.62 ± 0.89	6.88 ± 0.83	7.09 ± 0.73	**<.001**	**<.001**	
			d = - 1.94	d = - 1.71			
	MBI	8.36 ± 1.13	6.9 ± 0.87	7.2 ± 0.66			
			d =-1.29	d =-1.02			
Congruent RT SWCT	BFT	1159 ± 255	1096 ± 243	1133 ± 248	**-85.37 [-102.44; -68.30]**	**-79.14 [-97.07; -61.20]**	**<.001**
			d =-0.25	d = - 0.10			
	FT	1114 ± 179	1149 ± 259	**1178 ± 271 ***	**<.001**	**<.001**	
			d = 0.19	d = 0.36			
	MBI	1259 ± 257	**1078 ± 196 ***	**1070 ± 177 ***			
			d =-0.70	d = - 0.73			
Incongruent RT SWCT	BFT	1276 ± 323	1181 ± 289	1205 ± 291	**-111.23 [-137.72; -84.74]**	**-109.16 [-136.53; -81.79]**	**<.001**
			d = - 0.29	d =-0.22			
	FT	1195 ± 204	**1296 ± 300 ***	1273 ± 306	**<.001**	**<.001**	
			d = 0.49	d = 0.38			
	MBI	1394 ± 300	**1125 ± 208 ***	**1172 ± 252 ***			
			d = - 0.90	d = - 0.74			

Note: BFT: Brain Functional Training, FT: Functional Training, MBI: Mind–Body Interventions. SWCT: Stroop Word–Color Test; RT: Response Time. * Indicates a statistically significant effect derived from the group × time interaction in the generalized mixed model (Values marked with an asterisk represent estimated differences relative to the intercept, defined as the BFT group at the PRE moment).

6.3.4 Executive function

When comparing cognitive dual-task cost, a significant interaction effect between group and time was found ($p = 0.041$). Notably, a significant difference was identified in the comparison between BFT and MBI in PRE and POST ($\beta = 0.60$) and for PRE and DETR ($\beta = 0.69$). On the other hand, for motor dual-task cost, only an improvement over time was observed, regardless of group interaction, between PRE and POST ($\beta = -1.13$) and PRE and DETR ($\beta = -1.21$) (Figure 9).

Regarding the Stroop Effect, no significant main effects of time were found; however, a significant interaction effect was observed ($p = 0.005$). Specifically, BFT showed a significant difference compared to FT from PRE to POST (β = 62.61) and for MBI (β = -80.31) (Figure 9).

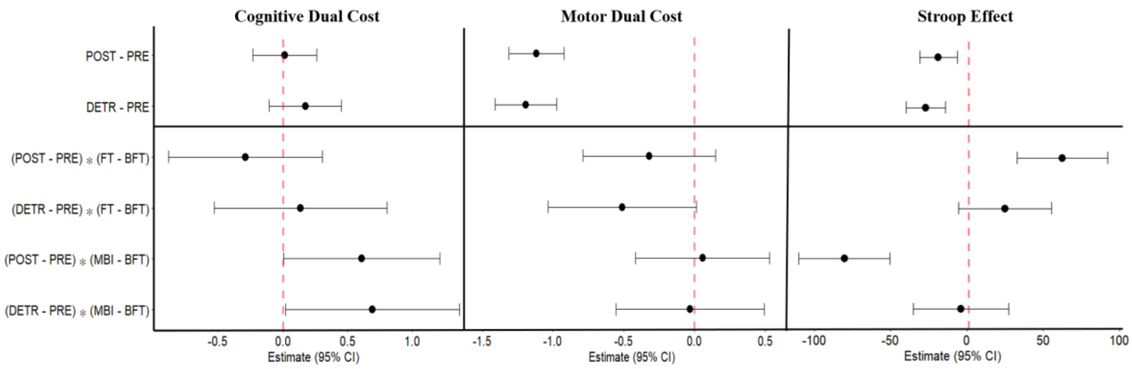

Figure 9. Forrest Plot regarding interactions of time and time*group of Cognitive Dual Cost, Motor Dual Cost and Stroop Effect.

Regarding Heart Rate Variability, SDNN values showed significant differences only at the Before timepoint, with a main effect of time observed between PRE and POST ($p = 0.014$; β = 29.35 [6.79; 51.90]). No significant effects were found for the other timepoints or interaction terms.

6.3.5 Body composition

About the body composition effects there was a clear improvement in ALST from PRE to POST. Mean PRE values ranged from approximately 6.58 to 6.82, while POST values increased to about 10.08 to 10.32. These changes correspond to large effect sizes (d values between approximately 4.57 and 5.66), indicating substantial gains immediately after training. After the detraining period, all groups demonstrated a decline in performance relative to POST, with DETR means falling to between 5.83 and 6.41. The negative effect sizes (ranging from around −0.47 to −1.30) show that this reduction reflected a meaningful loss of the gains previously acquired. The model-based estimates show a significant PRE × POST effect, with an estimated difference of 3.45 (95% CI: 3.27 to 3.63; $p < .001$), confirming that training led to a robust overall improvement across groups. Conversely, the PRE × DETR contrast indicated a significant decline, estimated at −0.66 (95% CI: −0.79 to −0.51; $p < .001$), demonstrating that part of the training benefit was lost after the detraining period. Finally, the interaction p-value of 0.167 indicates that the pattern of change over time did not differ significantly among the three training modalities.

6.4 DISCUSSION

This study aimed to verify the training and retention effects of 16 weeks of BFT, FT, and MBI on functional status and body composition in postmenopausal women. To the best of our knowledge, our study was the first to report findings related to BFT. The main findings revealed improvements in functional status and body composition for the BFT and are comparable to those observed in the traditional FT model and in another cognitive–motor model, MBI, with respect to motor aspects, while being superior to FT and inferior to MBI regarding executive function outcomes. In this context, we also reported perceived exertion and cognitive load during BFT sessions, showing similar levels of perceived exertion when compared with the FT model, but higher cognitive load than both FT and MBI. These findings partially corroborate our initial hypothesis that all three models of intervention would promote gains in functional status and lean mass in postmenopausal women, with BFT and FT presenting similar effects in performance tests. However, the hypothesis that BFT would be superior to FT and MBI in executive function tests was not supported. Additionally, although MBI did not demonstrate statistically smaller effects on aspects of functional fitness and lean mass, the observed effect sizes were partially consistent with our initial hypothesis.

Regarding the motor aspects of functional status, we observe similar adaptations in BFT and FT over the moments before training, after 16 weeks of training, and after 16 weeks of detraining, indicating minimal impact of the interference effect on this aspect. Specifically, it is notable an improvement in upper limb muscle power for both BFT and FT, whereas MBI did not show any effects. It is understandable that FT and BFT would demonstrate such effects, as they include stimuli for similar movement patterns during training sessions. Similarly, Vasconcelos et al. (2020) also found an increase in upper limb power after 12 weeks of FT in older women; however, it is notable that these power gains were only found with 8 kg loads, while no effects were found with lower loads, similar to those used in this study. (Vasconcelos et al., 2020). On the other hand, MBI does not include power stimuli in its training model, as it predominantly uses slow movements and does not involve load that challenges upper limb movement. Although MBI has been shown to have effects on strength, these are targeted on the lower limbs due to the semi-squatting positions adopted during exercise performance (Hong; Li, 2007).

On the other hand, no adaptations were observed in lower-limb muscle power estimated through the FTSTS. This result is not consistent with the findings of Aragão Santos et al., who reported improvements in FTSTS performance after four weeks of training with an FT protocol, with these gains maintained up to 16 weeks. Similar results have been described in other studies with different FT protocols (Aragão-Santos et al., 2024; Pereira-Monteiro et al., 2024). A plausible explanation for the absence of changes in the present study relates to the high initial performance level of the participants. All groups demonstrated times classified within the upper quartiles of the distribution proposed by Dantas et al. (2004) for a comparable population, falling near the third quartile (9.54–7.89 s) or even within the fourth quartile (<7.89 s) (Martin Dantas; Gomes De Souza Vale, 2004). Under these conditions, the margin for additional trainability is reduced, limiting the likelihood of detectable improvements over time, since individuals who are already well adapted tend to show lower responsiveness to further training stimuli (Zatsiorsky; Kraemer, 2005).

Interestingly, despite the differences in upper limb muscle power, tasks that simulate daily activities involving the upper limbs (GJST and PTS) showed no differences between the higher-exertion training models (BFT and FT) and the lower-exertion model (MBI), probably because the GJST and PTS tasks primarily require object control and planning for their execution, both capacities stimulated over all training protocols (Han et al., 2022). Unlike PTS, GJST showed improvements over time, with a reduction in completion time after the training protocol and partial maintenance of effects after 16 weeks of detraining. Similar results were reported by Aragão-Santos et al. (2021), who observed a reduction in GJST time after 16 weeks of FT in older women (Aragão-Santos et al., 2021).

From a physical perspective, while GJST reflects a more global functionality, involving upper limb strength, scapular stability, and trunk control, PTS seems to be more reflective of shoulder flexibility. It is also important to note that, based on standardized values from Vale et al. (2006), our sample remained within the "weak" category (+13.14 seconds), with a confidence interval reaching values considered "moderate" (between 13.14 and 11.62 seconds) (Vale et al., 2006). In contrast, Aragão-Santos et al. (2023) found improvements in PTS after 16 weeks of FT (Aragão-Santos et al., 2023). These results may be explained by the lack of exercises specifically targeting this physical capacity in the exercise protocols performed in the present study. Thus, we believe it is important to include a greater focus on exercises that promote an increased range of motion in the shoulder.

In addition to the GJST, the SPP also serves as an indicator of overall functional fitness. Although the full sample demonstrated improved performance after 16 weeks of training and a subsequent decline following detraining, the magnitude of change was small (β = -0.17 from PRE to POST; β = 0.24 from PRE to DETR). Moreover, mean values for all groups across all time points consistently remained within the second quartile for this population, ranging from 4.4 to 3.3 seconds (Martin Dantas; Gomes De Souza Vale, 2004). These findings suggest that the training interventions did not produce a meaningful effect on the ability to rise from the floor.

For the W10M test, no significant training effect was identified. Differences emerged only when comparing PRE and DETR, although the magnitude of this change was small (β = -0.29). Considering that the observed values reflect excellent performance for this population, these findings suggest that training primarily contributed to maintaining walking ability rather than enhancing it. Regarding cardiorespiratory fitness assessed through the W6min test, no significant differences were detected in the adaptation patterns between groups. After the detraining period, however, there was a notable decline, with performance values falling well below those recorded at baseline. This pattern further supports the interpretation that training plays an important role in preserving cardiorespiratory capacity, particularly in the BFT and FT groups, whose protocols incorporate circuit-based and intermittent characteristics (Ramos-Campo et al., 2021).

Regarding the TUG-based assessments, which are considered specific indicators of functional mobility, no group differences were observed for either the classical TUG or the TUGm. This result is likely due to the fact that all training protocols similarly enhance balance, essential component for the performance of this test in older adults (Howe et al., 2011). This interpretation is partially supported by the overall pattern in the sample, which showed improvements after training followed by a decline after detraining. Additionally, no changes were observed in lower-limb power estimated by the FTSTS, a component that also contributes to TUG performance. Previous evidence indicates that the Berg Balance Scale alone explains approximately 37.3 percent of TUG variability, and when combined with FTSTS, this proportion increases to 45.1 percent, reinforcing the relevance of both balance and lower-limb power to this task (Benavent-Caballer et al., 2016). Similarly, for the motor dual-task cost, the full sample improved after training and showed maintenance of these adaptations after detraining. However, no interaction effects were detected between groups, possibly because the dual-task motor behavior closely reflects performance in the single-task TUG, in which groups also did not differ.

Nevertheless, an interaction effect was observed for the TUGc, with BFT promoting greater improvements in performance after the training period compared with MBI. This adaptation may be related to improvements in cognitive flexibility. This finding may be partially explained by improvements in cognitive flexibility. In support of this interpretation, a 2021 systematic review indicated that endurance-based training interventions may enhance cognitive flexibility, whereas comparable effects have not been consistently demonstrated following MBI interventions (Xiong et al., 2021). In the same vein, the cognitive dual-task cost showed differences between BFT and MBI, indicating that BFT was similar to FT with respect to this cost, possibly due to the absence of motor changes in the TUG task.

With regard to executive function, improved performance of MBI compared with BFT was observed in both congruent and incongruent response times, with these effects being maintained even after the detraining period. These findings are inconsistent with those reported by Pantoja-Cardoso et al (2023), who identified improvements in congruent and incongruent response times in a group undergoing a FT protocol compared with a group performing balance and dual-task exercises with a lower level of intensity (Pantoja-Cardoso et al., 2023b). In another hand, the study by Liu et al. (2022), conducted with 839 older adults, demonstrated that higher levels of physical activity are associated with shorter cognitive response times (Liu et al., 2022). It is also worth noting that MBI practice may promote changes in brain states related to planning processes that could influence performance; however, such effects are likely to occur only after years of practice (Han et al., 2023).

We also highlight heart rate variability as an indicator of executive function to be used during the performance of the SCWT (Forte; Favieri; Casagrande, 2019), although no time-related effects were observed. However, when assessing the period immediately prior to the execution of the SCWT, a time-related effect was identified, which is consistent with the effects observed for the Stroop Effect. This approach represents a novel contribution of the present study, as it is, to our knowledge, the first to combine these two indicators of executive function, reinforcing the relevance of heart rate variability in its ability to predict performance in cognitive inhibition tasks (Magnon et al., 2022).

Additionally, BFT showed similar performance to FT in congruent response times, but differed when inhibitory control was required. This finding is aligned with the characteristics of the BFT protocol, which explicitly incorporates adaptations related to inhibitory control. These adaptations may be explained by the higher cognitive load imposed by the dual-task demands embedded in the BFT protocol, which may enhance activation and oxygenation of brain regions associated with executive functions, particularly the prefrontal cortex (Dallaway et al., 2023). Such neural engagement may lead to improved capacity to respond to cognitive challenges involving executive function (De Lima-Junior et al., 2023; Staiano et al., 2023). Finally, analysis of the Stroop effect, focusing on the relationship between congruent and incongruent tasks, indicated that a period of BFT training appears to promote greater adaptations than FT, but fewer than those observed with MBI.

Regarding body composition, a significant time effect was observed, characterized by an increase in lean mass after the 16-week training period and a subsequent reduction of similar magnitude following detraining. However, no group-by-time interaction was detected, indicating that the BFT, FT, and MBI groups experienced comparable gains in lean mass during the intervention period and similar losses after training cessation. In contrast to the present study, Pereira-Monteiro et al. (2023) found lean mass gains after only eight weeks of FT, with differences remaining even at 16 weeks. The similarity between groups in our study could be due to the absence of dietary control, even though participants were instructed to maintain their usual eating habits. Concerning MBI, other studies have also reported no changes in body composition following MBI protocols (Bai et al., 2023; Soltero et al., 2022).

Additionally, it can be observed that there was greater adherence to training in the BFT group. Faro et al. (2019) pointed out that FT models sessions tend to result in a higher perception of enjoyment compared to traditional machine-based training models (Faro et al., 2019). In turn, in a study who compares the perceptions of women with visual privation after FT and sports, Da Silva et al. (2022) suggests that the sense of self-efficacy may influence the feeling of enjoyment and, consequently, adherence to training. However, the same author found that in tasks with greater motor complexity (specifically sports), this perception is lower when compared to FT (Da Silva et al., 2022). In this context, one possibility is that BFT is able to foster strong feelings of self-efficacy by incorporating dual-task activities that are achievable over the course of four weeks of training, thereby contributing to higher adherence.

Based on the exertion scale, BFT and FT exhibit higher exertion for most of the time compared to MBI. We noted an interesting behavior of the exertion, at the beginning of the training period, the BFT does not show greater exertion than MBI, possible due to changes in cognitive patterns during this week, in which the participant prioritized understanding the new cognitive tasks and was unable to perform the exercise correctly. On other hand, at the final there are no differences between FT and MBI in W15 and W16, likely due to neuromuscular adaptation to the stimulus used in the sessions, leading to a reduced exertion load for FT at this point. In contrast, BFT stands out by presenting a higher cognitive load, which is also reflected in the exertion (Matthews et al., 2010). Similarly, Wisniowska et al. (2024) also demonstrated the need for bigger time to planning the tasks in sessions with dual task compared to singles task (Wiśniowska et al., 2023).

Regarding specifically cognitive load, only after the eighty week there was a significant increase for BFT. This result may indicate an adaptation period during which the primary concern was still the execution of motor patterns. However, since we did not control the response accuracy of the cognitive tasks, it is not possible to confirm whether the tasks were fully completed up to this point, although participants were instructed to always answer the questions correctly. It is also worth noting that the way cognitive load was assessed, using the term perceived difficulty, is more closely associated with intrinsic load, as this type of load is imposed by the task itself (DeLeeuw; Mayer, 2008).

Among the limitations, we can point out the lack of control over the accuracy of the responses, although we encouraged participants to provide the most accurate answers possible. Additionally, we did not control the dietary aspects of the population, although participants were instructed to maintain the same eating and physical activity habits throughout the intervention period. This approach has also been used in other studies that found effects of physical exercise on body composition (Pereira-Monteiro et al., 2024; Swift et al., 2018).

The practical application of this study lies in the use of BFT as an alternative to FT, showing very similar effects, but with greater potential for adherence and stronger effects on executive function. The findings indicate that interference does not hinder motor adaptations, and executive function can be maintained for a longer period. Furthermore, BFT appears to be more suitable for public health policies, as it shows greater adherence among the population.

6.5 CONCLUSION

The present study demonstrated that 16 weeks of BFT, FT, and MBI training produced similar improvements in motor aspects of functional status and body composition in postmenopausal women, with comparable retention of these effects after 16 weeks of detraining, with the only difference being in upper limb power adaptations, in which BFT was superior to MBI. However, regarding cognitive aspects associated with functional status, BFT proved to be more effective than FT and less effective than MBI in terms of executive function. In contrast, with respect to cognitive dual-task cost, BFT was more effective than MBI and comparable to FT. Notably, BFT elicited a higher cognitive load than both FT and MBI, while perceived exertion remained comparable to that observed in the FT model.

7 CONCLUSÃO

A presente tese representa, ao nosso conhecimento, a primeira investigação sistematizada acerca dos efeitos e dos mecanismos associados à modulação da complexidade da tarefa como variável de dose do treinamento físico sobre o estado funcional de mulheres idosas fisicamente independentes. Ao integrar evidências teóricas, experimentais agudas e intervenções crônicas, este trabalho avança no entendimento de que a prescrição do exercício físico não deve se restringir às variáveis tradicionais, incorporando a complexidade como um importante componente estruturante do estímulo.

Os achados permitem sustentar que a complexidade da tarefa atua como um modulador direto das demandas cognitivas impostas durante a execução motora. De forma aguda, o aumento da complexidade promove elevação consistente da carga mental, acompanhada por alterações no desempenho motor, caracterizadas principalmente pela redução da velocidade de movimento, aumento do tempo de execução e, em determinadas condições, diminuição da amplitude. Esses resultados indicam uma reorganização do comportamento motor frente a maiores exigências de planejamento, sem necessariamente implicar em aumento da percepção subjetiva de esforço.

Sob a perspectiva crônica, a exposição repetida a tarefas mais complexas demonstrou potencial para promover adaptações relevantes, especialmente no domínio cognitivo, com destaque para funções executivas e desempenho em situações de dupla tarefa. Embora os ganhos físicos tenham sido semelhantes entre diferentes modelos de treinamento, a superioridade do BFT em variáveis específicas de integração motor-cognitiva reforça sua aplicabilidade em contextos nos quais a funcionalidade depende da interação entre esses domínios. Adicionalmente, a manutenção parcial dos efeitos após o período de destreinamento sugere que tais adaptações apresentam relativa estabilidade, ainda que sensíveis à interrupção do estímulo.

Do ponto de vista mecanístico, os resultados sugerem, de forma indireta, de que o aumento da complexidade intensifica o recrutamento de regiões associadas ao planejamento do movimento, constituindo um possível elo entre a carga cognitiva aguda e as adaptações funcionais observadas ao longo do tempo. Essa perspectiva contribui para consolidar a complexidade da tarefa como uma variável legítima e mensurável dentro do conceito de dose do exercício físico.

Em síntese, conclui-se que a complexidade da tarefa é um fator-chave na prescrição do exercício físico, capaz de modular respostas agudas e adaptações crônicas de maneira diferenciada. Sua incorporação em programas de treinamento, especialmente por meio de modelos como o BFT, apresenta-se como uma estratégia promissora para otimizar o estado funcional em populações idosas, ampliando o escopo das abordagens tradicionais e oferecendo novas possibilidades para a prática clínica e a pesquisa em saúde.

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DECLARAÇÃO DE USO DE FERRAMENTA DE INTELIGÊNCIA ARTIFICIAL GENERATIVA

Declaro que, na elaboração desta dissertação, foi utilizada a ferramenta de Inteligência Artificial Generativa ChatGPT (OpenAI), com as seguintes finalidades: revisão linguística e ortográfica do texto; e geração da Figura 1.

Todo o conteúdo gerado com o auxílio da ferramenta foi criticamente revisado e validado pelo discente, e é de responsabilidade integral do discente, não cabendo à ferramenta qualquer atribuição de coautoria. A análise crítica, a interpretação dos resultados e as conclusões apresentadas neste trabalho são de exclusiva autoria intelectual do discente.

ANEXO A – Folha de rosto do artigo publicado derivado do Estudo I

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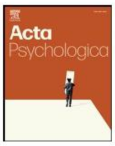

A new framework about exercise, functionality and health: Brain Functional Training

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ABSTRACT

Physical exercise is widely recognized for enhancing the ability to perform daily tasks. However, most studies focus primarily on physical capacities, often overlooking the contribution of cognitive processes. This article aims to present a theoretical framework underlying the concepts used in applying complexity as a dose variable to improve functionality within the health context, with a particular focus on cognitive aspects, as widely employed in Brain Functional Training. Manipulating task complexity increases planning demands, thereby inducing cognitive load, and through repeated exposure, drives chronic functional adaptations relevant to health. The primary mechanism underlying this hypothesis is the increased activity in neural regions associated with planning, particularly in the prefrontal cortex, which is acutely engaged during tasks. By applying cognitive stimuli that engage executive functions or motor stimuli that promote movement variability, this approach provides an alternative framework to traditional Functional Training. Brain Functional Training can be particularly useful in contexts where adjustments in training volume or intensity are limited, supporting the planning and execution of movements of daily living while potentially enhancing both motor and cognitive aspects of functional performance.

1. Introduction

The effects of physical exercise on cognition are well established in the scientific literature, involving modifications in the morphology and function of the central nervous system, especially improving white matter integrity, promoting neuroplasticity, and enhancing executive functions (De Sousa Fernandes et al., 2020; Xiong et al., 2021; Zhang, Zhou, & Chen, 2023). From this perspective, planning can be considered one of the core executive functions, defined as the ability to conceive, organize, and execute a sequence of actions toward a goal (Diamond, 2013; Lezak, 2004). This executive function may be more or less demanded according to the level of movement automatization, since tasks that are still being learned and are considered more complex require greater cortical engagement (Wu & Hallett, 2005).

The proper functioning of the executive functions is an essential part of functionality according to the Functional Status concept described in the Medical Subject Headings (MeSH): "Ability regarding basic physical and cognitive activities such as walking or reaching, focusing attention, and communicating, as well as the routine activities of daily living, including eating, bathing, dressing, transferring, and toileting [...]" (Dhammi & Kumar, 2014).

In this scenario, Functional Training stands out because its main objective is to improve functionality (Da Silva-Grigoletto & Teixeira, 2020), with some recent articles showing its positive long-term effects on executive functions (Martinez-Navarro et al., 2021; Pantoja-Cardoso, Aragão-Santos, Monteiro, et al., 2023). From the perspective of prioritizing the effects on planning ability as a result of the interaction between core executive functions, the possibility arises of employing cognitive dual-task paradigms specifically designed to enhance these executive functions, as has been implemented in another training model known as Brain Endurance Training (Dallaway et al., 2021; De Lima-Junior et al., 2023; Díaz-García et al., 2023; Staiano et al., 2023). In

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ANEXO B – Folha de rosto do *draft* do artigo derivado do Estudo III

For consideration in Geriatrics & Gerontology International Page 1 of 46

Geriatrics & Gerontology International

Original Article

Repeated Effect of Brain Functional Training on Functional Status and Body Composition of Postmenopausal Women: A Randomized Controlled Trial

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APÊNDICE A – Termo de Consentimento Livre e Esclarecido (Estudo II)

UNIVERSIDADE FEDERAL DE SERGIPE
PRÓ-REITORIA DE PÓS-GRADUAÇÃO E PESQUISA
PROGRAMA DE PÓS-GRADUAÇÃO EM CIÊNCIAS DA SAÚDE

TERMO DE CONSENTIMENTO LIVRE E ESCLARECIDO

Estamos te convidando a participar voluntariamente do projeto de pesquisa chamado "***Calisthenic Functional Training*** **na aptidão funcional de mulheres idosas**: avaliação dos efeitos e análise de custo-efetividade" o qual se refere a um projeto de pesquisa do professor Dr. Marzo Edir Da Silva Grigoletto.

Este projeto objetiva analisar os efeitos do *Calisthenic Functional Training* na aptidão funcional de mulheres idosas, e a sua custo-efetividade em relação ao Treinamento Funcional.

A senhora está sendo convidada a participar de um dentre três protocolos de treinamento, sendo submetida a 16 semanas de treinamento, o qual será realizado três vezes na semana totalizando 48 sessões de exercício, com momentos de avaliação funcional prévia, após 8 semanas de treinamento e posterior às 16 semanas. Você não terá custos para participar desta pesquisa; se você tiver gastos com exames, transporte e alimentação, inclusive de seu acompanhante (se necessário), eles serão reembolsados pelo pesquisador responsável. A pesquisa também não envolve compensações financeiras, ou seja, você não poderá receber pagamento para participar.

Caso haja danos decorrentes dos riscos previstos, o pesquisador assumirá a responsabilidade pelos mesmos. Por exemplo, durante os testes antropométricos é possível que haja um desconforto em se expor perante o sexo oposto. Para evitar essa situação, os testes antropométricos serão realizados por um avaliador do mesmo sexo objetivando um maior conforto e tranquilidade para a participante. Outro exemplo é que, durante os testes físicos é possível que haja desconforto devido ao esforço físico realizado, caso isso aconteça haverá um fisioterapeuta e equipe de enfermagem de plantão para o primeiro acompanhamento. Em caso de necessidade, a participante será conduzida ao centro médico mais próximo, a saber: Hospital de Urgência de Sergipe. Por fim, as participantes da pesquisa que vierem a sofrer qualquer tipo de dano resultante de sua participação na pesquisa, terão direito à indenização, por parte do pesquisador responsável nas diferentes fases da pesquisa.

No que abrange os três protocolos de treinamento (*Calisthenic Functional Training*, Treinamento Funcional e Alongamento), os mesmos podem ocasionar desconforto devido ao esforço e possivelmente alguma lesão física. O mesmo poderá ocorrer durante as sessões de análise aguda de respostas às variações em complexidade do exercício físico. Para evitar isso, profissionais da fisioterapia capacitados acompanharão a participante durante todo o treinamento para orientar e garantir sua segurança. Caso ocorra algo inesperado, os primeiros cuidados serão realizados por um fisioterapeuta com capacitação para realizar os primeiros socorros e a participante será conduzida ao Hospital de Urgência de Sergipe.

Como benefícios diretos do projeto, vale destacar o aumento da força, massa muscular, aptidão funcional e função cognitiva. Além disso, espera-se haver melhora da autonomia e independência na realização das atividades cotidianas. Como benefícios indiretos, haverá aumento da socialização (novas amizades), melhora da autoestima, melhora do humor, mudança no estilo de vida. Além disso, melhora da composição corporal, aumento da força muscular, maior autonomia e independência. Portanto, esse projeto objetiva a promoção da saúde e qualidade de vida para a população da 3ª idade.

A sua participação não é obrigatória. Você poderá se recusar a participar e/ou desistir e retirar seu consentimento a qualquer momento que desejar. Sua recusa, desistência ou retirada de consentimento não acarretará prejuízo ou danos. A sua participação não será remunerada e nem implicará em gastos pessoais.

Sua identidade não será revelada em nenhum momento, por isso a senhora receberá um número de identificação em todos os exames e no protocolo de treinamento, garantindo a confidencialidade e privacidade dos seus dados. O pesquisador responsável se compromete a tornar públicos nos meios acadêmicos e científicos os resultados obtidos sem qualquer identificação dos participantes. Caso você concorde em participar desta pesquisa, rubrique as três laudas e assine ao final deste documento, que possui duas vias, sendo uma delas sua e a outra do pesquisador responsável pela pesquisa. Essa pesquisa segue os critérios éticos das resoluções 466/2012 e 510/2016, do Conselho Nacional de Saúde.

Dados do Pesquisador
Nome: Marzo Edir Da Silva Grigoletto.
Programa de Pós-Graduação em Ciências da Saúde - PPGCS.
Universidade Federal de Sergipe.
Email: dasilvame@gmail.com
Telefone: (79) 99162-8168

Considerando que fui informada dos objetivos e importância desse estudo, de como será minha participação, riscos e benefícios, declaro o meu consentimento em participar da pesquisa.

| Impressão datiloscópica |

____
Assinatura da Participante da Pesquisa

____
Assinatura do Pesquisador

São Cristóvão, ____ de _______________ de _______.

Em caso de qualquer dúvida ou reclamação sobre a pesquisa, entrar em contato com:
Comitê de Ética em Pesquisa da Universidade Federal de Sergipe, Rua Cláudio Batista s/nº
Bairro: Sanatório–Aracaju CEP: 49.060-110–SE.
Contato por e-mail: cep@academico.ufs.br.
Telefone e horários para contato: (79) 3194-7208 – Segunda a sexta-feira das 07h às 12h.

APÊNDICE B – Termo de Consentimento Livre e Esclarecido (Estudo III)

Termo de Consentimento Livre e Esclarecido

UNIVERSIDADE FEDERAL DE SERGIPE
PRÓ-REITORIA DE PÓS-GRADUAÇÃO E PESQUISA
PROGRAMA DE PÓS-GRADUAÇÃO EM CIÊNCIAS FISIOLÓGICAS

TERMO DE CONSENTIMENTO LIVRE E ESCLARECIDO

Estamos te convidando a participar voluntariamente do projeto de pesquisa chamado **"Impacto do Treinamento Funcional na Saúde Física e Mental de Pessoas Idosas Independentes no Cenário Pós Pandêmico"** o qual se refere a um projeto de pesquisa do orientador do professor Dr. Marzo Edir Da Silva Grigoletto.

Este projeto objetiva analisar o impacto do treinamento funcional com e sem dupla tarefa sobre parâmetros de saúde física e mental e seu custo-efetividade em pessoas idosas independentes no cenário pós pandêmico.

O(a) senhor(a) está sendo convidado(a) a participar de dois protocolos de treinamento, sendo duas sessões iniciais com avaliações anteriores e imediatamente posteriores sobre dor e função cognitiva. Após esse momento, será submetida à 16 semanas de treinamento, o qual será realizado três vezes na semana totalizando 48 sessões de exercício, com momentos de avaliação prévia e posterior de força, composição corporal, funcionalidade, função cognitiva e dor. Essas avaliações envolverão testes físicos e de função executiva, questionários sobre dor, qualidade de vida, qualidade do sono, ansiedade e depressão e coleta sanguínea realizada por um profissional treinado, em local apropriado para coleta e utilizando materiais descartáveis. As amostras sanguíneas serão destinadas somente para esse estudo. Por isso, o pesquisador responsável compromete-se a ressarcir os seus valores necessários gastos com transporte e alimentação, como também do seu acompanhante, assim, o a senhor(a) não terá custos ao participar da pesquisa.

Caso haja danos decorrentes dos riscos previstos, o pesquisador assumirá a responsabilidade pelos mesmos. Por exemplo, durante os testes antropométricos é possível que haja um desconforto em se expor perante o sexo oposto. Para evitar essa situação, os testes antropométricos serão realizados por um avaliador do mesmo sexo objetivando um maior conforto e tranquilidade para a participante.

Neste sentido, por decorrência da pandemia de COVID-19, durante as coletas de dados e sessões de treinamento haverá álcool em gel 70% disponível para higienização das mãos e álcool 70% para higienização dos materiais utilizados no treinamento. Desde o início do projeto, todas as participantes são instruídas a informar caso sintam algum sintoma característico da COVID-19 e ficar em casa pelo período de isolamento.

Nesta mesma linha de raciocínio, durante os testes físicos é possível que haja desconforto devido ao esforço físico realizado, caso isso aconteça haverá um fisioterapeuta e equipe de enfermagem de plantão para o primeiro acompanhamento. Em caso de necessidade, a participante será conduzida ao centro médico mais próximo, a saber Hospital de Urgência de Sergipe. No que diz respeito aos testes bioquímicos, a participante pode sentir um leve desconforto devido a coleta sanguínea e o período de jejum necessário, nesse sentido, haverá um enfermeiro capacitado fazendo a coleta e será disponibilizado um lanche para o desjejum após a coleta.

As avaliações referentes a composição corporal serão realizadas por dois aplicadores, um do sexo feminino e outro do sexo masculino para garantir a integridade da avaliação e oferecer mais conforto à participante durante esse momento no qual pode sentir desconforto por utilizar roupas leves.

No que abrange o treinamento físico, o mesmo pode ocasionar desconforto devido ao esforço e possivelmente alguma lesão física. Para evitar isso, profissionais da fisioterapia capacitados acompanharão a participante durante todo o treinamento para orientar e garantir sua segurança. Caso ocorra algo inesperado, os primeiros cuidados serão realizados por um fisioterapeuta com capacitação para realizar os primeiros socorros e a participante será conduzida ao Hospital de Urgência de Sergipe.

Já no grupo que não realizará treinamento, as atividades de alongamento podem gerar algum tipo de desconforto por estar em contato com outras idosas realizando atividades que visam a interação. Nesse sentido, haverá um fisioterapeuta acompanhando todas as interações realizadas para garantir a execução segura e saudável das atividades.

Desse modo, oportunizando um momento de lazer e mantendo a participante em contato com o projeto.

Como benefícios diretos do projeto, vale destacar o aumento da força, massa muscular, funcionalidade e função cognitiva. Além disso, melhora da autonomia e independência na realização das atividades cotidianas. Como benefícios indiretos, haverá aumento da socialização (novas amizades), melhora da autoestima, melhora do humor, mudança no estilo de vida. Além disso, melhora da composição corporal, aumento da força muscular, maior autonomia e independência. Portanto, esse projeto objetiva a promoção da saúde e qualidade de vida para a população da 3ª idade.

A sua participação não é obrigatória. Você poderá se recusar a participar e/ou desistir e retirar seu consentimento a qualquer momento que desejar. Sua recusa, desistência ou retirada de consentimento não acarretará prejuízo ou danos. A sua participação não será remunerada e nem implicará em gastos pessoais.

Sua identidade não será revelada em nenhum momento, por isso o (a) senhor(a) receberá um número de identificação em todos os exames e no protocolo de treinamento, garantindo a confidencialidade e privacidade dos seus dados. O pesquisador responsável se compromete a tornar públicos nos meios acadêmicos e científicos os resultados obtidos sem qualquer identificação dos participantes. Caso você concorde em participar desta pesquisa, rubrique as três laudas e assine ao final deste documento, que possui duas vias, sendo uma delas sua e a outra do pesquisador responsável pela pesquisa. Essa pesquisa segue os critérios éticos das resoluções 466/2012 e 510/2016, do Conselho Nacional de Saúde.

Dados do Professor Orientador

Nome: Marzo Edir Da Silva Grigoletto.

Programa de Pós-Graduação em Ciências Fisiológicas-PROCFIS Universidade Federal de Sergipe.

Considerando que fui informada dos objetivos e importância desse estudo, de como será minha participação, riscos e benefícios, declaro o meu consentimento em participar da pesquisa.

Impressão datiloscópica	___________________________________ Assinatura do Participante da Pesquisa ___________________________________ Assinatura do Pesquisador

São Cristóvão, ____ de ____________ 2023.

Em caso de qualquer dúvida ou reclamação sobre a pesquisa, entrar em contato com: Comitê de Ética em Pesquisa da Universidade Federal de Sergipe, Rua Cláudio Batista s/nº Bairro: Sanatório–Aracaju CEP: 49.060-110–SE.
Contato por e-mail:cep@academico.ufs.br Telefone e horários para contato: (79) 3194-7208 – Segunda a Sexta-feira das 07 às 12h.

APÊNDICE C – Programa de treinamento das Intervenções Corpo-Mente

	Weeks - 1 to 4	**Weeks - 5 to 7**	**Weeks - 8 to 10**	**Weeks - 11 to 16**
Movement	Exercises	Exercises	Exercises	Exercises
1	Stretch arms up	One hand up	Half circle in the sky – one hand up	Half circle in the sky – one hand up
2	Bow and arrow	Touching heaven and earth - a single hand up and a single hand down	Touching heaven and earth - a single hand up and a single hand down	Touching heaven and earth - a single hand up and a single hand down
3	Stretch heaven and earth	Circle of life	Circle of life	Circle of life
4	Stretch your arms back and look to the sides	Slow squat with side step	Slow squat with side step	Slow squat with side step
5	Open legs, hand on knee, rotate trunk, neck follows movement	Postural tree hug – zhan zhuang	Lunge and crouch	Lunge and crouch
6	Hands up, down, when reaching the waist the hand goes back to the lower back and down embracing the posterior region	Union of hands stretches upwards and returns arm to the side	Hand on ear pushes forward – push with hand on ear	Hand on ear pushes forward – push with hand on ear
7	Forward punching motion, opens the hand, rotates outward and returns the waist, all during gentle knee flexion	Hands up, go down hugging your legs	One hand on the back of the neck and the other on the lower back - touch the back of the neck and the lower back	One hand on the back of the neck and the other on the lower back - touch the back of the neck and the lower back
8	Go up on your tiptoes and go down counting 1,2,3...	Weight redistribution (calf 3’ on the way down)	Stretching your leg with a push from your hands – improves balance, coordination of movements and leg strength	Stretching your leg with a push from your hands – improves balance, coordination of movements and leg strength
9			Raise your arms and touch the floor	Raise your arms and touch the floor