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EFFECTS OF PHYSICAL EXERCISE ON MOTOR FUNCTION IN ELDERLY PEOPLE WITH ALZHEIMER´S, PARKINSON´S OR MULTIPLE SLEROSIS DISEASES

Dissertação

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Dedicatória

Dedico este trabalho aos meus pais, por serem a minha maior fonte de amor, força e apoio em todos os momentos da minha vida.

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Acrónimos/Siglas

ACASO – Associação Cultural de Apoio Social de Olhão

ACSM – American College of Sports Medicine

AD – Alzheimer's Disease

ADL – Activities of Daily Living

AE – Aerobic Exercise

AE&RT – Aerobic and Resistance Training

AI – Artificial Intelligence

ApoE – Apolipoprotein E

APP – Amyloid Precursor Protein

BBS – Berg Balance Scale

BBT – Box and Block Test

CERT – Consensus on Exercise Reporting Template

CIS – Clinically Isolated Syndrome

CNS – Central Nervous System

CREDECI2 – Criteria for Reporting the Development and Evaluation of Complex Interventions in Healthcare (Version 2)

CT – Computed Tomography

CTTa – Color Trails Test A

CTTb – Color Trails Test B

DLPFC – Dorsolateral Prefrontal Cortex

DT – Dual Task

DTC – Dual-Task Cost

EEG – Electroencephalography

FC – Functional Connectivity

fMRI – Functional Magnetic Resonance Imaging

FOGQ – Freezing of Gait Questionnaire

FTSST – Five Times Sit-to-Stand Test

GC – Control Group

GI – Intervention Group

HAST – Hand Active Sensation Test

HRMAX – Maximum Heart Rate

IA – Artificial Intelligence

IMUs – Inertial Measurement Units

LEDD – Levodopa Equivalent Daily Dose

LSVT-BIG – Lee Silverman Voice Treatment BIG

MCI – Mild Cognitive Impairment

miniBEST – Mini Balance Evaluation Systems Test

MoCA – Montreal Cognitive Assessment

MRI – Magnetic Resonance Imaging

MS – Multiple Sclerosis

MDTW – Motor Dual-Task Walking

NA – Non-Adaptive Dynamic Cycling

NHPT – Nine-Hole Peg Test

NR – Not Reported / Not Referenced

OLST – One-Leg Stance Test

PD – Parkinson's Disease

PD-MCI – Parkinson’s Disease with Mild Cognitive Impairment

PD SAFEx™ – Parkinson’s Disease Sensory Attention Focused Exercise

PDQ-39 – Parkinson’s Disease Questionnaire – 39 items

PET – Positron Emission Tomography

PICOS – Population, Intervention, Comparison, Outcomes, Study Design

POMA – Performance Oriented Mobility Assessment

PPMS – Primary Progressive Multiple Sclerosis

PRISMA – Preferred Reporting Items for Systematic Reviews and Meta-Analyses

PROSPERO – International Prospective Register of Systematic Reviews

PSADC – Patient-Specific Adaptive Dynamic Cycling

PSEN1 – Presenilin 1

PSEN2 – Presenilin 2

RCT – Randomized Controlled Trial

RRMS – Relapsing-Remitting Multiple Sclerosis

RSB – Rock Steady Boxing

RT – Resistance Training

SPECT – Single-Photon Emission Computed Tomography

SPMS – Secondary Progressive Multiple Sclerosis

tDCS – Transcranial Direct Current Stimulation

TMT – Trail Making Test

TR – Telerehabilitation

TT – Treadmill Training

TT + VR – Treadmill Training Combined with Virtual Reality

ULVRE – Upper Limb Virtual Reality Exercises

UPDRS – Unified Parkinson's Disease Rating Scale

UPDRS-II – Unified Parkinson’s Disease Rating Scale Part II

UPDRS-III – Unified Parkinson's Disease Rating Scale – Part III

VO_2 – Oxygen Consumption

VR – Virtual Reality

WHO – World Health Organization

WPST – Wrist Position Sense Test

Efeitos do Exercício Físico na Função Motora em Idosos com Doença de Alzheimer, Parkinson ou Esclerose Múltipla

Resumo

Enquadramento: A Doença de Alzheimer (DA), a Doença de Parkinson (DP) e a Esclerose Múltipla (EM) constituem as principais doenças neurodegenerativas, afetando milhões de pessoas em todo o mundo. Estas patologias comprometem significativamente a funcionalidade e a realização das atividades da vida diária. Contudo, a prática regular de exercício físico tem demonstrado benefícios relevantes na melhoria da função motora, configurando-se como uma intervenção promissora para esta população.

Objetivo: O presente trabalho teve como objetivo apresentar o propósito e a metodologia de três estudos: i) analisar o estado da arte relativamente aos efeitos do exercício físico na função motora de idosos com Doença de Alzheimer, Doença de Parkinson e Esclerose Múltipla; ii) desenvolver e validar um programa de exercício físico direcionado para idosos com estas patologias; iii) avaliar os efeitos da Doença de Alzheimer nas funções motoras.

Métodos: Para cumprir o primeiro objetivo, foi realizada uma revisão sistemática da literatura com base nas orientações do protocolo PRISMA. Para o segundo objetivo, a validação do programa de exercício foi realizada de acordo com as recomendações do modelo CREDECI2 e do instrumento CERT. Relativamente ao terceiro objetivo, foi desenvolvido um estudo caso, com uma idosa, com Doença de Alzheimer.

Resultados: Na revisão sistemática identificaram-se 125 artigos, dos quais 13 cumpriram os critérios de inclusão. A evidência demonstrou que o exercício físico estruturado promove melhorias na função motora, equilíbrio, mobilidade e independência funcional, particularmente em indivíduos com DP. Também foram observados benefícios em idosos com DA, especialmente através de intervenções com dupla tarefa. O programa de exercício físico considerado válido e adequado pelo painel de especialistas. Por fim, o estudo caso mostrou ligeiras alterações nas funções motoras. Para além disso, os IMUs e a inteligência artificial (IA) serviram para treinar modelos individuais de monitorização/avaliação de indivíduos.

Discussão e conclusões: Concluiu-se que o exercício físico e a atividade física representam uma estratégia segura e eficaz para idosos com doenças neurodegenerativas, contribuindo para a melhoria da função motora e da coordenação motora. Os resultados reforçam a importância de se realizar mais investigação envolvendo populações com EM e maior amostra.

Palavras-chave: Exercício Físico, Função Motora, Idosos, Doença de Alzheimer, Doença de Parkinson; Esclerose Múltipla; Treino de modelos de IA

Effects of Physical Exercise on Motor Function in Elderly People with Alzheimer´s, Parkinson´s or Multiple Sclerosis Diseases

Abstract

Background: Alzheimer's Disease (AD), Parkinson's Disease (PD), and Multiple Sclerosis (MS) are among the most prevalent neurodegenerative disorders, affecting millions of people worldwide. These conditions significantly impair functionality and the performance of activities of daily living. However, regular physical exercise has demonstrated relevant benefits in improving motor function, making it a promising intervention for this population.

Objective: This dissertation aimed to present the purpose and methodology of three studies: (i) to analyze the current state of knowledge regarding the effects of physical exercise on motor function in older adults with Alzheimer's Disease, Parkinson's Disease or Multiple Sclerosis; (ii) to develop and validate a physical exercise program tailored for older adults with these conditions; and (iii) to evaluate the effects of Alzheimer's Disease on motor functions.

Methods: To address the first objective, a systematic literature review was conducted following the PRISMA guidelines. For the second objective, the exercise program was validated according to the recommendations of the CREDECI2 model and the CERT framework. Regarding the third objective, a case study was conducted involving an older woman diagnosed with Alzheimer's Disease.

Results: The systematic review identified 125 articles, of which 13 met the inclusion criteria. The evidence showed that structured physical exercise promotes improvements in motor function, balance, mobility, and functional independence, particularly in individuals with PD. Benefits were also observed in older adults with AD, especially through dual-task interventions. The exercise program was considered valid and appropriate by the expert panel. Finally, the case study revealed slight changes in motor function. Furthermore, inertial measurement units (IMUs) and artificial intelligence (AI) were used to train individual monitoring and assessment models.

Discussion and Conclusions: It was concluded that physical exercise and physical activity represent a safe and effective strategy for older adults with neurodegenerative diseases, contributing to the improvement of motor function and motor coordination. The results reinforce the importance of further research involving populations with MS and a larger sample size.

Key-words: Physical Exercise; Motor Functions; Older Adults; Alzheimer’s Disease; Parkinson’s Disease; Multiple Sclerosis; AI model training

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1. Dissertation Introduction

1.1. Background

This dissertation evaluates the effects of physical exercise on elderly individuals with Alzheimer’s Disease (AD), Parkinson’s Disease (PD) or Multiple Sclerosis (MS). The present study is divided into five chapters. The first chapter provides the theoretical framework for the dissertation. The second chapter is entitled “Study 1 – Effects of Physical Exercise on Motor Function in Elderly People with Alzheimer’s Disease, Parkinson’s Disease or Multiple Sclerosis: A Systematic Review.” The third chapter focuses on the validation of a physical exercise program tailored to this population, entitled “Study 2 – Development and Validation of a Physical Exercise Program for Elderly People with Alzheimer’s Disease or Parkinson’s Disease.” The fourth chapter includes “Study 3 – Effects of Alzheimer´s Disease on Motor Function: a Case Study with the use of machine learning algorithms training”. The fifth chapter is dedicated to the general discussion and conclusions of this dissertation.

The dissertation was originally written in Portuguese, then translated into English using ChatGPT (OpenAI). The translated version was subsequently carefully reviewed, edited, and corrected by the author and an expert in this language, to ensure linguistic accuracy, appropriate terminology, and fidelity to the original content. The author assumes full responsibility for the final version of the text.

1.2. Concepts and Literature Review

1.2.1. Physical Activity

Physical activity is “defined as any bodily movement produced by the contraction of skeletal muscles that results in a substantial increase in energy expenditure above resting levels” (ACSM, 2021).

1.2.2. Physical Exercise

Physical exercise, in turn, is any “type of physical activity that is planned, structured, and repetitive, with the aim of improving and/or maintaining physical fitness. Physical fitness is defined as the ability to perform daily tasks with vigor and alertness, without undue fatigue” (ACSM, 2021).

1.2.3. Older Adult or Elderly

Elderly refers to “a person aged 65 or older. However, the same definition also considers elderly those who are between 50 and 64 years old and who have chronic conditions or physical limitations that affect their mobility and ability to practice physical exercise” (ACSM, 2021).

1.2.4. Benefits of Physical Exercise in Older Adults

Recognizing the benefits of exercise, together with identifying appropriate types of physical activities for older adults, is essential to increase awareness and encourage engagement in physical activity within this population. Such encouragement may lead to a longer, healthier, and more active life. Given the more complex healthcare needs resulting from additional functional decline, older adults require specialized attention (Suryadi et al., 2024). The onset of aging in older adults often results in a reduction in skeletal muscle mass, strength, and functional capacity, highlighting the critical need for targeted exercise interventions to address these effects (Izquierdo et al., 2021; Suryadi et al., 2024). With aging, there is a natural decline in functional capacity, which is further exacerbated by lifestyle factors that contribute to an increased incidence of hypertension and, consequently, a higher prevalence of degenerative diseases. Recognizing these challenges, the World Health Organization (WHO) advocates the combination of physical activity and a nutritious, balanced diet as essential components of a healthy lifestyle for older adults. Such practices are not only crucial for disease prevention but also for promoting successful aging, improving quality of life, and extending healthy life expectancy (Suryadi et al., 2024).The importance of physical activity extends beyond disease prevention. Authors highlight the role of physical exercise in improving health, enhancing functional capacity in daily tasks, slowing the aging process, and delaying the onset of age-related decline among older adults. Thus, physical activity is presented as a multifaceted approach to addressing the health challenges faced by the aging population. Activities such as walking, cycling, gymnastics, and yoga (Di Lorito et al., 2021) have been shown to be highly beneficial for older adults, improving muscle strength, maintaining balance, and promoting cardiovascular health. In addition, strength training, such as lifting light weights, plays a fundamental role in preventing the loss of muscle mass (Suryadi et al., 2024). Physical activity also has a significantly positive influence on the mental well-being of older adults. Engaging in physical exercise can reduce the risk of depression, improve mood, and enhance cognition and brain function (Suryadi et al., 2024).

With aging, older adults begin to lose not only muscle mass but also muscle power, affecting their physical performance. Therefore, resistance training is important in slowing this loss of muscle mass associated with sarcopenia. In addition to promoting gains in muscle mass and strength, this type of training increases contraction speed and muscle power, reduces the difficulty of performing daily tasks, increases energy expenditure, and improves body composition. It also enhances insulin sensitivity and glycemic control in older adults, improves mitochondrial function, and contributes to increased oxygen consumption and pulmonary ventilation levels (Pontedeira, 2022). As individuals age, they may develop a fear of falling, either due to a previous history or even without having experienced a fall. In this context, resistance training contributes to improvements in the sensory system, which in turn enhances stability and balance, ultimately helping to reduce the number of falls (Pontedeira, 2022). Muscle power decreases with advancing age due to a reduction in fast-twitch muscle fibers, consequently impairing the functional capacity of older adults. Power training helps to delay the loss of neuromuscular function and functional capacity (Jiménez-Lupión et al., 2023). When incorporated into resistance training, it contributes to improvements in lower limb power and beyond, as well as enhancing neural adaptations and increasing activation of agonist muscles (Pontedeira, 2022). There is a greater risk of falls in older adults who have a reduced ability to generate rapid force in the lower limbs and an accumulation of intramuscular adipose tissue in the hip abductor region, resulting in increased gait instability and reduced balance. Therefore, this type of training is crucial in reducing the risk of falls (Pontedeira, 2022).

1.2.5. Neurogenerative Diseases

Etymologically, the term "*neurodegenerative*" is composed of the prefix "*neuro*", which refers to nerve cells, and "*degeneration*", which describes the progressive deterioration of the structure or function of a tissue or organ (Srinivasan et al., 2020). Neurodegenerative diseases therefore comprise a heterogeneous group of disorders characterized by the progressive loss of neuronal structure and function, leading to cognitive and motor impairment. Although numerous neurodegenerative diseases have been identified, some exhibit a substantially higher prevalence than others. Alzheimer's disease (AD) is the most prevalent neurodegenerative disorder, accounting for approximately 60–80% of all dementia cases (Alzheimer Association, 2023). Parkinson's disease is the second most common neurodegenerative disorder, affecting more than 8 million individuals worldwide (Szunyogh et al., 2025). Multiple sclerosis follows, affecting approximately 2.8 million people globally (Montague et al., 2025). In contrast, other neurodegenerative disorders, such as amyotrophic lateral sclerosis (ALS), with a prevalence of 5.2 cases per 100,000 individuals (Yuan et al., 2024), and Huntington's disease (HD), with a global prevalence of 2.1 cases per 100,000 individuals, are considerably less prevalent. This epidemiological distribution justifies the focus of the present dissertation on Alzheimer's disease, Parkinson's disease, and multiple sclerosis.

1.2.5.1. Alzheimer´s Disease

It is estimated that there are 47.5 million people worldwide living with dementia, a number that may reach 75.6 million by 2030 and nearly triple to 135.5 million by 2050 (Alzheimer Portugal, 2025). According to the (2023 Alzheimer's Disease Facts and Figures, 2023), Alzheimer's Disease (AD) accounts for approximately 60 to 80% of all dementia cases.

As a historical note, this disease was first described in 1907 by the German physician Alois Alzheimer (Zheng & Wang, 2025). Alzheimer's Disease is a type of dementia characterized by the progressive and irreversible degeneration of several cognitive functions, such as memory, attention, concentration, language, thinking, and reasoning (Zhang et al., 2024). This deterioration leads to changes in behaviour, personality, and functional capacity, making it increasingly difficult to perform activities of daily living (Alzheimer Portugal, 2025). As brain cells gradually decrease in size and number, neurofibrillary tangles form within neurons and senile plaques develop in the extracellular space, impairing communication within the brain and damaging connections between brain cells. These cells eventually die, resulting in an inability to retain and recall information (Alzheimer Portugal, 2025).

There are two main types of this disease. Sporadic AD, or "late-onset," can affect adults of any age but typically occurs after the age of 65. The bridge integrator gene 1 (BIN1), located on chromosome 2 in humans, has been identified as a critical risk gene for sporadic Alzheimer's disease (Monteiro et al., 2023). However, in individuals carrying the ApoE ε4 gene, symptoms may appear earlier, between the ages of 60 and 70. This is the most common form of the disease and may affect individuals with or without a family history. Nevertheless, some individuals may inherit a higher or lower predisposition to developing the condition (Gomes, 2015). Familial AD, or "early-onset," is primarily caused by autosomal dominant mutations in the APP, PSEN1, or PSEN2 genes and accounts for only 1 to 5% of total AD cases (Gomes, 2015). The presence of these genes typically leads to disease onset between the ages of 40 and 60 (Alzheimer Portugal, 2025).

Patients with AD do not experience symptoms in the same order or with the same severity. However, there is a general pattern of disease progression. The Braak and Braak model classifies neuropathological progression into six stages, correlating them with subsequent clinical symptoms (Gomes, 2015). The preclinical (asymptomatic) phase of AD corresponds to stages I and II, also known as the trans entorhinal phase. During this stage, there is a gradual neuronal loss in structures of the limbic system, such as the hippocampus, entorhinal and trans entorhinal cortex, basal nucleus of Meynert, and amygdala (Gomes, 2015). This asymptomatic period is often followed by an insidious onset of episodic memory decline, associated with damage to the entorhinal cortex and hippocampus. This corresponds to stages III and IV, or the limbic phase. At this stage, the patient cannot yet be diagnosed with dementia, a social functioning is not severely impaired. However, memory problems begin to worsen. Clinically, this stage is referred to as Mild Cognitive Impairment (MCI). Gradually, this impairment begins to interfere with daily activities, becoming increasingly challenging for the individual (Gomes, 2015). When a clinical diagnosis is established, the disease progresses to stages V and VI, or the neocortical phase. At this stage, the entorhinal cortex and hippocampus are significantly deteriorated, and there is also involvement of the frontal and temporoparietal cortex. Patients may become disoriented and confused, with impairments in language, comprehension, and verbal fluency (Gomes, 2015). Other characteristic symptoms include persistent and frequent memory difficulties, especially regarding recent events; vague speech during conversations; loss of interest in previously enjoyed activities; increased time required to perform routine tasks; forgetting familiar people or places; difficulty understanding questions and instructions; deterioration of social skills; and emotional unpredictability (Alzheimer Portugal, 2025). Depending on the individual and the brain regions affected, symptoms may vary and disease progression may occur at different rates. A person’s abilities may fluctuate from day to day or even within the same day and may worsen during periods of stress, fatigue, or illness. However, it is certain that deterioration will occur over time. Alzheimer’s Disease is progressive, degenerative, and currently irreversible (Gomes, 2015).

Several potential causes are currently under investigation, including environmental factors, biochemical disturbances, and immune process. One of them is sleep disorders, type 2 diabetes mellitus, diets high in fat and high sodium intake in the diet (Monteiro et al., 2023).

Although anyone can develop this disease, it is more common after the age of 65. Globally, AD affects approximately 1 in 80 women aged 65 to 69, and 1 in 60 men in the same age group. Among individuals over 85 years old, the disease affects approximately 1 in 4 people of both sexes (Alzheimer Association, 2023). The diagnosis of Alzheimer’s Disease can be established through neuropsychological testing, morphological assessment, magnetic resonance imaging (MRI), computed tomography (CT), metabolic evaluation, positron emission tomography (PET), and electrical activity analysis using electroencephalography (EEG). Additionally, brain damage can be assessed through clinical analysis of cerebrospinal fluid biomarkers or through genetic testing, such as genotyping of apolipoprotein E (ApoE), amyloid precursor protein (APP), and presenilins 1 and 2 (PSEN1 and PSEN2) (Gomes, 2015).

Disease progression varies from person to person. However, individuals with Alzheimer’s Disease may live between three and twenty years after diagnosis, with an average life expectancy of seven to ten years (Alzheimer Portugal, 2025).

1.2.5.2. Parkinson´s Disease

Parkinson's Disease is a chronic, degenerative and progressive disease that affects approximately 8,5 million people worldwide, making it the second most common neurodegenerative disease after Alzheimer’s (Szunyogh et al., 2025).In Portugal, it is estimated that there are currently around 18,000 patients, with symptoms most commonly beginning after the age of 55, and cases diagnosed before the age of 40 being rare (Gago et al., 2025). The first description of patients with Parkinson’s Disease was made by the English physician James Parkinson in 1817. Later, the French neurologist Jean-Martin Charcot provided a more detailed description of the symptoms and was the first to propose the name “Parkinson’s Disease” (Gago et al., 2025).

The characteristic motor manifestations of Parkinson’s Disease arise due to the death of neuronal cells in a region of the brain known as the substantia nigra (Ye et al., 2023). These cells, also known as neurons, project to another brain region, the striatum, where they release a molecule called dopamine, which modulates the function of other neurons that are able to detect its presence. It is estimated that motor symptoms of Parkinson’s Disease appear when 60 to 80% of dopaminergic neurons (which produce dopamine) have already died and disappeared from the brain (Vázquez-Vélez & Zoghbi, 2021). Thus, when the level of dopamine in the substantia nigra becomes abnormally low, it leads to difficulties in controlling muscle tone and movement. This affects muscles both at rest and during activity (APDPk, 2025).

There is Parkinson’s Disease and two other types of parkinsonism: primary parkinsonism and secondary parkinsonism (Figure 1). Primary parkinsonism has no clear cause and includes several neurodegenerative diseases. Within primary parkinsonism, a distinction is made between typical and atypical parkinsonism. Typical primary parkinsonism corresponds to Parkinson’s Disease, in which there is selective degeneration of the nigrostriatal pathway. This is the most common form of parkinsonism. In atypical parkinsonism, sometimes also called Parkinson-plus syndromes, neuronal degeneration of the nigrostriatal pathway occurs within a more widespread neurodegenerative process. Thus, in these forms of parkinsonism, clinical manifestations differ from those typically described in Parkinson’s Disease. Unlike Parkinson’s Disease, where motor symptoms progress slowly, respond to treatment, and no additional symptoms are present in the early stages, atypical parkinsonism's usually progress more rapidly, show little or only transient response to treatment, and may include other symptoms that typically appear in later stages of Parkinson's Disease but occur earlier in these conditions. These symptoms and warning signs include recurrent falls, swallowing difficulties, visual hallucinations, cognitive impairment, low blood pressure, fainting, or urinary incontinence. The presence of atypical features should raise suspicion of atypical parkinsonism, calling into question the diagnosis of Parkinson's Disease (Gago et al., 2025). In secondary parkinsonism, a specific cause can be identified that may or may not be reversible and/or controllable. Drug-induced parkinsonism (iatrogenic parkinsonism) may account for up to one-fifth of parkinsonism cases and is the most common form after Parkinson's Disease. This type of parkinsonism can be reversible if the medication is identified and discontinued. Cerebrovascular disease or infections affecting the basal ganglia may also lead to the development of parkinsonism (Gago et al., 2025).

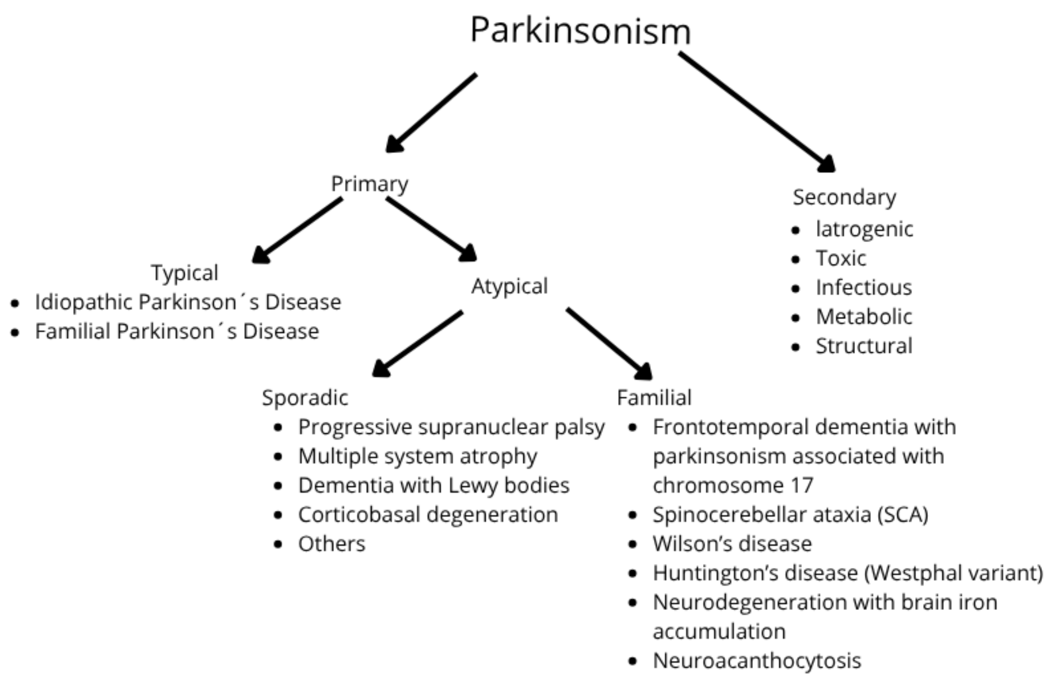


Figure 1 - Classification of Parkinsonism

Still, the reasons why dopaminergic neurons become dysfunctional and eventually die are not fully understood. However, several environmental and genetic factors have been associated with an increased risk of developing this disease (Gago et al., 2025). The only definitive risk factor for the onset of Parkinson's Disease is aging. However, despite the decline in striatal dopamine levels with physiological aging, this process is distinct from the neuropathological changes observed in Parkinson's Disease (Gago et al., 2025).

The diagnosis of this disease is made by a neurologist, based on clinical criteria of parkinsonism, supported by medical history and neurological examination (Bloem et al., 2021). To confirm Parkinson's Disease and exclude other primary or secondary parkinsonism's, the neurologist may rely on additional diagnostic tests. These include blood tests and brain computed tomography (CT). In some cases, brain magnetic resonance imaging (MRI), single-photon emission computed tomography (SPECT) using the radiopharmaceutical isoflurane, cardiac scintigraphy with 123 MIBG, or genetic testing may be required (Gago et al., 2025). Symptoms vary depending on the brain region affected by neuronal loss. Some of the most common symptoms include (Vázquez-Vélez & Zoghbi, 2021): akinesia and bradykinesia, resting tremor, rigidity, instability, and gait disturbances.

Akinesia is a key symptom of this disease. It refers to difficulty in initiating movement, with a progressive reduction in speed and amplitude, as well as difficulty in executing a motor plan. Bradykinesia consists of slowness and general poverty of movement and may also be present in other conditions besides Parkinson's Disease. In other words, akinesia and bradykinesia manifest as difficulty and slowness in actions such as opening and closing the hands, holding a cup, standing up from a chair and starting to walk, and progressive difficulty in writing, which tends to become smaller (micrography), among others. Other manifestations include reduced facial expression with the lips slightly apart at rest (hypomimia), decreased blinking, and speech difficulties (dysarthria) with a progressively softer voice (hypophonia). In more advanced stages, there may be difficulty swallowing (dysphagia) due to pharyngeal akinesia and drooling of saliva (sialorrhea) (Tarakad, 2025). Resting tremor is a rhythmic movement of the extremities, mainly affecting the hands, face, lips, and chin, and occurring primarily at rest. It usually appears asymmetrically, affecting either the left or right hand, and may progress to involve both sides and occur during voluntary movements, such as bringing a fork to the mouth (Tarakad, 2025). Rigidity consists of resistance to passive movement (flexion, extension, or rotation around a joint) of a body segment (neck, trunk, and limbs), remaining constant throughout the entire range of flexion or extension ("lead-pipe rigidity" or "cogwheel rigidity" when combined with tremor), further contributing to bradykinesia (Tarakad, 2025). Everyday examples include difficulties when combing hair, brushing teeth, or walking. In the long term, rigidity contributes to musculoskeletal problems and muscle atrophy due to disuse and should be a focus of targeted physiotherapy. Postural instability results from impaired postural reflexes due to delayed responses to changes in the body's centre of mass. There is a direct correlation between postural instability and disease severity, as well as other symptoms such as rigidity or cognitive impairment (Lenka & Jankovic, 2021). Some patients present gait disturbances, characterized by small steps and reduced arm swing, known as a "shuffling gait" (Zanardi et al., 2021).They may also show difficulty lifting their feet and, at times, involuntarily increase walking speed with progressively shorter steps (festination). Other patients may experience freezing of gait, especially at initiation or during walking, with feet seemingly “stuck” to the ground and difficulty restarting movement (Monaghan et al., 2023).However, before the onset of these motor symptoms, there is a preclinical phase lasting approximately 5 to 7 years. During this stage, changes are mainly non-motor, such as sleep disturbances, constipation, and loss of smell, among others. This phase occurs because the severity of Parkinson’s Disease is related to the loss of dopaminergic neurons, with motor symptoms typically appearing only after 60 to 80% of these neurons have been lost (Bloem et al., 2021). After clinical diagnosis, during the first 3 to 5 years, most patients experience a “honeymoon phase,” in which medication effectively controls symptoms. However, as the disease progresses, its effectiveness decreases, requiring higher doses, with shorter duration of effect, poorer symptom control, and increased side effects.

Finally, staging of Parkinson’s Disease is performed using the Hoehn & Yahr scale (Table 1). This scale reflects the progression of the disease over the years (Gago et al., 2025).

Table 1. Stages of Parkinson´s Disease Severity.

Stage Level	Characteristics
Stage 1	Unilateral disease
Stage 1.5.	Unilateral and axial involvement
Stage 2	Bilateral disease without postural instability
Stage 2.5.	Bilateral disease, mild postural instability, with recovery in the retropulsion test
Stage 3	Bilateral disease, mild postural instability, physical independence
Stage 4	Significant difficulty in walking and postural stability, but still able to ambulate without assistance
Stage 5	Unable to walk without assistance, confined to a wheelchair or bed

Patients with late-onset Parkinson's Disease tend to show a faster disease progression and a higher risk of developing dementia. Patients with early-onset or juvenile Parkinson’s Disease (onset before 40 years of age) generally present a slower progression. However, these patients tend to develop motor complications earlier and with greater severity, such as motor fluctuations (Gago et al., 2025).

1.2.5.3. Multiple Sclerosis

MS is a chronic inflammatory and degenerative disease. It is one of the most common diseases of the Central Nervous System (CNS) (Montague et al., 2025). MS was first defined as a disease in 1968 by Charcot (Montague et al., 2025). Its prevalence is increasing, and globally, in 2020, an estimated 2.8 million people were living with the disease. The incidence is higher with an average age at diagnosis of approximately 32 years, and women typically develop the disease 2 to 5 years earlier than men (Montague et al., 2025). Female susceptibility to MS is thought to result from a combination of sex-specific epigenetic changes, significant hormonal fluctuations during puberty, and environmental factors, including lower levels of sun exposure compared to men (Wang et al., 2023). It is a progressive, incurable disease that mainly affects young adults (Sá, 2009). In this disease, the immune system fails to distinguish between the body's own cells and foreign cells, beginning to attack its own tissues. One of the main targets of this attack is myelin, a fatty layer that protects and surrounds nerve fibres and helps in the transmission of signals. These attacks result in scars that cluster into structures known as areas of "sclerosis," also referred to as "plaques" or "lesions." As the disease progresses, these lesions affect thousands of nerve fibres, severely disrupting signal transmission in the body (Palavra et al., 2025).

In MS, inflammation damages or destroys the myelin sheaths of nerve cells, which is why the disease is considered "demyelinating." Axons that lose their myelin are no longer able to conduct nerve impulses properly, leading to the neurological symptoms typically experienced during an MS relapse. Over time, this axonal damage explains the degenerative (or progressive) nature of MS. Since the location of demyelinating lesions in the CNS is unpredictable, the nature of neurological deficits associated with relapses can be highly variable (Palavra et al., 2025).

The types of Multiple Sclerosis are defined according to how the disease evolves over time. The most common forms are Relapsing-Remitting Multiple Sclerosis (RRMS), Secondary Progressive Multiple Sclerosis (SPMS), Primary Progressive Multiple Sclerosis (PPMS), and Clinically Isolated Syndrome. The Multiple Sclerosis Relapsing-Remitting form (RRMS) is the most common type of the disease, characterized by periods of relapses, usually followed by recovery to the baseline or normal state (the "remission" phase). Relapses are one of the distinctive features of the disease and are typically acute episodes involving the appearance of one or more new symptoms, or the worsening of an existing symptom, lasting more than 24 hours. During a relapse, symptoms generally develop over a few days, remain stable for three to four weeks, and then disappear after about one month. During this period, full or partial recovery of symptoms is possible. Approximately 85% of people with MS are initially diagnosed with RRMS. In some individuals, the disease course eventually becomes progressive, and after several years they may develop Secondary Progressive Multiple Sclerosis (SPMS). Secondary Progressive Multiple Sclerosis (SPMS), previously known as Chronic Progressive Multiple Sclerosis, may develop after an initial relapsing-remitting phase lasting a variable period (usually more than 10 years). Some people with SPMS may still experience relapses, but during this stage recovery from symptoms is often no longer complete, and over time there is a gradual and continuous increase in symptoms and disability. SPMS develops differently in each person: while some experience very slow accumulation of disability, others may notice a faster progression. Over time, SPMS can be classified as "active" (when there are a relapse or new lesions on MRI) or "not active." It can also be classified as "with progression" (with evidence of worsening symptoms) or "without progression" (during stable periods). In Primary Progressive Multiple Sclerosis (PPMS), symptoms worsen gradually and continuously from the onset of diagnosis. Disability progresses slowly, but PPMS varies from person to person, and may stabilize at certain points or continue worsening over months or years. In a minority of cases, occasional relapses may occur. Thus, over its course, PPMS can also be classified as "active" (with an occasional relapse or new MRI lesions) or "not active," and as "with progression" (with evidence of worsening disability) or "without progression" (during stable periods). Around 15% of people with MS have PPMS. It typically appears at a later age, usually affecting individuals aged 40 or older, and is less common in younger people. It affects men and women equally, and the prognosis is generally worse than for other types. Multiple Sclerosis Clinically Isolated Syndrome (CIS) refers to the first episode of neurological symptoms associated with an inflammatory and demyelinating lesion of the central nervous system (CNS), in other words, the first relapse. In CIS symptoms last more than 24 hours, typically develop over several days, and tend to gradually improve over a period of about one month. A person with CIS who shows lesions on magnetic resonance imaging (MRI) similar to those seen in MS has a significant likelihood of experiencing a second relapse. When CIS is not accompanied by other lesions on MRI, the probability of developing MS is significantly lower.

Although extensively studied, the trigger for MS remains unknown. However, it is known that certain factors (possible causes), including genetic and environmental influences, may trigger this inflammatory response. Studies on MS incidence in twins have shown that in only about 30% of cases do both twins develop the disease. This means that heredity contributes approximately 30% to the disease cause, while the remaining 70% is attributed to environmental factors. To date, environmental factors associated with an increased risk include vitamin D deficiency, infection with the Epstein–Barr virus (especially later in life, i.e., after childhood), smoking, and obesity during childhood or adolescence (Palavra et al., 2025).

The progression, type, and severity of symptoms, as well as the extent of neurological damage associated with Multiple Sclerosis (MS), vary considerably among individuals and cannot be accurately predicted at the time of diagnosis. Common nonspecific symptoms include fatigue, which affects more than 75% of individuals with MS, and cognitive dysfunction ((Montague et al., 2025). The clinical presentation of MS is highly heterogeneous, reflecting the multifocal nature of the disease and the variable distribution of lesions within the Central Nervous System (CNS). Consequently, patients may experience a wide range of symptoms involving sensory, motor, visual, cognitive, and autonomic functions. The clinical spectrum commonly includes alterations in sensation, impaired mobility, balance and coordination difficulties, visual disturbances, sphincter dysfunction, and cognitive impairment (Portaccio et al., 2024).

Finally, the diagnosis of this disease begins with a neurological examination. To confirm or exclude MS, a magnetic resonance imaging (MRI) scan, lumbar puncture, blood tests, and evoked potentials may be performed (Bloem et al., 2021).

1.2.6. Effects of Exercise on Neurogenerative Diseases

Scientific evidence demonstrates that physical exercise is an effective intervention for improving functional capacity and quality of life in individuals with neurodegenerative diseases, although its effects vary according to the specific characteristics of each condition. Overall, exercise programs that combine strength, balance, muscular endurance, and aerobic training promote improvements in both physical and cognitive function. In Alzheimer's disease (AD), physical exercise provides consistent benefits, although the objectives of the intervention depend on the stage of the disease. During the early and moderate stages, the primary goal is to preserve functional and cognitive capacity, whereas in the advanced stages, the emphasis shifts toward preventing falls and maintaining independence (Adzhar et al., 2022). Exercise programs incorporating strength, endurance, and balance training improve physical function, muscle mass, cardiovascular health, and quality of life through mechanisms including reduced inflammation and oxidative stress, as well as enhanced brain plasticity (Adzhar et al., 2022). Furthermore, a meta-analysis by De la Rosa et al. (2020) reported that regular physical activity is associated with a 45% reduction in the risk of developing Alzheimer's disease. Regarding cognitive outcomes, Panza et al. (2018) found that aerobic exercise produced moderately favorable effects on cognitive function, whereas combined aerobic and resistance training programs yielded less pronounced benefits. The authors also emphasized that greater adherence to exercise programs was associated with larger cognitive improvements, recommending moderate-intensity exercise approximately three times per week for about 45 minutes per session. These findings are further supported by Yoon et al. (2017), who reported significant improvements in cognitive function, muscle strength, and functional capacity following a 12-week elastic resistance band training program. Superior outcomes were observed when exercises were performed at high velocity compared with traditional resistance training.

In Parkinson's disease (PD), physical exercise also provides consistent motor, functional, and psychological benefits. Specific interventions such as aquatic Tai Chi have been shown to improve pain, balance, and functional capacity in individuals with mild to moderate Parkinson's disease (Pérez de la Cruz, 2017). Similarly, programs based on the LSVT BIG (Lee Silverman Voice Treatment BIG) method, which emphasize activities of daily living (ADLs), have demonstrated improvements in manual function, ADL performance, anxiety, depression, and quality of life (Choi & Kim, 2022). Beyond these functional benefits, Johansson et al. (2022) demonstrated that aerobic exercise induces neuroplastic changes by reducing global brain atrophy and increasing functional connectivity between the right dorsolateral prefrontal cortex and the right frontoparietal network, brain regions involved in cognitive control. However, no significant changes were observed in the integrity of the substantia nigra.

In Multiple Sclerosis (MS), individuals exhibit reduced aerobic capacity, muscle weakness, impaired balance, and decreased muscular endurance compared with healthy individuals, supporting the implementation of disease-specific exercise programs that incorporate complex, multisegmentar movements (Döring et al., 2012). In this context, Gutiérrez-Cruz et al. (2020) found that a 24-week exercise program significantly increased maximal isometric strength (11%), rate of force development (36%), balance, and performance in activities of daily living (ADLs). Additionally, participants demonstrated substantial improvements in gait speed (54%) and step length (48%).

Overall, the studies reviewed demonstrate that physical exercise plays an important role in mitigating the functional limitations associated with neurodegenerative diseases, although the magnitude of its benefits depends on the type, intensity, duration, and frequency of the intervention, as well as the clinical characteristics of the participants.

1.2.7. Motor Functions

A search was conducted in scientific research databases (PubMed) and gray literature (Google Scholar) using the keywords "motor function*"* and *"função motora"* with the aim of identifying a conceptual definition of the term. As of June 25, 2026, only one explicit definition of motor function was identified. According to the American Physical Therapy Association, as cited by Hallemans et al., (2020) motor function is defined as the "ability to learn or demonstrate the skillful and efficient assumption, maintenance, modification, and control of voluntary postures and movement patterns," thus referring to "goal-directed voluntary behavior." Despite the scarcity of conceptual definitions, several authors describe motor function through related concepts. Stodden et al., (2009) state that motor function represents physical performance and is frequently equated with the physiological components of physical fitness. Similarly, Shumway-Cook & Woollacott, (2007a) define motor control as the "ability to regulate or direct the mechanisms essential to movement.". Therefore, within the context of the present dissertation, motor function is defined as the ability to produce, control, and coordinate movements with proficiency, enabling the effective performance of activities of daily living. Impairments in motor function are manifested through motor deficits that compromise functionality and may lead to different levels of disability.

1.2.7.1. Motor Coordination

According to Bernstein, (1984) motor coordination is the "process of mastering the redundant degrees of freedom of the body in motion, that is, converting them into a controllable system." In contrast, Turvey et al., (1982) conceptualize coordination as a coordinative structure, that is, a group of muscles and joints functioning as a single functional unit. Latash, (2012) in turn, describes motor coordination as an abundance of solutions, arguing that the multiple degrees of freedom available within the motor system enable the precise execution of motor tasks. According to Richard A. Schmidt et al., 2017) coordination involves the "constraints that exist among multiple moving components, such that the variables being coordinated obey a simple function." From Lamba, P. F & Bartlett, R. M., (2018) perspective, coordination consists of "mastering the many degrees of freedom involved in movement." Grosser, (1983) as cited in (Bessa, 2012) defines motor coordination as the ability to perform precise movements, maintain balance, and respond appropriately to external stimuli, thereby enabling the execution of movements with predetermined rhythms. These motor abilities are divided into two categories: coordinative abilities and conditional abilities. Conditional abilities include strength, speed, and endurance, whereas coordinative abilities include flexibility, reaction, balance, and rhythm (Rodio et al., 2024),

From this perspective, Newell, 1986) constraints model will be adopted as the conceptual framework for the present study, providing a structure for organizing the factors that influence the emergence of coordination patterns into three main categories: organism, task, and environmental constraints. Organism constraints refer to the individual's characteristics, such as anthropometric features (e.g., somatotype, body weight, and height). Environmental constraints refer to external factors that are generally beyond the individual's control, such as ambient temperature, lighting conditions, and other contextual factors. Task constraints, in turn, correspond to the objectives, rules, and specific demands of the activity being performed. Finally, the present dissertation is grounded in the Dynamic Systems Theory (Kelso, 1995) which proposes that motor behavior emerges as a result of the continuous interaction among the organism, the environment, and the task. From this perspective, motor coordination does not result from the isolated action of a single system but rather from the self-organization of the different components of the motor system.

1.3. Synthesis and Presentation of the Problem

The underlying issue of this research lies in the need to develop specific physical exercise for older adults with Alzheimer’s Disease, Parkinson's Disease or Multiple Sclerosis with the aim of creating a non-pharmacological treatment tool.

The proposed dissertation seeks to explore the benefits of physical exercise and the effects of the disease which include improved motor function, quality of life, and reduction of symptoms associated with these neurodegenerative diseases.

1.4. Objectives

The general objective of this dissertation is: 1) to verify how a physical exercise program contributes to motor function in people with neurodegenerative diseases and 2) to evaluate the effect of Alzheimer´s Disease.

The specific objectives are: 1) to review the state of the art regarding the effects of physical exercise on motor function in older adults with Alzheimer’s Disease, Parkinson’s Disease or Multiple Sclerosis; 2) to develop and validate an exercise program for older adults with Alzheimer’s Disease or Parkinson’s Disease; 3) to evaluate the effect Alzheimer´s Disease on motor coordination with the use of machine learning algorithms training.

2. Development

The second chapter includes the various studies planned in this work. Three distinct methodologies are presented.

2.1. Study 1 - Effects of Physical Exercise on Motor Function in Elderly People with Alzheimer´s Disease, Parkinson´s Disease or Multiple Sclerosis: A Systematic Review

Abstract

Background: Population ageing is a global phenomenon that has intensified in recent decades, representing one of the greatest challenges for healthcare systems. This process is associated with a significant increase in the prevalence of chronic and neurodegenerative diseases, among which Alzheimer's disease, Parkinson's disease, or Multiple Sclerosis stand out. These conditions are characterized by a progressive and irreversible course, significantly impairing individuals' motor, cognitive, and functional abilities, with a direct impact on autonomy and quality of life.

Objective: The present study aimed to examine the state of the art regarding the effects of physical exercise on motor function for older adults with Alzheimer's Disease (AD), Parkinson's Disease (PD) or Multiple Sclerosis (MS).

Methods: A systematic review was conducted in accordance with the PRISMA protocol and registered in PROSPERO, using the PICOS method as the eligibility criterion. The search was carried out in the PubMed, Web of Science, and EBSCO databases between June and July 2025, using the keywords: Alzheimer, Parkinson, Multiple Sclerosis, exercise, motor function, older adults, and elderly. Articles included in this systematic review met the following inclusion criteria: individuals with AD, PD, or MS; studies including a physical exercise intervention; articles published within the last 5 years; randomized controlled trials (RCTs) or clinical trials; studies published in English. Articles were excluded if they did not assess motor function in participants or if participants presented another clinical condition.

Results: The search identified 125 articles, of which 13 met the inclusion criteria. The results demonstrated that structured physical exercise promotes significant improvements in motor function, with more robust evidence for older adults with PD. For AD, one study showed benefits in mobility and functional independence through dual-task exercises. No eligible studies involving MS were identified.

Discussion and Conclusion: Physical exercise is an effective and safe non-pharmacological therapeutic strategy for older adults with neurodegenerative diseases, with a positive impact particularly in PD and AD.

Keywords: Alzheimer´s, Effects, Motor Function, Multiple Sclerosis, Parkinson´s, Physical Exercise

2.1.1. Introduction and Presentation of the Research Question

The recognition of the benefits provided by physical activity, combined with the identification of practices appropriate for the older population, is essential to increase awareness and encourage regular participation. Such interventions are fundamental to promoting longevity and active aging. Given that progressive functional decline leads to increasingly complex healthcare needs, older adults require specialized care (Suryadi et al., 2024), particularly those with neurodegenerative diseases.

Among these conditions, Alzheimer's disease (AD) represents the leading cause of cognitive impairment and dementia in individuals aged ≥ 65 years worldwide (Atri, 2019). As the disease progresses, neuropsychiatric symptoms may emerge, including periods of confusion, disorientation, aggression, and agitation (Tahami Monfared et al., 2022). It is also important to note that normal ageing is often associated with cognitive decline, affecting functions such as memory, language, and executive function (Harada et al., 2013), which can make it difficult to distinguish between changes related to normal ageing and those caused by the disease. Nevertheless, AD is estimated to account for approximately 50–70% of all dementia cases (Monteiro et al., 2023). In Portugal, in 2017, 1,569 deaths were attributed to this condition (1,568 residents and 1 non-resident). Approximately 99% of these deaths occurred in individuals aged 65 years or older, and about 92% occurred in individuals aged 75 years or older (Instituto Nacional de Estatística, I.P., 2019).

Parkinson's disease (PD), in turn, is characterized by dysfunction of the nigrostriatal dopaminergic system and the presence of motor symptoms, namely bradykinesia, muscular rigidity, resting tremor, and postural instability (Kanegusuku et al., 2021). In Portugal, in 2017, 935 deaths were associated with this disease (934 residents and 1 non-resident). Similar to AD, the vast majority of deaths occurred in individuals aged 65 years or older (97%), with 85% occurring in individuals aged 75 years or older (Instituto Nacional de Estatística, I.P., 2019).

Multiple sclerosis (MS) is an inflammatory demyelinating disease of the central nervous system (CNS) (Haki et al., 2024), characterized by processes of demyelination, inflammation, neuronal loss, and the formation of gliosis (scarring). This condition presents a wide heterogeneity of symptoms, including muscle weakness, fatigue, and gait disturbances (Haki et al., 2024). It is estimated that approximately 2.3 million people worldwide live with this disease, which is most frequently diagnosed between the ages of 20 and 50 years (Haki et al., 2024).

Given this context, it becomes imperative to develop and implement effective, safe, and sustainable intervention strategies capable of slowing functional decline, promoting autonomy, and improving the quality of life of these populations. Traditionally, the most predominant therapeutic approach has been pharmacological. However, despite significant advances in pharmacological treatments, these therapies present limitations in controlling both motor and non-motor symptoms.

In this context, physical exercise emerges as a highly relevant non-pharmacological therapeutic strategy. Scientific literature has shown that the regular practice of physical exercise in populations with neurodegenerative diseases plays an important role, as it stimulates neuronal mechanisms (Bispo et al., 2024), improves the efficiency of motor and cognitive circuits, and mitigates the impact of disease progression (Zhang et al., 2023). Recent studies have also shown that exercise programs integrating aerobic, resistance, and neuromotor component (Yang et al., 2022) enhance the benefits of physical exercise on motor function, improving mobility, balance, and muscle strength (Zeng et al., 2026).

Thus, the central research question guiding this investigation is: what are the effects of physical exercise on motor function in older adults with neurodegenerative diseases, namely, Alzheimer's, Parkinson's, and multiple sclerosis diseases?

Within this framework, the objective of this investigation is to examine the state of the art regarding the effects of physical exercise on motor function in older adults diagnosed with neurodegenerative diseases, namely Alzheimer's, Parkinson's, and multiple sclerosis diseases. It also aims to identify the most frequently used types of intervention, the main assessment instruments, and the outcomes related to motor function.

2.1.2. Methods

2.1.2.1. Protocol and Registration

This systematic review was conducted in accordance with the PRISMA guidelines – Preferred Reporting Items for Systematic Reviews and Meta-Analyses Protocols (Page et al., 2021) and was registered on the PROSPERO platform – the International Prospective Register of Systematic Reviews, registered with the code CRD420251141650.

2.1.2.2. Eligibility Criteria

The present research was structured according to the PICOS acronym, in which P (participants) refers to older adults with Alzheimer's disease, Parkinson's disease, or Multiple Sclerosis; I (intervention) corresponds to a physical exercise program specifically designed for these populations; C (comparisons) refers to comparisons between pre- and post-intervention assessments; O (outcomes) concerns the effects of physical exercise on motor function; and S (study design) includes randomized controlled trials (RCTs) and clinical trials.

2.1.2.3. Search Strategy and Databases

The search was conducted between June and July 2025 in the following electronic databases: PubMed, Web of Science, and EBSCO. The selection of these databases was based on their high scientific quality, thematic scope, and complementarity in indexing the literature. Together, these databases allow access to a wide range of scientific publications directly related to the scientific areas of this research. That being said, in PubMed and EBSCO, the search strategy used was: ((alzheimer) OR (parkinson) OR (multiple sclerosis)) AND ((older adults) OR (elderly)) AND (exercise) AND (motor function). In PubMed, the following filters were applied: publications from the last 5 years, availability of abstract, and study types limited to randomized controlled trials and clinical trials. In EBSCO, the search was limited to results with the terms present in the title, abstract, or keywords and was also restricted to the last 5 years. In Web of Science, the following search strategy was applied: (alzheimer OR parkinson OR multiple sclerosis) AND exercise AND motor function AND (older adults OR elderly). The filter applied in this database was a temporal restriction on publications from the last 5 years.

The temporal restriction to the five years preceding the literature search was established to synthesize the most contemporary scientific evidence regarding the effects of physical exercise on motor function in older adults with neurodegenerative diseases. In recent years, research in this field has been characterized by the evolution of exercise protocols, the increasing use of multicomponent interventions, and the integration of technological tools and more objective methods for assessing motor function. Therefore, limiting the review to studies published within a recent time frame helped reduce the temporal heterogeneity associated with changes in diagnostic criteria, therapeutic approaches, exercise prescription recommendations, and the assessment instruments used to evaluate intervention outcomes. Before defining this time frame, an exploratory search was conducted in the selected databases to identify previously published systematic reviews related to the topic. Two reviews with objectives similar to those of the present study were identified. One examined the effects of a patient-specific adaptive dynamic cycling paradigm on motor function and functional mobility in individuals with Parkinson’s disease, while the other investigated the effects of a program combining aerobic exercise and resistance training on motor function, postural stability, and cognitive processing speed. However, both reviews focused primarily on Parkinson’s disease and on specific exercise modalities, without simultaneously addressing the three major neurodegenerative diseases considered in the present review. Therefore, the present systematic review was designed to update and expand the existing body of knowledge by synthesizing the most recent evidence on different exercise modalities across multiple neurodegenerative diseases.

The exclusive inclusion of articles published in English in this systematic review is justified by several methodological and practical factors. First, English is the primary language for the dissemination of scientific knowledge on a global scale, and most publications indexed in international databases are written in this language. Adopting this criterion aims to maximize the comparability and scope of the selected evidence, ensuring access to studies with greater visibility and academic impact. Additionally, the use of a single language of analysis helps reduce translation and interpretation biases that could compromise the consistency of data extraction and result synthesis. Choosing articles in English also ensures greater terminological standardization, particularly with regard to assessment instruments and interventions, thereby facilitating cross-study analysis. Furthermore, restricting the review to publications in English aligns with the primary goal of enhancing continuity in the research process, including the future dissemination and publication of findings in international peer-reviewed journals where English is the standard language of scientific communication.

2.1.2.4. Inclusion Criteria

The articles included in this systematic review met the following inclusion criteria: (i) older adults with Alzheimer's disease, Parkinson's disease, or Multiple Sclerosis; (ii) adults aged over 50 years; (iii) studies that included a physical exercise intervention; (iv) articles published within the last 5 years; (v) RCTs or clinical trials; and (vi) studies written in English.

2.1.2.5. Exclusion Criteria

Studies were excluded if: (i) they did not assess motor function in participants; or (ii) participants presented another clinical condition, such as diabetes, fibromyalgia, among others.

2.1.2.6. Study Selection

Study selection was performed independently by two researchers, in accordance with the search strategy described above. In cases of disagreement between the two researchers, a third researcher was consulted. Articles considered relevant were imported into the Zotero reference management software 7.0.32. After removing duplicate records, both researchers screened the articles according to the eligibility criteria, inclusion and exclusion criteria, and also analyzed the outcomes of the intervention programs (baseline data and post-intervention data).

2.1.2.7. Data Extraction

From each study, the following data were extracted: (i) authors; (ii) year of publication; (iii) title; (iv) country; (v) objective; (vi) sample; (vii) age; (viii) sex; (ix) body mass index; (x) disease stage; (xi) disease duration; (xii) assessment instruments; (xiii) intervention duration; (xiv) equipment; (xv) type of exercise; (xvi) frequency; (xvii) intensity; (xviii) session duration; (xix) supervision; (xx) results; and (xxi) conclusions.

2.1.2.8. Quality Assessment

In a systematic review, it is essential to ensure the quality and credibility of the results derived from the synthesis of studies. Therefore, the methodological quality of the included studies must be assessed using methodological quality assessment scales or checklists. The importance of using such tools is described in literature as an incentive to improve the quality of manuscript reporting, as well as evidence of the rigor associated with the methodologies employed in the studies (Moseley et al., 2011).

Accordingly, in the process of assessing the methodological quality of each selected article, the Downs and Black scale (Downs & Black, 1998) was applied. This scale was developed to address the need to assess both RCTs and non-randomized studies. This scale includes five subdomains related to: (i) reporting quality, that is, whether the information presented in the study allows the reader to interpret the data and results without difficulty; (ii) external validity; (iii) internal validity - bias; (iv) confounding factors; and (v) study power. To address these subdomains, 27 criteria are listed, which were scored as “one” when identified by the evaluator. The absence of a criterion was scored as “zero.” The following cutoff points were used to categorize the studies: excellent (26–28), good (20–25), fair (15–19), and poor (<15 points).

2.1.3. Results

The initial search included 125 articles through PubMed, Web of Science, and ESBCO databases. Seventeen duplicate articles were identified and subsequently removed. The remaining 108 articles were analysed based on their titles and abstracts. However, when there was insufficient information, the article was read in full, resulting in the removal of 58 articles. Finally, after a complete reading of all articles, a further 37 articles were excluded for not meeting the eligibility criteria. Thus, 13 articles were included in this systematic review (Figure 2). The reliability between independent researchers was equal in both stages (title/abstract; full text), with 100% agreement and without the need for judgment by a third reviewer.

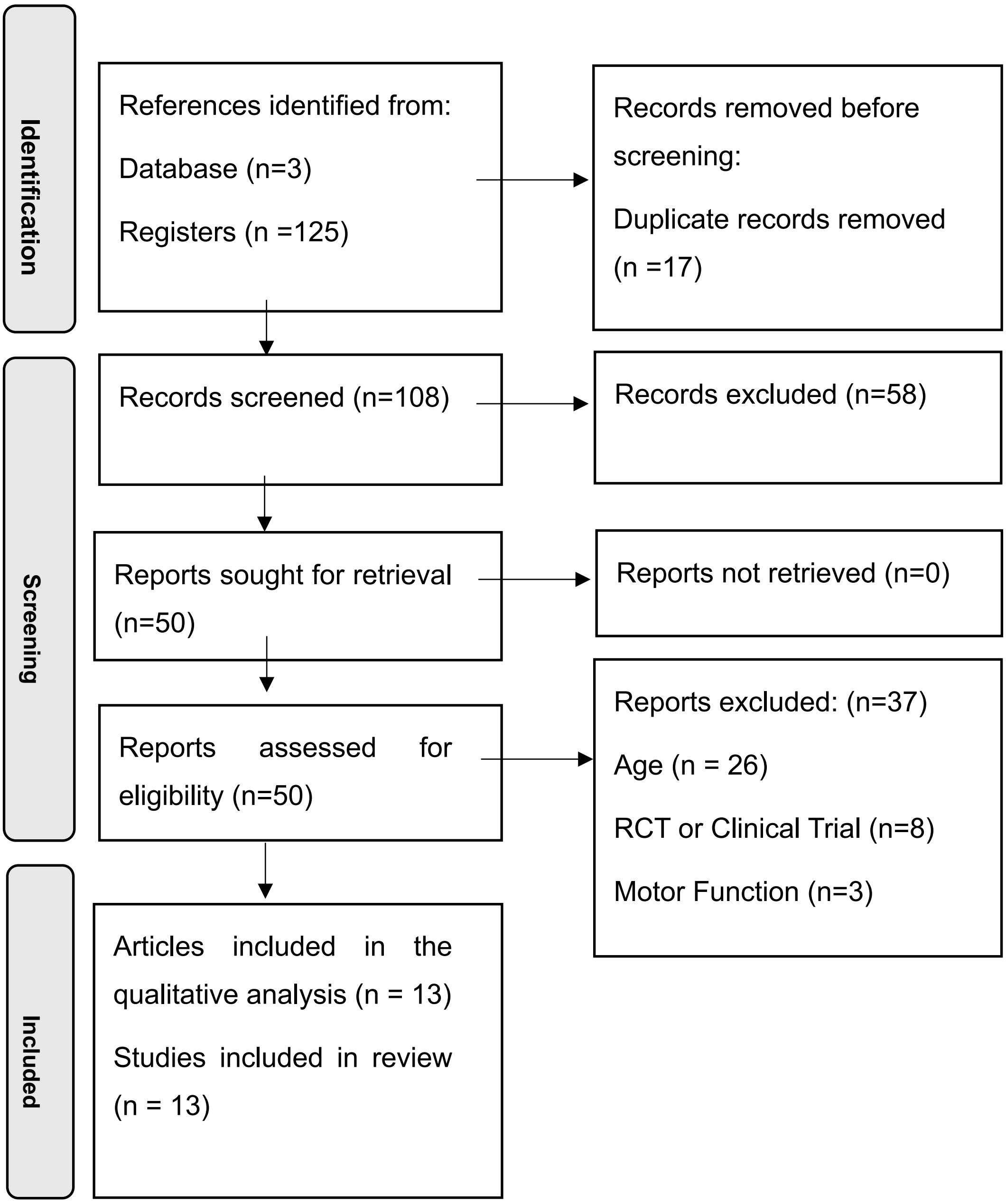


Figure 2 – Flowchart

2.1.4. Study Characteristics

The present systematic review included thirteen RCTs and clinical trials published between 2020 and 2025, which investigated the effects of physical exercise in older adults with Parkinson's disease (PD) or Alzheimer's disease (AD). Table 2 presents the main methodological characteristics of the included studies, namely, information of authors, study location, objectives, sample characteristics, participants' age and sex, disease stage and severity, intervention duration, and assessment instruments used.

Table 2. Characteristics of intervention studies.

Author (Year)	Title	Country	Aim	Sample (N)	Age (M±DP)	Sex	IMC	Disease Stage	Disease Duration	Assessment Instruments
(Droby et., 2020)	Distinct Effects of Motor Training on Resting-State Functional Networks of the Brain in Parkinson's Disease.	NR	To extend previous functional magnetic resonance imaging (fMRI) findings and investigate functional connectivity (FC) patterns in large-scale negative functional networks in Parkinson's disease patients trained for 6 weeks with treadmill training (TT) or TT combined with virtual reality (TT + VR) as part of the V-TIME study.	TT + VR:18	72.8 ± 6.7	F: 7; M:11	NR	2.47 ± 0.44	8.4 ± 6.03	UPDRS-III, LEDD, DT, miniBEST, MoCA, CTTa e CTTb
				TT:19	73.6 ± 6.5	F:8; M:11	NR	2.61 ± 0.44	9.6 ± 6.6	
(Cancela et al., 2020)	Effects of a High-Intensity Progressive-Cycle Program on Quality of Life and Motor Symptomatology in a Parkinson's Disease Population: A Pilot Randomized Controlled Trial.	United States of America	To determine whether high-intensity aerobic training using cycle ergometers and balance training can improve motor symptoms and quality of life in people with Parkinson's disease with a Hoehn and Yahr disability score of 1 to 3.	GC: 5	69.20 (4.44)	F: 14.28%	30.53 4.34	NR	NR	UPDRS, PDQ-39, 2-minute step test, 6-minute walk, 8-foot up-and-go,tinetti test
				GI: 7	67.71 (4.61)	F: 40.00%	28.27 4.45	NR	NR	

(Sangarapillai et al., 2021)	Boxing vs Sensory Exercise for Parkinson's Disease: A Double-Blinded Randomized Controlled Trial.	Canada	To compare the effects of high-intensity boxing and sensory exercises on the severity of Parkinson's disease, and to determine whether these effects persist or fade over time	RSB: 20	64.2 (9.8)	NR	NR	2.5	6.38 (4.9)	UPDRS-III, PDQ-39, CHAMPS, Stride Length, Stride velocity
				PD SAFEx: 20	65.1 (9.2)	NR	NR	2.5	7.82 (5.2)	
(Menengi Ç et al., 2022)	Effectiveness of motor-cognitive dual-task exercise via telerehabilitation in Alzheimer's disease: An online pilot randomized controlled study.	NR	To investigate the effectiveness of exercise delivered through home-based telerehabilitation (TR) in Alzheimer's disease (AD).	GC: 10	80.6 (6.11)	F:7; M:3	NR	NR	NR	5XSST, TUG, FIM, OLST, KATz-ADL, Functional Independence Measure
				TR:10	77.7 (5.29)	F:7; M:3	NR	NR	NR	
(Hashemi et al., 2022)	The effects of supervised and non-supervised upper limb virtual reality exercises on upper limb sensory-motor functions in patients with idiopathic Parkinson's disease.	Iran	To investigate the effects of supervised and unsupervised virtual reality upper-limb exercises (ULVRE) on sensorimotor functions in patients with idiopathic Parkinson's disease.	GC: 15	61.07 ± 7.01	F:3; M:12	NR	Hoehn & Yahr Scale (1): 3 Hoehn & Yahr Scale (2): 9 Hoehn & Yahr Scale (3): 3 Hoehn & Yahr Scale (4): 0	8.20±4.43	HAST, WPST, BBT, NHPT, UPDRS, Grip strength, Pinch strength
				ULVRE supervised: 15	54.80 ±10.51	F:6; M:9	NR	Hoehn & Yahr Scale (1): 6 Hoehn & Yahr Scale (2): 4 Hoehn & Yahr Scale (3): 4 Hoehn & Yahr Scale (4): 1	6.83±4.08	
				ULVRE unsupervised: 15	60.07 ± 7.29	F:7; M:8	NR	Hoehn & Yahr Scale (1): 3 Hoehn & Yahr Scale (2): 10 Hoehn & Yahr Scale (3): 2 Hoehn & Yahr Scale (4): 2	8.73±5.84	
(Yan et al., 2024)	The effect of multi-component exercise intervention in older people with Parkinson's disease and mild cognitive impairment: A randomized controlled study	China	This study aims to analyze the feasibility and effectiveness of a theory-based multicomponent physical exercise intervention in older adults with PD-	GC: 23	68.2 (5.8)	F:6; M:17	24.0 (3.4)	Hoehn & Yahr Scale (1): 1 (4.3) Hoehn & Yahr Scale (1,5): 7 (30.4) Hoehn & Yahr Scale (2): 7 (30.4) Hoehn & Yahr Scale (2,5): 6 (26.1) Hoehn & Yahr Scale (3): 2 (8.7)	5.1 (4.0)	MoCA, PD, PDQ-39, Tinetti POMA, TMT, UPDRS, Gait speed, the power of gripping-right, the power of gripping-left

			MCI.	GI: 23	70.5 (5.4)	F:8; M:16	23.1 (3.5)	Hoehn & Yahr Scale (1): 7 (30.4) Hoehn & Yahr Scale (1,5): 6 (26.1) Hoehn & Yahr Scale (2): 6 (26.1) Hoehn & Yahr Scale (2,5): 3 (13.0) Hoehn & Yahr Scale (3):1 (4.3)	5.1 (4.8)	
(Wong et al., 2024)	Effects of motor and cognitive complex training on obstacle walking and brain activity in people with Parkinson´s disease: a randomized controlled trial	Taiwan	To explore the effects of two novel obstacle-based gait training programs on gait performance and cortical activity in individuals with Parkinson's disease.	GC: 10	64.94 ± 4.98	F:4; M:6	NR	Hoehn & Yahr Scale (1-1.5):5 Hoehn & Yahr Scale (2-2.5):4 Hoehn & Yahr Scale (3):1	5.4 (2.8; 7.0)	MoCA, UPDRS-III, LEDD, TUG
				cognitive motor group: 11	67.63 ± 6.92	F:4; M:7	NR	Hoehn & Yahr Scale (1-1.5):7 Hoehn & Yahr Scale (2-2.5):3 Hoehn & Yahr Scale (3):1	3.0 (1.0; 7.5)	
				gait speed group: 11	65.86 ± 5.60	F:5; M:6	NR	Hoehn & Yahr Scale (1-1.5):5 Hoehn & Yahr Scale (2-2.5):5 Hoehn & Yahr Scale (3):1	5.0 (1.6; 9.0)	
(Kim et al., 2024)	Assessing Changes in Motor Function and Mobility in Individuals with Parkinson's Disease After 12 Sessions of Patient-Specific Adaptive Dynamic Cycling.	United States of America	To examine the effects of the PSADC paradigm (patient-specific adaptive dynamic cycling) on motor function and functional mobility in Parkinson's disease, compared with non-adaptive dynamic cycling (NA).	PSADC:13	72.08 ± 5.56	NR	25.54 ± 5.48	2.38 ± 1.12	1.96 ± 1.5	UPDRS- III, TUG, Kinesia One Motor Function Test Score Changes (speed, amplitude and rhythm of the movemnet during finger tapping, hand movement, and pronation–supination movements of hands)
				NA:10	72.20 ± 4.82	NR	27.69 ± 3.52 54.1	2.10 ± 0.56	4.39 ± 3.91	
(Ge et al., 2024)	Home physical therapy versus telerehabilitation in improving motor function and quality of life in Parkinson's disease: a randomized	China	To compare the effectiveness and adherence of home physical therapy (HPT) and telerehabilitation	TR: 90	69.12(6.11)	F:45; M:45	23.41(3.12)	Hoehn & Yahr Scale (1): 44 Hoehn & Yahr Scale (2):28 Hoehn & Yahr Scale (3): 18	NR	UPDRS-III, BBS, TUG, FTSST, FOGQ, IDEEA activity monitor, muscle strength assessed by isokinetic dynamometry, UPDRS-II, PDQ-39
				HPT: 100	70.95(5.74)	F:40; M:60	23.75(2.76)	Hoehn & Yahr Scale (1): 26 Hoehn & Yahr Scale (2): 39 Hoehn & Yahr Scale (3): 35	NR	

	controlled trial.		(TR) in mitigating motor symptoms and improving quality of life in patients with mild to moderate Parkinson's disease.						
(Moraes et al., 2024)	Sensorimotor functioning changes in response to global exercise versus handwriting upper limb exercise training in Parkinson's disease, results from a phase II randomised controlled trial.	United Kingdom	To estimate the extent to which two different physical training protocols (global training and manual handwriting exercise training for the upper limbs) impact reaction time, movement speed, and accuracy in Parkinson's disease.	Global Training: 35	65.5 ± 7.6	F:15; M:65	NR	NR	NR	UPDRS III, TUG, Two-minute walk test, Vo2, Leg power, Grip strengh
				Manual handwriting: 35	67.2 ± 6.9	F:19; M:16	NR	NR	NR	
(Wong et al., 2024)	Effects of DLPFC tDCS Followed by Treadmill Training on Dual-Task Gait and Cortical Excitability in Parkinson's Disease: A Randomized Controlled Trial.	Taiwan	To investigate the effects of tDCS followed by treadmill training (TT) on DTW performance and cortical excitability in people with Parkinson's disease.	DLPFC tDCS + TT: 17	68.1 (5.8)	F:12; M:5	NR	Hoehn & Yahr Scale (1): 4 Hoehn & Yahr Scale (1,5): 2 Hoehn & Yahr Scale (2):7 Hoehn & Yahr Scale (2,5): 2 Hoehn & Yahr Scale (3):2	5.5 (4.3)	UPDRS-III, MoCA, CDTW, DTC, MDTW
				Sham tDCS + TT: 17	66.8 (6.9)	F:8; M:9	NR	Hoehn & Yahr Scale (1): 6 Hoehn & Yahr Scale (1,5): 2 Hoehn & Yahr Scale (2):5 Hoehn & Yahr Scale (2,5): 3 Hoehn & Yahr Scale (3):1	7.9 (5.6)	
(Chen & Chen, 2025)	The impact of combined aerobic and resistance exercise on the prognosis of early Parkinson's disease	NR	To investigate the effects of a combined aerobic and resistance training program	AE:112	61.52 ± 5.03	F:32; M:80	18.95 ± 2.11	NR	NR	UPDRS, TUG, Center of Pressure Area, Berg Balance Scale, Trail Making Test A and Symbol Digit Modalities
				AE&RT:124	62.08 ± 4.52	F:35; M:89	19.02 ± 2.37	NR	NR	

	patients.		(AE&RT) on motor function, postural stability, and cognitive processing speed in patients with early-stage Parkinson's disease.							Test. Peak oxygen consumption: Measured during peak exercise using a standardized treadmill test.
(Orcioli-Silva et al., 2025)	Aerobic exercise acutely increases EEG gamma power in the motor/sensorimotor areas during walking in people with Parkinson's disease	NR	To investigate the immediate effects of a single session of moderate aerobic exercise on gait characteristics and cortical activity during single- and dual-task walking in people with Parkinson's disease.	GC: 15	71.33 ± 5.79	F:8; M:7	NR	NR	4.31 ±2.84	UPDRS-III, LEDD, Trail Making Test, single task-walking (step lenght, step time, step velocity, swing time, step legth variability, step time variability, step velocity variability swing time variability); dual-task walking (step lenght, step time, step velocity, swing time, step legth variability, step time variability, step velocity variability swing time variability)
				GI: 15	67.29 ± 5.03	F:3; M:11	NR	NR	4.87 ±3.15	

Note: *AE – Aerobic Exercise; AE&RT – Aerobic and Resistance Exercise; BBS – Berg Balance Scale; BBT – Box-Block Test; CTTa – Color Trails Test A; CTTb – Color Trails Test B; CDTW – Cognitive Dual-Task Walking; CHAMPS – Community Health Activities Model Program for Seniors; DLPFC – Dorsolateral Prefrontal Cortex; DT – Dual Task; DTC – Dual-Task Cost; ESB – Borg Subjective Scale ; HRMÁX –Maximum Heart Rate; FOGQ – Freezing of Gait Questionnaire; FTSST – Five Times Sit-to-Stand Test; GC – Control Group; GI – Intervention Group; HAST – Hand Active Sensation Test; Katz-ADL – Katz Activities of Daily Living Scale; LEDD – Levodopa Equivalent Daily Dose; MDTW – Motor Dual-Task Walking; miniBEST – mini-Balance Evaluation Systems Test; MoCA – Montreal Cognitive Assessment; NR: Not referenced; NHPT – Nine-Hole Peg Test; OLST – One-Leg Stance Test; PD – Parkinson Disease; PDQ-39 – 39-item Parkinson's Disease Questionnaire; PD SAFEx™ – Parkinson's Disease Sensory Attention Focused Exercise; POMA – Tinetti Performance Oriented Mobility Assessment; RSB – Rock Steady Boxing Inc.; RT – Resistance Training; TMT – Trail Making Test; TT – Treadmill Training; TT+VR – Treadmill with Virtual Reality; TUG – Timed Up-and-Go; ULVRE – Upper Limb Virtual Reality Exercises; UPDRS-II – Unified Parkinson's Disease Rating Scale Part II; UPDRS-III – Unified Parkinson's Disease Rating Scale Part III; WPST – Wrist Position Sense Test.*

One study by Droby et al., (2020) aimed to extend previous functional magnetic resonance imaging (fMRI) findings by investigating functional connectivity patterns in large-scale negative functional networks in patients with PD who underwent 6 weeks of treadmill training (TT) or treadmill training combined with virtual reality (TT+VR) as part of the V-TIME study. The TT+VR group showed overall improvements in gait speed, stride length, cadence performance during U-turn walking, balance, and cognitive test performance (CTTb). In contrast, the TT group demonstrated improvements in U-turn gait speed, stride time, cadence, dual-task gait speed, balance, and CTTb.

Cancela et al., (2020) in the United States of America, demonstrated that 8 weeks of high-intensity aerobic training using cycle ergometers combined with balance training improved motor symptoms and quality of life in individuals with PD classified as Hoehn and Yahr stages 1 to 3. Training sessions were conducted in person and supervised by a physiotherapist and an exercise professional. Significant improvements were observed in PDQ-39 ($p = 0.036$), MDS-UPDRS III ($p = 0.033$), and total scores ($p = 0.047$) in the experimental group compared with the control group. However, no differences were observed between groups in balance tests or the 6-Minute Walk Test.

In Canada, Sangarapillai et al., (2021) compared the effects of a 10-week program combining high-intensity boxing (RSB) and sensory exercises (PD SAFEx) in individuals with PD. The intervention consisted of in-person sessions supervised by qualified instructors. After the intervention, the PD SAFEx group showed improvements in disease severity, stride length, and gait speed ($p < 0.007$). The PD SAFEx™ group demonstrated greater improvements in motor symptoms compared with the RSB group at post-intervention ($p < 0.0001$) and during the washout period ($p < 0.006$), whereas symptoms worsened in the RSB group ($p < 0.033$).

Regarding AD, Menengi Ç et al., (2022) evaluated the effectiveness of a 6-week home-based telerehabilitation exercise program with dual-task motor–cognitive exercises delivered online by a physiotherapist. After the intervention, significant differences favouring the TR group were observed for all primary and secondary outcomes ($p < 0.05$), except for ZCBI, Katz-ADL, and OLST ($p > 0.05$).

In Iran, Hashemi et al., (2022) investigated the effects of supervised and unsupervised virtual reality exercises (ULVRE) on sensorimotor function in individuals with idiopathic PD. A 24-session program was implemented, in which the control group performed stretching, trunk rotation, postural control exercises, fine and gross motor movements, ball exercises, coordination tasks, and activities of daily living, while both ULVRE groups received occupational therapy. After the intervention, significant improvements were observed in discriminative sensory function (HAST-weight and

HAST-total), wrist proprioception, gross manual dexterity, grip strength of both the less and more affected hands, and fine manual dexterity of the more affected hand across all groups ($p < 0.05$).

Yan et al., (2024), in China, evaluated the feasibility and effectiveness of a 12-week multicomponent intervention in older adults with PD, combining resistance training, balance, and gait training, compared with a control group. The intervention group showed significantly greater improvements than the control group in global cognitive function (MoCA, $p = 0.005$), physical motor function (UPDRS III, $p = 0.044$), executive function (TMT-B, $p = 0.003$), balance and gait (Tinetti POMA total, $p = 0.037$; Tinetti POMA–balance, $p = 0.015$), quality of life (PDQ-39, $p < 0.001$), and depression (GDS-15, $p = 0.038$).

Wong et al., (2024) in Taiwan, investigated the effects of two 6-week training programs on obstacle gait and cortical activity in individuals with PD. The motor–cognitive group combined motor training (including resistance, balance, and gait) with cognitive–motor training, while the walking group performed gait training only. The intervention was delivered in person and supervised by a physiotherapist. Following the intervention, the motor–cognitive group showed significantly greater increases in speed ($p = 0.013$) and stride length ($p = 0.006$) of the lower limbs, as well as turning speed ($p = 0.010$), compared with the walking group.

In the United States of America, Kim et al., (2024) analysed the effects of adaptive dynamic cycling (PSADC) versus non-adaptive cycling (NA) over 6 weeks. Only the PSADC group demonstrated significant improvements in MDS-UPDRS Motor III scores ($p < 0.001$) and dopamine sensitivity symptoms ($p = 0.001$). Both groups showed non-significant improvements in the Timed Up and Go (TUG) test.

Ge et al., (2024), in Beijing, compared the effectiveness and adherence of home-based physiotherapy (HPT) and telerehabilitation (TR) in mitigating motor symptoms and improving quality of life in patients with PD. A 4-week exercise program was implemented, including balance training, resistance strength training, gait training (e.g., LSVT BIG), stretching, and aerobic exercise. The HPT group was supervised by a physiatrist and a physiotherapist. After the intervention, significant differences were observed in UPDRS III, BBS, TUG, FTSST, FOGQ, step length, gait speed, pre-swing angle, UPDRS II, and PDQ-39 scores. The reduction in UPDRS III scores was significantly greater in the HPT group (−3.38 points) than in the TR group (−1.45 points) among older participants ($p = 0.021$), with no significant difference in younger participants ($p = 0.416$). Similar changes favouring the HPT group were observed in BBS, TUG, gait speed, and mean extension torque.

In the United Kingdom, Moraes et al., (2024) examined the effects of two 24-week protocols (global exercise training versus upper-limb handwriting exercises) on reaction time, movement speed, and accuracy in PD. Both groups were supervised by exercise specialists and/or physiotherapists. No significant effects were found for most variables; however, in the global training group, reaction time on the right side was significantly higher than in the handwriting group ($p = 0.028$).

Another study by Yan et al., (2024), conducted in Taiwan, evaluated the effects of transcranial direct current stimulation (tDCS) followed by treadmill training (TT) on dual-task walking (DTW) performance and cortical excitability in individuals with PD. The 5-week intervention, supervised by a physiotherapist, resulted in significantly greater improvements in complex DTW speed ($p = 0.046$), cadence ($p = 0.043$), and stride time ($p = 0.041$) in the DLPFC tDCS+TT group compared with the sham tDCS+TT group. Additionally, the DLPFC tDCS+TT group demonstrated a significant increase in resting motor threshold in the stimulated hemisphere ($p = 0.026$). No significant differences were observed between groups for MDTW performance or other outcomes.

Chen & Chen, (2025) investigated the effects of a 1-year program combining aerobic exercise and resistance training (AE&RT) on motor function, postural stability, and cognitive processing speed in patients with PD. The AE group performed supervised aerobic exercises, including walking, cycling, and treadmill training, while the AE&RT group combined aerobic exercise with resistance training using weights, elastic bands, and body weight. At the end of the intervention, the AE&RT group showed significantly greater improvements in tremor ($p < 0.001$), muscle rigidity ($p < 0.001$), gait instability ($p < 0.001$), sleep problems ($p < 0.001$), and hyposmia ($p < 0.001$). The AE group showed a statistically significant advantage in reducing movement speed ($p = 0.004$), while improvements in emotional problems did not reach statistical significance between groups ($p = 0.045$). The AE&RT group also demonstrated superior postural stability, reflected by a smaller centre of pressure area ($p < 0.001$), and higher scores on the Berg Balance Scale ($p < 0.001$).

Finally, Orcioli-Silva et al., (2025) analysed the immediate effects of a single session of moderate aerobic exercise on gait characteristics and cortical activity during single- and dual-task walking in individuals with PD. Following the session, an increase in step length ($p = 0.045$) and a reduction in variability of both step speed ($p = 0.025$) and swing time ($p = 0.005$) were observed.

2.1.5. Quality of the Articles

The quality of the articles was assessed using the Downs & Black, (1998). All 13 articles were analyzed and scored according to 27 criteria. The total score obtained ranged from 11 to 24 points, reflecting different levels of methodological rigor. All articles were included in the final synthesis (Table 3). This approach contributed to ensuring greater reliability and internal validity in the analysis of the results, reinforcing the robustness of the conclusions obtained.

Table 3. Quality of the articles.

Authors (Year)	Item																											Total Score
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	
(Yan et al., 2024)	1	1	1	1	2	1	1	0	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	0	1	1	23
(Sangarapillai et al., 2021)	1	1	0	1	2	1	1	0	1	1	0	0	0	1	1	0	1	1	1	1	1	1	1	1	0	1	0	20
(Wong et al., 2024)	1	1	1	1	2	1	1	1	1	1	0	0	0	0	1	0	1	1	1	1	1	1	1	1	0	0	0	20
(Kim et al., 2024)	1	1	1	1	1	1	1	1	0	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0	20
Ge et al., 2024)	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	0	1	1	1	1	1	1	1	1	0	1	0	21
(Moraes et al., 2024)	1	1	1	1	2	1	1	1	1	1	0	0	0	1	1	0	1	1	1	1	1	1	1	1	1	1	0	23
(Menengiç et al., 2022)	1	1	1	1	1	1	1	1	1	1	0	0	0	1	0	0	1	1	1	1	1	1	1	0	1	1	1	21
(Chen & Chen, 2025)	1	1	1	0	2	1	1	0	0	1	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0	18
(Wong et al., 2024)	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	0	1	1	1	23
(Hashemi et al., 2022)	1	1	1	1	1	1	1	0	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	0	1	0	21
(Cancela et al., 2020)	1	1	1	1	2	1	1	1	1	1	0	0	0	1	0	0	1	1	1	1	1	1	1	1	1	1	0	22
(Droby et al., 2020)	1	1	1	0	2	1	1	1	1	1	0	0	0	0	0	0	1	1	1	1	1	1	1	0	1	1	0	19
(Orcioli-Silva et al., 2025)	1	1	1	1	2	1	1	0	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	24

2.1.6. Intervention Program Characteristics

The interventions analyzed ranged from 4 weeks to 1 year, with a predominant frequency of two to three sessions per week, combining in-person sessions and online practice. Session duration ranged between 40 and 60 minutes (Table 4).

Table 4. Characteristics of the intervention programs

Author (Year)	Grupe	Program Duration	Equipment	Type of Exercise	Frequency/Intensity/Session Duration	Supervised	Results	Conclusion
(Droby et., 2020)	TT + VR	6 weeks	NR	NR	3x/week (face-to-face) 45min session	NR	TT + VR: ↑ gait speed, ↑ step length, ↑ U-walk performance, ↑ balance, and ↑ CTTb. TT alone: ↑ U-walk and DT gait speed, ↑ step time and cadence, ↑ DT gait speed, ↑ balance, and ↑ CTTb.	The TT group, with and without the addition of a VR component, affects distinct neural pathways, highlighting the potential for beneficial neural plasticity in PD. These distinct, task-specific pathways may facilitate interventions tailored to the individual needs of patients with PD.
	TT		NR	NR	3x/week (face-to-face) 45min/session	NR		
(Cancela et al., 2020)	GC	8 weeks	NR	Tai Chi: 5–10 minutes warm-up + 45 minutes Classical Yang Style (24 forms + weight shifting + body alignment awareness + multi-segment movement coordination) + 5–10 minutes cool-down Balance: BOSU ball balance and ball exercises + ring coordination with single-leg stance and ball exercises + straight-line walking with head up + straight-line walking with hip flexion, knee flexion, and head up	1x/week balance + 2x/week Tai Chi (face-to-face) Balance: 2 sets of 2 min per exercise + 30 sec rest between exercises Balance: 10 min/session Tai Chi: 60 min/session	exercise specialist and/or physiotherapist	↑ PDQ-39 (p = 0.036), ↑ MDS-UPDRS III (p = 0.033), and ↑ total score (p = 0.047) in the experimental group vs. control. Balance and walking: no significant differences (balance test and 6-Minute Walk Test).	After considering the number of individuals in each group, the results suggest that the population with PD can tolerate high-intensity lower-limb cycle ergometer exercise. This exercise is a beneficial therapy for them, as it reduces the motor symptoms of the disease and, in addition, enhances and improves the patient's quality of life.
	GI		Cycle ergometer (Oxycycle III, active & passive MSD Europe) + PolarElectro (Inc., PortWashington, NY)	Tai Chi: 5–10 minutes warm-up + 45 minutes Classical Yang Style (24 forms + weight shifting + body alignment awareness + multi-segment movement coordination) + 5–10 minutes cool-down Balance: BOSU ball balance and ball exercises + ring coordination with single-leg stance and ball exercises + straight-line walking with head up +	1x/week balance + 2x/week Tai Chi + Progressive Cycle Program (face-to-face) Balance: 2 sets of 2 min per exercise + 30 sec rest between exercises Progressive Cycle			

				straight-line walking with hip flexion, knee flexion, and head up Progressive Cycling Program: 2 minutes warm-up (resistance 0) + (Week 1–2: 3×2 min; Week 3–4: 4×2 min; Week 5–6: 5×2 min; Week 7–8: 6×2 min) + 1 minute cool-down (resistance 0)	Program: Cycling with resistance (3-4) + 2min rest or 120bpm Balance: 10 min/session Tai Chi: 60 min/session Progressive Cycle Program: 25-35 min session			
(Sangarapillai et al., 2021)	RSB	10 weeks	NR	Warm-up + boxing-specific exercises (high-intensity exercises, shadow boxing, jumping jacks, and speed bag exercises) + cool-down	3x/weeks (face-to-face) 60 min/session ESB:NR	Certified trainer by Rock Steady Boxing	Motor symptoms: PD SAFEx™: ↑ improvement post-intervention ($p < 0.0001$) and at washout ($p < 0.006$); RSB: ↓ performance post-intervention ($p < 0.033$) and at washout ($p < 0.04$) vs baseline. Gait – step length: PD SAFEx™: ↑ from 1.46 → 1.73 m (+0.27 m) post-intervention and 1.76 m at washout;RSB: no change post-intervention and ↓ −0.09 m at washout. Gait – step velocity: PD SAFEx™: ↑ step velocity ($p < 0.007$).	Sensory exercise, compared with boxing, had an effect on disease severity, and the improvements were maintained even after the program ended. This was reflected in UPDRS-III scores as well as objective computerized gait data related to disease severity.
	PD SAFEx		NR	Warm-up + specific sensory exercises (stretching, walking, and chair-based exercises) + cool-down	3x/weeks (face-to-face) 60 min/session	Graduate student in kinesiology		
(Menengi Ç et al., 2022)	GC	NR	NR	No intervention	NR	NR	TR vs control: ↑ all primary and secondary outcomes ($p < 0.05$) except ZCBI, OLST, and Katz-ADL ($p > 0.05$); Post-treatment: primary outcomes showed no difference, secondary outcomes ↑ in TR except OLST, Katz-ADL, and ZCBI.	TR may provide significant improvements in cognition and mobility, enhance functional independence and caregiver well-being, and reduce anxiety and depressive symptoms in people with Parkinson's disease.
	TR	6 weeks	NR	Dual-task motor-cognitive exercises	4-5x/weeks (online) 15-40min/session	Physiotherapist		

(Hashemi et al., 2022)	GC	8 weeks	NR	Stretching + trunk rotation + postural control exercises + fine and gross motor movements + ball exercises + coordination movements and various tasks in the form of activities of daily living	3x/weeks (face-to-face) 75min/session	NR	↑ discriminative sensory function (HAST-weight and HAST-total), ↑ wrist proprioception, ↑ gross manual dexterity, and ↑ handgrip strength in both more- and less-affected hands ($p < 0.05$); ↑ fine manual dexterity in the more-affected hand in all three groups ($p < 0.05$).	The results of this study indicated that both supervised and unsupervised RMVE using the Kinect device can potentially improve certain aspects of upper limb sensorimotor functions in patients with PD. Therefore, RMVE with the Kinect device can be used in tele-rehabilitation, especially under the current limitations induced by the COVID-19 pandemic, to enhance upper limb functions in patients with PD.
	ULVRE supervised		Monitor + camera Kinect + computer	Occupational therapy (5 minutes warm-up + 50–60 minutes main exercise + 10 minutes cool-down)		therapist		
	ULVRE no supervised					NR		
(Yan et al., 2024)	GC	12 weeks	NR	Online workout session + self-training session	3x/weeks (face-to-face) 60 min/session	NR	Primary outcome: GI vs GC: ↑ global cognition (MoCA; $p = 0.005$) and ↑ motor function (UPDRS III; $p = 0.044$) post-intervention. Secondary outcomes: GI vs GC: ↑ executive function (TMT-B; $p = 0.003$); ↑ balance/gait (Tinetti POMA total: $p = 0.037$; balance: $p = 0.015$); ↑ quality of life (PDQ-39; $p < 0.001$); ↓ depression (GDS-15; $p = 0.038$).	This study indicates that a multicomponent exercise intervention may be effective in improving motor abilities and balance in individuals with Parkinson's disease, demonstrating potential for integration into rehabilitation programs for this population.
	GI		NR	Initial phase, weeks 1 to 4: * Resistance training: Full-body exercises (2 sets per exercise + 10 reps per set) * Balance training: Seated balance + standing balance (with eyes open and closed) + dynamic balance (10–15 seconds + 2 sets) * Gait training: Marching in place (1–2 sets, with 30–50 steps per set) + walking and turning, with 1–2 back-and-forths per set (2 sets) + obstacle crossing (5–10 steps to each side + 2 sets) Intermediate phase, weeks 5 to 8: Resistance, balance, and gait exercises Final phase, weeks 9 to 12: Practice all resistance, balance, and gait movements.		NR		
(Wong et al.,	GC	6 weeks		Maintain daily activities	NR	Researcher	Cognitive-motor group vs	Twelve sessions of

2024)	cognitive motor group		NR	5 minutes warm-up + 15 minutes motor training (resistance, balance, and gait training) + 15 minutes combined motor–cognitive training + 5 minutes cool-down	2x/weeks (face-to-face)	Physiotherapist	control: ↑ gait speed ($p = 0.013$), ↑ step length ($p = 0.006$), and ↑ cadence/velocity ($p = 0.010$). Complex walking vs control: No significant differences.	cognitive-motor training improved obstacle walking performance, with increased SMA activity in people with Parkinson's disease. However, complex walking training did not produce effects as beneficial as cognitive-motor training.
	gait speed		NR	5 minutes warm-up + 30 minutes gait training + 5 minutes cool-down				
(Kim et al., 2024)	PSADC	7 weeks	Heart rate monitor (Mi Band 6, Xiaomi, China) + cycle ergometer	5 minutes warm-up (60 RPM) + 30 minutes dynamic cycling + 5 minutes cool-down (60 RPM)	3x/weeks (face-to-face) EBS (6-20)	NR	PSADC vs NA: ↑ MDS-UPDRS III ($p < 0.001$) and ↑ dopamine sensitivity ($p = 0.001$); NA: no improvement. Both groups: ↑ TUG (not significant)..	PSADC demonstrated enhanced treatment effects on motor function in Parkinson's disease compared with NA, while also reducing variability in individual responses. The integration of IMU sensors was essential for precise monitoring, reinforcing the potential of a data-driven, individualized exercise approach to optimize treatment outcomes for people with Parkinson's disease.
	NA			5 minutes warm-up (60 RPM) + 30 minutes dynamic cycling (80 RPM) + 5 minutes cool-down (60 RPM)		NR		
(Ge et al., 2024)	TR	4 weeks	NR	Balance training + muscular strength and endurance exercises + gait training (e.g., LSVT BIG) + stretching exercises and aerobic exercise (e.g., walking and cycling)	5x/ weeks (online) 40-60 min/session EBS (6-20)	NR	Motor function, balance, and quality of life: - Both groups: significant differences from baseline to 4 weeks in UPDRS III, BBS, TUG, FTSST, FOGQ, step length/velocity, pre-swing angle, UPDRS II, and PDQ-39. Between-group comparison (by age): - Older age group: HPT vs RE: greater ↓ in UPDRS III for HPT (−3.38 vs −1.45; p =	Both HPT and TR demonstrated efficacy, safety, and feasibility in patients with Parkinson's disease. However, the HPT program showed greater efficacy in older patients and higher patient adherence compared with TR.
	HPT		NR	Balance training + muscular strength and endurance exercises + gait training (e.g., LSVT BIG) + stretching and aerobic exercises (e.g., walking and cycling)	5x/weeks (3 face-to-face + 2 self-training) 40-60 min/session EBS (6-20)	Physiatrist, physiotherapist		

							0.021); similar improvements favoring HPT in BBS, TUG, step velocity, and mean extension torque. - Younger age group: no significant differences between groups (p = 0.416)	
(Moraes et al., 2024)	Global Training	24 weeks	NR	30 minutes aerobic training + 30 minutes resistance training	60 min/session (face-to-face) 55-85%HRmáx	exercise specialist and/or physiotherapist	Mean TR and CoV of speed: no effect. CoV of TR (right side): ↑ in the exercise group vs. handwriting (p = 0.028).	We report the potential of comprehensive exercise interventions to facilitate improvements in reaction time and movement speed, as well as in other motor control metrics, with lasting effects up to 12 months, particularly on the non-dominant side.
	Manual Handwriting		NR	Warm up hand movements + writing exercises with the dominant hand (3 -10 times per session)	NR			
(Wong et al., 2024)	DLPFC tDCS + TT	5 weeks	NR	20 minutes DLPFC tDCS + 30 minutes TT	2-3x/weeks (face-to-face) 50min/session EBS (<13)	NR	DLPFC tDCS+TT: ↑ CDTW speed (p=0.046), cadence (p=0.043), stride time (p=0.041); ↑ resting motor threshold in the stimulated hemisphere. Other results: no significant differences (MDTW and other measures).	The present study demonstrated that tDCS over the DLPFC followed by TT had more beneficial effects on CDTWe performance and cortical excitability than TT alone in individuals with PD. The application of tDCS over the DLPFC prior to TT may be recommended for use during gait rehabilitation in people with PD.
	Sham tDCS + TT		NR	20 minutes sham tDCS + 30 minutes TT	2-3x/weeks (face-to-face) 50min/session EBS (<13)	Physiotherapist		
(Chen & Chen, 2025)	AE	1 year	NR	Supervised aerobic exercises (walking, cycling and treadmill)	4-5x/weeks (face-to-face) 15-40min/sessions	NR	AE & RT: ↑ tremor, rigidity, gait instability, sleep, hyposmia, postural stability, and performance on the Subjective Berg Scale (p < 0.001); AE alone: ↓ movement speed.	The results suggest that integrating AE&RT in patients with early-stage PD leads to more comprehensive improvements in motor symptoms, cognitive function, postural stability, and cardiovascular fitness compared with aerobic
	AE&RT		NR	supervised aerobic exercises + resistance training (weights, elastic bands and bodyweight exercises)	3x/weeks (face-to-face)	NR		

								exercise alone. These findings have important implications for developing personalized exercise interventions to enhance the physical and cognitive well-being of individuals with early-stage PD.
(Orcioli-Silva et al., 2025)	GC	1 session	Horizontal cycling ergometer (EB597e, Uniforce Fitness) + polar V800	Exercise on the ergometer	40 min/session (face-to-face) HR maintained within 5% of resting heart rate at minimum revolutions per minute.	NR	↑ step length (p = 0.045); ↓ step velocity variability (p = 0.025) and ↓ swing time variability (p = 0.005).	Acute exercise improves movement control and sensorimotor integration during walking, as evidenced by increased gamma power. Changes in gamma power in motor/sensorimotor areas may enhance step length during dual-task walking.
	GI			5 minutes warm-up (55-65% HRmáx) + 30 minutes main session (65-70%HRmáx) + 5 minutes cool-down (60%HRmáx)	40 min/session (face-to-face) 55-70%Hrma´x	NR		

Note: AE – Aerobic Exercise; AE&RT – Aerobic and Resistance Exercise; BBS – Berg Balance Scale; BBT – Box-Block Test; CDTW – Cognitive Dual-Task Walking; CHAMPS – Community Health Activities Model Program for Seniors; CTTa – Color Trails Test A; CTTb – Color Trails Test B; DLPFC – Dorsolateral Prefrontal Cortex; DT – Dual Task; DTC – Dual-Task Cost; F – Feminine; FOGQ – Freezing of Gait Questionnaire; FTSST – Five Times Sit-to-Stand Test; GC – Control Group; GI – Intervention Group; HAST – Hand Active Sensation Test; HPT – Home Physical Therapy; LEDD – Levodopa Equivalent Daily Dose; M – Masculine; MDTW – Motor Dual-Task Walking; miniBEST – mini-Balance Evaluation Systems Test; MoCA – Montreal Cognitive Assessment; MIN – Minute; NR – Not Referenced; NHPT – Nine-Hole Peg Test; NA – Non-Adaptive Dynamic Cycling; OLST – One-Leg Stance Test; PD – Parkinson Disease; PD SAFEx™ – Parkinson's Disease Sensory Attention Focused Exercise; PDQ-39 – 39-item Parkinson's Disease Questionnaire; PSADC – Patient-Specific Adaptive Dynamic Cycling; POMA – Tinetti Performance Oriented Mobility Assessment; RSB – Rock Steady Boxing Inc.; RPM – Revolutions Per Minute; RT – Resistance Training; SEC – Seconds; tDCS – Transcranial Direct Current Stimulation; TR – Telerehabilitation / Reaction Time; TMT – Trail Making Test; TT – Treadmill Training; TT+VR – Treadmill Training with Virtual Reality; TUG – Timed Up-and-Go; ULVRE – Virtual Reality Upper-Limb Exercises; UPDRS-II – Unified Parkinson's Disease Rating Scale Part II; UPDRS-III – Unified Parkinson's Disease Rating Scale Part III; WPST – Wrist Position Sense Test.

2.1.7. Discussion

This systematic review aimed to synthesize the effects of physical exercise on motor function in older adults with Parkinson's, Alzheimer's or Multiple Sclerosis diseases. Overall, the analysed studies converge on evidence that regular, structured physical exercise, supervised by qualified professionals and adapted to participants' limitations, leads to significant improvements in both motor function and quality of life in these populations.

In terms of geographic context, the most representative countries among the included studies were China, Taiwan, and the United States. Sample sizes varied widely, ranging from small groups of 5 to 35 participants to larger studies with 112 to 124 individuals. The mean age of participants was generally between 60 and 75 years, although one study included individuals over 80 years old. Sex distribution tended to be balanced. Some studies focused on patients in mild to moderate disease stages, as classified by Hoehn & Yahr (stages 1 to 3). Regarding objectives and intervention types, there was a clear tendency to combine physical and cognitive exercises. Standardized assessments, such as the Unified Parkinson's Disease Rating Scale – Part III (UPDRS-III) and the Timed Up and Go (TUG) test, were widely applied to measure intervention effects.

Cross-sectional analysis of the studies targeting Parkinson's disease revealed a diversity of approaches. Multicomponent interventions were predominant, integrating aerobic exercise, strength training, and balance. Technology-mediated interventions also emerged, including virtual reality programs, transcranial stimulation, as well as specific modalities such as boxing and cycling. Generally, there was a trend to integrate physical and cognitive components to enhance outcomes. Regarding the structure of the interventions, the most prevalent frequency was observed to be 3 session per week, with an average duration of 45 to 75 minutes per session. Additionally, positive results were also observed in programs with a frequency of 4 to 5 sessions per week. However, in programs conducted only twice a week, the results proved to be less significant. Total program duration also varied widely, ranging from 4 weeks to 1 year, with longer protocols tending to produce more consistent and lasting benefits. Exercise intensity was monitored using the Borg Rating of Perceived Exertion or estimated maximum heart rate (HRmax), strategies that allow individualized and safe load adjustments. Overall, results consistently indicated that physical exercise improves mobility, balance, and quality of life.

For Alzheimer's disease, only one study met the inclusion criteria, using dual-task motor-cognitive exercises designed to simultaneously stimulate motor and cognitive functions to enhance neural plasticity. The intervention consisted of 25 sessions, starting with 15-minute sessions five times per week and progressing to 40-minute sessions four times per week. Exercise intensity was not clearly specified. Assessment instruments included motor function measures such as the 5XSST, TUG, FIM, and OLST. Results demonstrated significant improvements in cognition, mobility, and functional independence, as well as reductions in anxiety, indicating that telerehabilitation interventions are a feasible and effective strategy for individuals with Alzheimer's disease.

No eligible studies involving individuals with multiple sclerosis were identified, highlighting an important gap in the literature and reinforcing the need for future research in this population.

Comparative analysis across the three clinical conditions suggests that physical exercise, regardless of type, has a positive impact on motor function in populations with neurodegenerative diseases, with the most pronounced effects observed in individuals with Parkinson's disease. Based on the results of this review, it is recommended that older adults engage in physical exercise 4 to 5 times per week, with sessions lasting 45–60 minutes. For aerobic and resistance components, a frequency of 4 sessions per week is suggested, while flexibility and neuromotor training is recommended 2–3 times per week. For aerobic training, moderate intensity of approximately 50 to 60% of maximum heart rate, for at least 30 minutes per session, performed continuously or cumulatively, is recommended. For resistance training, intensity should range from 30 to 70% of 1RM (one-repetition maximum), performing 1 to 3 sets of 8 to 12 repetitions per exercise with 1 to 2 minutes of rest between sets. Neuromotor exercises should be performed in 2 to 3 sets of more than 12 repetitions with similar rest intervals.

These recommendations align with the guidelines proposed by the American College of Sports Medicine (ACSM), particularly regarding the number of repetitions and sets. However, unlike ACSM guidelines, which suggest neuromotor training primarily for older adults with Parkinson's disease, the findings of this review support the inclusion of neuromotor training for older adults with Alzheimer's disease as well, given the evidence of benefits on cognition, mobility, and functional independence.

2.1.8. Limitations

This systematic review presents several limitations that should be considered when interpreting the results. First, there is considerable methodological heterogeneity among the included studies, particularly regarding the duration, frequency, type, and intensity of interventions, as well as the assessment instruments used. Additionally, there was a lack of standardization in the description of interventions, with insufficient information on key parameters. This lack of methodological detail compromises scientific reproducibility and hinders the practical implementation of the proposed programs. Second, the small sample sizes in most of the analysed studies represent a limiting factor. The predominance of small samples may increase the risk of selection bias, affecting the robustness and external validity of the results.

Finally, the absence of eligible studies on multiple sclerosis is a notable limitation. This gap restricts the understanding of the effects of physical exercise in this population and prevents comparative analysis across the three neurodegenerative conditions originally considered.

2.1.9. Implications for Professional Practice

The results of this systematic review reinforce the evidence that physical exercise, when properly structured, supervised, and adapted to individual needs, is an effective and safe strategy for promoting motor function in older adults with neurodegenerative diseases. Consequently, it is essential that exercise professionals and physiotherapists consider the systematic integration of physical exercise programs for these populations.

Additionally, it is recommended that healthcare institutions and residential care facilities for older adults sustainably implement these programs as an integral part of their core practices. The goal is to support the maintenance of autonomy, prevent physical and cognitive decline, and promote improvements in quality of life for individuals living with neurodegenerative conditions.

2.1.10. Implications for Future Research

This systematic review highlighted important gaps in the literature that should be addressed in the design of future studies. Accordingly, it is recommended that subsequent research:

- Include larger and more representative samples, allowing for subgroup analyses based on variables such as age, sex, and type and severity of disease;

- Adopt standardized physical exercise protocols with clear and detailed descriptions of the intervention components, to facilitate replicability and comparison across studies;
- Incorporate follow-up assessments to analyse the sustainability of intervention effects over the medium and long term;
- Conduct targeted research on multiple sclerosis, as no eligible studies on this condition were identified in the present review. The scarcity of scientific evidence limits understanding of the effects of physical exercise in this population.

2.1.11. Conclusion

This systematic review compiled and analysed up-to-date scientific evidence on the effects of physical exercise on motor function in older adults with neurodegenerative diseases. The results consistently demonstrate that exercise-based interventions, when properly structured, supervised, and adapted to participants' abilities, promote significant improvements.

At the motor level, consistent improvements were observed in gait speed and step length, balance, functional mobility, postural stability, and cardiovascular fitness. In addition, some exercise programs contributed to reducing the severity of motor symptoms, such as tremor, rigidity, and gait instability, which was reflected in a greater ability to perform activities of daily living. In the cognitive domain, improvements were observed in executive function, cognitive processing speed, and performance in tasks requiring dual-tasking (motor–cognitive). These findings suggest that physical exercise may stimulate mechanisms of neuroplasticity and improve the efficiency of motor and cognitive circuits.

Although there is heterogeneity in the protocols and methodologies adopted in the included studies, the conclusions converge in recognizing physical exercise as an effective and complementary non-pharmacological therapeutic strategy, with the potential to mitigate the functional decline characteristics of disease progression.

Nevertheless, observed methodological limitations, small sample sizes, and insufficient protocol descriptions highlight the need for future research with greater scientific rigor, robust study designs, representative samples, and long-term follow-up assessments to consolidate the existing evidence.

In summary, this systematic review underscores the importance of physical exercise as an essential intervention tool for older adults with neurodegenerative diseases.

2.2. Study 2 – Development and Validation of a Physical Exercise Program for Elderly People with Alzheimer's Disease or Parkinson's Disease: Development and Validation of the Physical Exercise Program as a Comprehensive Intervention

Abstract

Background: Physical exercise promotes several physical and psychological benefits. Considering that neurodegenerative diseases interfere with daily activities and individuals' quality of life, it becomes relevant to analyse how a physical exercise program specialized for these diseases can contribute to their health.

Objective: This methodological study aims to design and validate a physical exercise program for older adults with Alzheimer's Disease (AD) or Parkinson's Disease (PD).

Methods: The design and validation of the program were conducted according to the guidelines of the CREDCI2 model and the CERT instrument, and it was developed for older adults with AD or PD. Data collection was carried out after obtaining informed consent from the participants, respecting ethical principles and ensuring the confidentiality of information. Finally, the study was approved by the Ethics Committee of the Polytechnic Institute of Santarém.

Results: The results showed an overall positive acceptance of the program, with high levels of agreement regarding its adequacy, variety, and functional potential, as well as the feasibility of its implementation in a real-world context. Validation by experts also allowed the identification of suggestions for improvement, which were incorporated into the final version of the program.

Discussion and conclusions: Structured and multicomponent physical exercise represents an important strategy for intervention among people with neurodegenerative diseases, showing potential to contribute to functionality and quality of life.

Key-words: Alzheimer, Intervention Parkinson, Physical Exercise, Program

2.2.1. Introduction

Population aging has been associated with a significant increase in diseases, particularly neurodegenerative conditions such as Alzheimer’s Disease (AD) and Parkinson’s Disease (PD). These pathologies are characterized by progressive changes in cognitive and motor function, compromising autonomy, functionality, and quality of life.

Scientific literature has increasingly demonstrated the positive impact of regular physical exercise, highlighting it as a promising non-pharmacological intervention, with consistent evidence of benefits in cognition, mood, and motor function (Suryadi et al., 2024). Regarding AD, studies indicate that engaging in physical exercise is associated with improvements in cognition and mobility, as well as reductions in anxiety levels (Menengi Ç et al., 2022). In the context of PD, randomized controlled trials (RCTs) show that physical exercise programs including aerobic training, strength training, and balance exercises are associated with significant gains in motor function, balance, and gait (Yan et al., 2024), as well as reductions in tremors and muscle rigidity (Chen & Chen, 2025).

Despite these results, there is still a significant gap in the development of properly structured, described, and validated physical exercise programs for these populations. Additionally, many existing programs lack detailed methodological descriptions and scientific validation, which constitutes a barrier to the implementation of evidence-based interventions and their replication by other professionals.

Therefore, there is a need to develop physical exercise programs targeted at older adults with Alzheimer’s Disease or Parkinson’s Disease, grounded in scientific evidence and adapted to individual needs, that can be replicable and applicable by other professionals.

In this context, the aim of the present study was to develop and validate a physical exercise program aimed at older adults with AD or PD, with the purpose of attenuating the main motor and non-motor symptoms, improving functional parameters, and promoting a sustainable lifestyle.

2.2.2. Methods

2.2.2.1. Study Design

The present study was classified as a qualitative methodological study focused on the design and validation of a physical exercise program.

2.2.2.2. Participants

The physical exercise program was designed for individuals diagnosed with Alzheimer’s Disease or Parkinson’s Disease. The program was structured by a physical exercise specialist with a bachelor's degree in Sport, Physical Fitness, and Health, under the supervision of a PhD professor in Human Motricity with specialization in Biomechanics.

2.2.2.3. Instruments

Two guidelines were used for the development and validation of the exercise program. The first was the CREDECI2 model (Criteria for Reporting the Development and Evaluation of Complex Interventions in Health Care), developed and validated by (Möhler et al., 2015). This model consists of 13 items organized into three stages: development, piloting, and evaluation.

Additionally, to verify the physical exercise program, the CERT instrument (Consensus on Exercise Reporting Template), validated by (Slade et al., 2016), was used. This instrument consists of a 16-item checklist considered essential for the description of physical exercise programs, ensuring their reproducibility in future contexts.

2.2.2.4. Ethical Considerations

All procedures were conducted in accordance with the Declaration of Helsinki (1964). The study protocol was submitted to the Ethics Committee of the Polytechnic Institute of Santarém and received prior approval. Data collection began only after obtaining written informed consent from all participants (appendix III). Voluntary participation and agreement regarding the use and dissemination of data for scientific purposes were ensured. At all stages of the study, anonymity and confidentiality of information were guaranteed in accordance with ethical principles.

2.2.3. Results

The exercise program consisted of a set of exercises selected according to the clinical conditions of the participants. All lesson plans were systematically described in a digital manual, ensuring standardization and reproducibility. The development of the program followed the three phases proposed by (Möhler et al., 2015), encompassing the development, piloting, and evaluation stages.

First Stage: Program Development

Item 1: Description of the Underlying Theoretical Basis of the Intervention

The theoretical basis underlying this intervention is grounded in scientific evidence demonstrating the benefits of regular physical exercise in older populations with neurodegenerative diseases. Several studies highlight the ability of exercise to promote neuroplasticity, improve motor function, reduce muscle rigidity, and enhance functional capacity in individuals with Parkinson's Disease. In individuals with Alzheimer's Disease, exercise has been associated with the maintenance of cognitive function and improvements in mood.

The intervention developed in this study is based on the recommendations of the American College of Sports Medicine (ACSM). Therefore, the design of the program is grounded in evidence-based exercise prescription principles, ensuring that the intervention is robust, safe, and effective.

Item 2: Description of all components of the intervention, including the reasons for their selection, as well as their essential objectives/functions

• CERT Item 1: Detailed description of the type of equipment used for the exercises

To implement the exercise program, the following materials were required:

i. A speaker, used for musical support and auditory stimulation;
ii. Balls of different sizes, suitable for various types of exercises and levels of difficulty;
iii. A towel, used as support in mobility and resistance exercises, as well as personal protective equipment;
iv. Elastic resistance bands, intended for strength and flexibility training;
v. Ankle weights, used to intensify the muscular work of the lower limbs.

Participants were required to wear appropriate sports clothing and footwear that were comfortable and safe in order to ensure efficient and secure practice of the proposed activities.

The indoor space used for the sessions had a non-slip floor and appropriate ventilation and acoustic conditions, ensuring a safe and functional environment.

Additionally, for the implementation of the functional assessment protocol based on the test battery proposed by (Rickli & Jones, 2013a), the following materials were required: a stopwatch, a 45-centimeter measuring tape, tape or a cord, a chair with a backrest approximately 43 cm in height, dumbbells weighing 2.77 kilograms and 3.63 kilograms, and two MEMS-type inertial sensors (TDK, TDK InvenSense, ICM-20948 9-dof, Tokyo, Japan).

To provide a more detailed explanation of the program, a description of the 16 CERT items is presented below:

• CERT Item 2: Detailed description of the qualifications, teaching/supervision knowledge, and/or training of the exercise professional

The program was implemented by a physical exercise professional with a bachelor's degree in Sport, Physical Fitness, and Health from the Rio Maior School of Sport, currently undertaking advanced studies in Physical Activity and Health. It was also supervised by a physical exercise specialist holding a PhD in Human Motricity, with specialization in Biomechanics (2016) from the University of Lisbon, a master's degree in Sport with specialization in Physical Fitness and Health (2010), and a Bachelor's and Licentiate degree in Sport, Physical Fitness specialization (2001/2002). He currently serves as an Adjunct Professor at the Polytechnic Institute of Santarém, Coordinator of the master's degree in physical Activity and Health, Member of the School Assembly, Member of the Technical-Scientific Council, and Member of the Pedagogical Council of the Rio Maior School of Sport.

He is also an associate member of the Interdisciplinary Centre for the Study of Human Performance at the Faculty of Human Kinetics. He has published 43 articles in specialized journals, authored 16 book chapters and 4 books, and participated in 35 scientific events. He has co-supervised 2 doctoral theses and supervised 15 master's dissertations. He has received 7 awards and/or honours. His work focuses on the fields of Medical and Health Sciences, particularly Health Sciences and Sport Sciences.

• CERT Item 3: Description of the exercises (individually or in groups)

The physical exercise program (appendix IV) was designed to be implemented in a group setting, through face-to-face sessions lasting between 45 and 60 minutes, with a weekly frequency of four sessions. The training sessions consisted of: a) Warm-up, lasting 5 to 10 minutes; b) Main phase, consisting of aerobic exercises (20 minutes) and resistance exercises (20 minutes); c) Cool-down and stretching, lasting 5 minutes.

• CERT Item 4: Description of the exercises (supervised or unsupervised) and how they are delivered

The exercise program was supervised by the professional with the highest academic qualification, in this case the scientific coordinator responsible for the intervention.

The presentation and demonstration of the exercises were conducted by the professional responsible for the intervention, with special attention given to the correct execution by participants. This was monitored through direct observation and continuous feedback. This approach aims to optimize the effectiveness of the intervention, promote an appropriate perception of effort, reduce the risk of injury, and reinforce the participants' perception of technical competence.

• CERT Item 5: Detailed description of how exercise adherence is measured and reported

Adherence to the program was monitored through systematic attendance records of the participants, using an attendance sheet completed throughout the 40 intervention sessions.

• CERT Item 6: Detailed description of motivational strategies

In order to enhance interaction between participants and the professional involved in the intervention, continuous motivational feedback was provided during the training sessions. Additionally, suggestions for improvement were collected from both the participants and the scientific coordinator of the intervention, promoting a collaborative environment that was responsive to participants' needs.

• CERT Item 7: a) Detailed description of the decision rules used to determine exercise progression

The progression of exercise intensity throughout the program was monitored using the following variable: the subjective rating of perceived exertion, based on the

Borg Rating of Perceived Exertion Scale. The instructor progressed to the subsequent phase only when the objectives of the previous phase had been achieved.

• CERT Item 7 b): Detailed description of how the exercise program progresses

The program was designed based on the guidelines established by the American College of Sports Medicine (ACSM), which recommends structured exercise prescription as an effective strategy for promoting functional health, aerobic capacity, muscular strength, and flexibility. For individuals with these conditions, the ACSM recommends moderate to high-intensity physical activity, provided that it is supervised, safe, and adapted to the clinical conditions of the participants. In this context, the present program was structured to respond to the specific needs of these populations, taking into account the symptomatic complexity of the disease.

• CERT Item 8: Detailed description of each exercise to allow replication

A detailed description of each exercise was provided in a technical exercise manual, which included examples of sessions organized by mesocycle. For each session, detailed descriptions of the exercises were presented, accompanied by illustrative images demonstrating the correct execution, with the aim of facilitating replication and ensuring the standardization of the intervention.

• CERT Item 9: Detailed description of any program component performed at home

This program did not include unsupervised home-based exercise.

• CERT Item 10: Description of the existence of any non-exercise components

The present study did not include any additional components beyond the implementation of the physical exercise program.

• CERT Item 11: Description of the type and number of adverse events occurring during exercise

This item does not apply to the present study, as no adverse events associated with the implementation of the physical exercise program occurred during its duration.

• CERT Item 12: Description of the location where the exercises are performed

The sessions of the physical exercise program were carried out in an indoor space that was properly prepared and provided by the *Associação Cultural e de Apoio Social de Olhão* (ACASO). The location provided suitable conditions for safe physical activity, including a non-slip floor, good ventilation, adequate lighting, and controlled acoustics, promoting a comfortable and functional environment.

• CERT Item 13: Detailed description of the exercise intervention

The physical exercise program was delivered in groups through face-to-face sessions lasting 45 to 60 minutes, conducted four times per week. Each session was organized into six structured phases:

i. Session Opening (2–3 minutes)

This phase aimed to create a relaxed, motivating, and welcoming environment. It encouraged integration and active participation of the older adults, reinforced guidance on intensity control, safety, and hydration, and included attendance registration and assessment of participants' general condition.

ii. Warm-up (5–10 minutes)

Objective: Prepare the body for exercise, promoting a gradual transition from rest to activity. This phase included:

- Body awareness exercises, promoting posture and segmental alignment;
- Breathing exercises to stimulate respiratory control;
- Joint mobilization through wide and gentle movements of major joints;
- Gradual increase of body temperature and joint range of motion, preparing muscles and tendons for subsequent exertion.

iii. Aerobic Exercises (20 minutes)

Objective: Improve cardiorespiratory capacity through rhythmic, continuous, moderate-intensity activities.

iv. Resistance Training and Neuromotor Exercises

- Resistance Training (10 minutes): Focused on strength exercises targeting the major muscle groups.

- Neuromotor Exercises (10 minutes): Included coordination, balance, agility, and dual-task exercises, combining physical movements with cognitive stimuli to enhance neuromuscular integration.

v. Cool-down (5 minutes)

Objective: Promote recovery and relaxation after exertion. This phase included:

- Stretching of the main muscle groups worked during the session;
- Breathing and relaxation exercises;
- A reflective moment emphasizing the importance of physical exercise for maintaining quality of life and functional autonomy.

vi. Session Closing

This final phase was intended to reinforce the social and motivational bonds among participants and to organize and store the equipment used during the session.

- CERT Item 14 (a): Describe whether the exercises are generic (applicable to anyone) or individualized

The exercises were designed according to the characteristics of the participants, with special attention to age and stage of disease progression. Thus, the program is applicable and can be reapplied to individuals with similar characteristics.

- CERT Item 14 (b): Detailed description of how exercises are adapted to individuals

The exercise program manual includes a detailed and illustrated description of each exercise, as well as clear guidance on progression and variations, both in terms of intensity and complexity. This structure provides practical support for exercise professionals in planning and delivering sessions.

Personalization of the intervention is ensured through systematic adaptation of exercise intensity, volume, and type based on the results of the initial assessment and continuous monitoring of participant progress.

- CERT Item 15: Describe the decision rule for determining the initial level at which individuals start a physical exercise program

The program was specifically adapted for older adults aged 50 years and above with Alzheimer’s Disease or Parkinson’s Disease. Based on this premise, participants’ initial level was defined as beginner.

Additionally, the Functional Tests Battery was applied to assess motor function. This evaluation identified baseline physical abilities, potential limitations associated with the pathology, and the individual's prior physical activity history. The resulting classification enabled stratification of participants by functionality level (low, moderate, or high), guiding the selection of exercises and the corresponding degree of difficulty, intensity, and volume.

• CERT Item 16 (a): Describe how adherence or fidelity to the exercise intervention is assessed/measured

Adherence to the program was monitored through the attendance sheet, which included an additional field to record the reason for absence. This allowed identification of whether absences were related to the participant's health condition or other causes.

• CERT Item 16 (b): Describe the extent to which the intervention was delivered as planned

Fidelity of implementation was assessed by cross-referencing the intervention manual with the weekly records of sessions conducted. The responsible professional documented the content delivered, any adaptations made, and the actual time spent on each exercise, allowing verification of the degree to which the intervention was carried out according to plan.

Item 3: Illustration of any intended interaction between different components

In this study, no additional components beyond the physical exercise program were planned. The intervention exclusively focused on adapted physical training tailored to the needs of the target population, without including education, nutrition, or other multidisciplinary sessions.

Item 4: Description and consideration of the characteristics of the intervention context

The program was developed as part of a master's dissertation in Physical Activity and Health, with the ACASO selected as the context for implementation. ACASO is a reference institution in the Algarve region, offering social services and support tailored to older adults, including psychosocial assistance. This institutional framework proved suitable for implementing the intervention, providing specialized human resources, facilities prepared for group activities, and a resident population with characteristics aligned with the study's objectives.

The program was implemented in an indoor room at the institution, equipped with a non-slip floor, adequate ventilation, and sufficient space for dynamic exercises, ensuring safety and functionality. The structured and routine institutional environment facilitated participant adherence, contributing to the consistency of the intervention process. Planning, execution, and supervision of the sessions were managed by the exercise professional, who followed the methodological principles defined in the manual. The professional ensured uniform application of the content, monitored participant intensity and responses to effort, implemented necessary adaptations, and ensured compliance with safety recommendations.

Second Stage: Feasibility and Piloting

Item 5: Description of the pilot test and its impact on the final intervention

The main objective of the pilot test was to assess the feasibility, practicality, and clarity of the developed exercise program, in order to ensure that it was appropriate for the target population and feasible in a real-world setting. The first version of the program was developed by two exercise specialists: one with a degree in Physical Fitness and Health, and the other holding a PhD in Human Motricity with specialization in Biomechanics.

For preliminary evaluation, a detailed program manual was developed, accompanied by a structured questionnaire, which was subsequently distributed to a panel of experts in the field of physical activity and health. The questionnaire included 21 items assessed using a 5-point Likert scale, where 1 corresponded to "Strongly disagree" and 5 to "Strongly agree." The analysis of expert feedback made it possible to identify aspects that required clarification or reformulation, leading to improvements in the content and structure of the intervention (Table 5) below presents the questions included in the questionnaire, as well as the feedback (response frequency) provided by the professionals.

Table 5. Responses to the questionnaire.

Number	Question	Scale	Responses (N)	Total (%)	Suggestions
1	Do you consider the "walking" exercise appropriate?	(1) Strongly disagree	1	11,1	This type of special population presents specific characteristics regarding motor and cognitive manifestations/symptoms, which benefit from a more targeted intervention addressing these particularities. It is important to make the exercise more realistic from a daily-life perspective and to combine it with other stimuli, including the use of cueing.
		(2) Disagree	0	0	
		(3) Neither agree nor disagree	2	22,2	
		(4) Agree	1	11,1	
		(5) Strongly agree	5	55,5	
2	Do you consider the “Step Up and Down” exercise appropriate?	(1) Strongly disagree	0	0	Low height; it may be functional.
		(2) Disagree	1	11,1	
		(3) Neither agree nor disagree	1	11,1	
		(4) Agree	3	33,3	
		(5) Strongly agree	4	44,4	
3	Do you consider the “Sit-to-Stand” exercise appropriate?	(1) Strongly disagree	0	0	
		(2) Disagree	0	0	
		(3) Neither agree nor disagree	1	11,1	
		(4) Agree	4	44,4	
		(5) Strongly agree	4	44,4	
4	Do you consider the “Sit-to-Stand” exercise appropriate?	(1) Strongly disagree	0	0	
		(2) Disagree	1	11,1	
		(3) Neither agree nor disagree	1	11,1	

		(4) Agree	3	33,3	
		(5) Strongly agree	4	44,4	
5	Do you consider the "knee extension" exercise appropriate?	(1) Strongly disagree	1	11,1	
		(2) Disagree	0	0	
		(3) Neither agree nor disagree	2	22,2	
		(4) Agree	3	33,3	
		(5) Strongly agree	3	33,3	
6	Do you consider the "knee flexion" exercise appropriate?	(1) Strongly disagree	1	11,1	The analytical model has not been shown, on its own, to be the most effective in this population. In contrast, the functional model for resistance training has demonstrated better results. Furthermore, leaning on the back of the chair, for this population, may compromise client safety.
		(2) Disagree	0	0	
		(3) Neither agree nor disagree	1	11,1	
		(4) Agree	4	44,4	
		(5) Strongly agree	3	33,3	
7	Do you consider the "hip abduction and adduction" exercise appropriate?	(1) Strongly disagree	0	0	
		(2) Disagree	0	0	
		(3) Neither agree nor disagree	2	22,2	
		(4) Agree	3	33,3	
		(5) Strongly agree	4	44,4	
8	Do you consider the "seated row" exercise appropriate?	(1) Strongly disagree	0	0	There are marked postural changes, particularly more flexed, and this type of exercise can—especially if performed with compensations—emphasize this type of posture.
		(2) Disagree	2	22,2	
		(3) Neither agree nor disagree	1	11,1	It may be necessary to consider adaptations for participants who have difficulty maintaining a neutral posture with trunk flexion, or even a lack of stability.
		(4) Agree	3	33,3	
		(5) Strongly agree	3	33,3	
9	Do you consider the "triceps	(1) Strongly disagree	1	11,1	Too technically challenging, with a high

	kickback" exercise appropriate?	(2) Disagree	1	11,1	likelihood of poor execution.
		(3) Neither agree nor disagree	4	44,4	
		(4) Agree	3	33,3	
		(5) Strongly agree	0	0	
10	Do you consider the "shoulder press" exercise appropriate?	(1) Strongly disagree	0	0	Caution should be exercised when using weights in cases of muscle stiffness in individuals withPD
		(2) Disagree	1	11,1	
		(3) Neither agree nor disagree	2	22,2	
		(4) Agree	4	44,4	
		(5) Strongly agree	2	22,2	
11	Do you consider the "biceps curl" exercise appropriate?	(1) Strongly disagree	0	0	
		(2) Disagree	0	0	
		(3) Neither agree nor disagree	3	33,3	
		(4) Agree	3	33,3	
		(5) Strongly agree	3	33,3	
12	Do you consider the "upper and lower limb coordination with dumbbells" exercise appropriate?	(1) Strongly disagree	0	0	
		(2) Disagree	0	0	
		(3) Neither agree nor disagree	5	55,6	
		(4) Agree	2	22,2	
		(5) Strongly agree	2	22,2	
13	Do you consider the "ball manipulation with lower limbs" exercise appropriate?	(1) Strongly disagree	0	0	
		(2) Disagree	0	0	
		(3) Neither agree nor disagree	1	11,1	
		(4) Agree	4	44,4	
		(5) Strongly agree	4	44,4	

14	Do you consider the "ball manipulation over the head" exercise appropriate?	(1) Strongly disagree	0	0	Consider adaptations for cases with joint limitations.
		(2) Disagree	1	11,1	
		(3) Neither agree nor disagree	3	33,3	
		(4) Agree	1	11,1	
		(5) Strongly agree	4	44,4	
15	Do you consider the "sit-to-stand with ball" exercise appropriate?	(1) Strongly disagree	0	0	It depends on the functionality of the lower limbs; for some individuals, it will be difficult without support.
		(2) Disagree	0	0	
		(3) Neither agree nor disagree	2	22,2	
		(4) Agree	3	33,3	
		(5) Strongly agree	4	44,4	
16	Do you consider the "stand up, fetch the ball with movement, and sit down" exercise appropriate?	(1) Strongly disagree	0	0	
		(2) Disagree	0	0	
		(3) Neither agree nor disagree	3	33,3	
		(4) Agree	2	22,2	
		(5) Strongly agree	4	44,4	
17	Is there sufficient variety of exercises?	(1) Strongly disagree	0	0	
		(2) Disagree	2	22,2	
		(3) Neither agree nor disagree	1	11,1	
		(4) Agree	3	33,3	
		(5) Strongly agree	3	33,3	
18	Does the program have potential to improve motor function?	(1) Strongly disagree	0	0	
		(2) Disagree	0	0	
		(3) Neither agree nor disagree	2	22,2	
		(4) Agree	2	22,2	

		(5) Strongly agree	5	55,6	
19	Is the program feasible in a real-world setting?	(1) Strongly disagree	1	11,1	
		(5) Strongly agree	8	88,9	
20	What do you consider to be the strengths of the program?	Open-ended response	Focus on muscle strengthening.		
			Include both strength and mobility training.		
			These exercises are easy to apply; if you create a manual, they can be easily replicated by other professionals.		
			Ease		
			All		
			The functionality of the exercises. The attached material can help increase motivation.		
			Variety and diversification of exercises.		
			Improvement of physical function; maintenance of functional autonomy; and social stimulation.		
			Variety of stimuli addressing different abilities.		
21	What do you consider to be the main limitations or aspects to improve?	Open-ended response	Balance and dual-task training, as they are essential for these clients.		
			It combines two populations with different symptom profiles and seemed to me to be less targeted to them, appearing more suitable for the senior population. There are already patented and tested programs for this population, and it would be sufficient to base one on them. Attention must be paid to ensuring safe execution. Follow the recommendations of guidelines for these populations.		
			Depending on the duration you intend for the program, the exercises may become repetitive and, consequently, less motivating. This issue can be addressed		

			by adapting the exercises or creating context for them, for example, associating them with daily activities, a story, or incorporating games that involve these exercises.		
			Restricted to a group that is more limited, or that is very well adapted to the disease. Not all participants felt motivated to maintain this training plan in the long term.		
			Some participants may not have enough strength to perform certain exercises.		
			Any physical limitations should be accommodated.		
			Keep the back away from the chair during seated exercises to engage the core muscles.		
			Lack of motivation and adherence. Older adults may forget, lose interest, or not understand the purpose of the activity. Aspects to improve include using consistent routines, enjoyable exercises, and positive reinforcement.		
			Exercises for proprioception, laterality, and dexterity.		

The sample consisted of 9 specialists, aged between 22 and 50 years, demonstrating relevant age diversity for a critical analysis of the program. Regarding gender, 6 participants were female and 3 were male, reflecting a predominance of females.

In terms of academic background, most specialists were from the field of Physical Education/Sport Sciences (n=5), followed by Physiotherapy (n=3) and Social Work (n=1). There were no participants from Nursing, Medicine, Psychology, or Neurology. Regarding academic qualifications, 5 participants held a bachelor's degree, 3 held a master's degree, and 1 held a PhD, indicating an overall high academic level. In terms of general professional experience, 2 specialists had less than 5 years of experience, 1 had between 5 and 10 years, 4 had between 11 and 20 years, and 2 had more than 20 years of experience. This reflects a heterogeneous sample, including professionals at different stages of their careers. Regarding experience with neurodegenerative populations, 2 specialists reported experience with Alzheimer's Disease, 2 with Parkinson's Disease, 2 with both conditions, and 3 with other neurodegenerative diseases, such as Multiple Sclerosis and Huntington's Disease. The number of years of specific experience with neurodegenerative diseases ranged from 1 to 22 years, showing considerable variability. Regarding professional context, 1 specialist worked in a clinical setting, 2 in a community setting, 1 in an academic/research setting, and 5 in other contexts, including clinical and community environments, gyms, and family settings. This diversity strengthens the broad applicability of the proposed physical exercise program. Finally, most participants (n=7) reported having experience in prescribing physical exercise, while only 2 indicated that they did not have such experience.

Regarding the proposed exercises, the questionnaire results show an overall positive acceptance, although with relevant variations across different types of exercises. The "walking" exercise obtained 66.6% of responses at agreement levels ("Agree" and "Strongly agree"), a value identical to that observed in the exercises "knee extension," "seated row," "shoulder press," "biceps curl," and "stand up, pick up the ball with displacement, and sit down," suggesting a favourable perception. Higher agreement percentages (77.7%) were recorded for the exercises "step up and down," "knee flexion," "hip abduction and adduction," and "sit-to-stand with a ball," indicating greater consensus regarding their potential. The highest values were observed for the exercises "sit-to-stand" and "ball manipulation with the lower limbs," both with 88.8% agreement, reinforcing the relevance of these exercises. In light of these results, all exercises were retained in the program, as they demonstrated adequacy, safety, and functional potential for individuals with Alzheimer's Disease and Parkinson's Disease.

In contrast, the “triceps kickback” exercise showed only 33.3% agreement, while “upper and lower limb coordination with dumbbells” obtained 44.4%, and “ball manipulation over the head” 55.5%, reflecting greater hesitation among specialists, possibly associated with increased demands in coordination, balance, and motor control. Considering these limitations, it was decided to replace the “triceps kickback” exercise with chair-supported dips, as this alternative allows for the recreation of the functional “pushing” movement, while ensuring greater body stability and improved motor control. Regarding the “upper and lower limb coordination with dumbbells” exercise, it was decided to maintain its inclusion in the program, as it simultaneously combines coordination and muscular resistance training, which is considered essential for this population. Similarly, the “ball manipulation over the head” exercise was also maintained, despite the moderate level of agreement, as it represents a relevant stimulus for upper limb mobility, bilateral coordination, and body awareness.

Overall, 66.6% of responses fell within the agreement levels regarding exercise variety, 77.7% recognized their functional potential, and 88.9% agreed with the feasibility of implementation in a real-world context. These results indicate that, despite the overall acceptance of the program, specialists adopted a critical and selective approach, recognizing that certain exercises require greater caution and individual adaptation.

After revisions, a pilot test was conducted with an older participant diagnosed with Parkinson’s Disease, classified at stage 1 according to the Hoehn and Yahr Scale. The objective of this stage was to assess the understanding of instructions, observe the practical execution of the exercises, and identify any difficulties in adherence or barriers to participation. This stage made it possible to verify the adequacy of task duration, the clarity of explanations, and the need for adjustments in exercise progression.

The feedback obtained from this pilot test led to final refinements in the program, making it more accessible, safe, and better adapted to the characteristics and needs of the target population.

Third Stage: Evaluation

Item 6: Description of the control condition (comparator) and reasons for its selection

The intervention was implemented in a supervised practice context as part of this research. Participant selection was carried out through recruitment conducted by the

ACASO, in accordance with previously defined inclusion criteria, ensuring that the target population was appropriate for the program and that exercise practice was safe.

Before the start of the program, a detailed baseline assessment was conducted to collect reference data on motor function and the general condition of participants. Intermediate and final assessments were also performed, allowing monitoring of functional progress over time and evaluation of the effectiveness of the intervention. This pre-post approach allowed each participant to act as their own comparator, controlling for individual variability and providing an internal reference for interpreting the effects of the program.

Item 7: Description of the strategy to implement the intervention in the study context

The intervention was carefully structured to be carried out in institutional settings, specifically at the facilities of the ACASO. The adopted strategy followed a supervised, systematic, and progressive approach, aiming to promote improvements in motor function in older adults with Parkinson's Disease or Alzheimer's Disease.

The intervention was operationalized as follows:

- Group-based, face-to-face sessions, conducted four times per week, lasting 45 to 60 minutes.
- Division of sessions into structured phases, including initial instruction, warm-up, main phase, and cool-down.
- Continuous supervision by a qualified exercise professional, supported by the program coordinator, ensuring safety, correct technique, and monitoring of exercise intensity.
- Adaptation of exercises based on the participant's initial assessment and ongoing progress, using variations in intensity, volume, and complexity.
- Use of a digital exercise manual, which guided the correct execution of activities and ensured standardization of the intervention.

Item 8: Description of all materials or tools used in the intervention

The physical exercise program was planned to be implemented in an indoor environment. Whenever possible, it is recommended to conduct sessions in a spacious area (approximately 50 square meters), with a non-slip floor and adequate ventilation and acoustics. The materials used for the program are described in CERT Item 1.

Additionally, a digital manual of the physical exercise program was developed to serve as a support tool for the professionals involved in program delivery. This manual includes detailed information about the training sessions, describing the exercises, their sequence, and providing guidance for proper execution, adaptation, and progression of activities, ensuring standardization and fidelity.

Item 9: Description of fidelity or delivery process compared to the study protocol

The exercise program was implemented according to a previously developed detailed plan, which included:

- Session structure: total duration, weekly frequency, sequence of exercises;
- Detailed description of each exercise: objectives, targeted muscle groups, number of sets and repetitions, rest periods, and required materials;
- Intensity levels and progression: based on ACSM recommendations, allowing for individual adaptation.
- Exercise variations and alternatives: for participants with different degrees of motor or cognitive limitations.
- Illustrations and visual instructions: to facilitate understanding and correct execution of movements.

The implementation of the program was systematically monitored, ensuring that each session followed the defined protocol, maintaining consistency, safety, and suitability for the target population.

Item 10: Description of a process evaluation and its underlying theoretical basis

The effectiveness of the program was evaluated using the functional fitness tests from the Senior Fitness Test Battery, which is widely validated and recognized for its applicability in older adult populations. This battery allowed for a comprehensive assessment of different components of physical fitness, including strength, endurance, agility, and others.

For data collection during the tasks, two MEMS-type inertial sensors (TDK, TDK InvenSense, ICM-20948 9-dof, Tokyo, Japan) were used to record linear acceleration and angular velocity across the three planes of movement (sagittal, frontal, and transverse). The selected tests from the Senior Fitness Test included: Sit-to-Stand; Bicep Curl; Sit-and-Reach; Back Scratch; Seated 2.44-Meter Walk and Return Test; Two-Minute Step Test. These tests are described in detail below, providing objective measures to evaluate functional capacity, track progress, and guide adjustments in the exercise program.

a) Sit-to-Stand

This test aimed to assess lower limb strength and endurance by measuring the maximum number of repetitions performed in 30 seconds. A stopwatch and a chair with a backrest approximately 43 cm in height were used for execution. Participants began the test seated in the centre of the chair, with their back straight, feet shoulder-width apart and fully supported on the floor, and arms crossed over the chest. They were then instructed to stand up fully (to a vertical position) and sit back down completely.

Errors were recorded if the participant did not stand up fully, did not sit down completely, uncrossed their arms, or lifted their feet while sitting. Before the official test, participants were allowed to practice the procedure once or twice, and the test was repeated in case of mistakes or misunderstanding, after an adequate rest period. Finally, the inertial sensor was placed immediately on the lateral condyle of the right femur and on the right lateral malleolus.

b) Bicep Curl

The purpose of this test was to assess upper limb strength and endurance by counting the maximum number of repetitions performed in 30 seconds. The dumbbell used weighed 2.77 kilograms for females and 3.63 kilograms for males. A chair with a backrest approximately 43 cm high and a stopwatch were also required.

Participants began seated in the centre of the chair, with their back straight and resting against the backrest, feet shoulder-width apart and fully supported on the floor, holding the dumbbell in their dominant hand at the side of the chair, perpendicular to the floor. The assessor kneeled beside the participant’s dominant side, placing their fingers on the biceps to stabilize the upper arm and ensure a full flexion movement. The assessor could also place the other hand behind the elbow so that the participant could feel the full extension and avoid swinging movements of the forearm.

Before the official test, participants practiced the procedure once or twice, and the test was repeated in case of errors or misunderstanding, after an adequate rest period. Finally, the inertial sensor was placed on the styloid process of the right radius.

c) Sit-and-Reach

The purpose of this test was to assess lower limb flexibility. For its execution, a 45-centimeter measuring tape and a chair with a backrest approximately 43 cm in height were used. The participant began the test seated, with one leg bent at approximately 90 degrees and the foot in dorsiflexion, while the other leg remained extended with the foot fully supported on the floor. With both hands overlapped, the participant attempted to reach as close as possible to the dorsiflexed foot, and this distance was subsequently measured by the assessor.

After a demonstration by the assessor, the participant was asked about their dominant hand. They then performed one or two familiarization attempts, followed by two valid test attempts. The best result was recorded. The cutoff values were -10.16 cm for males and -5.08 cm for females. For this test, the inertial sensor was placed on the lateral condyle of the right femur and on the right lateral malleolus.

d) Back Scratch Test

The purpose of this test was to assess upper limb flexibility, specifically the distance the hands can reach behind the back. A 45-centimeter measuring tape was used for this test. The participant performed the test standing, placing the dominant hand over the shoulder and reaching as far down as possible toward the middle of the back, with the palm facing down, fingers extended, and elbow pointing upward. The other hand was positioned behind and below, with the palm facing up, attempting to reach as far as possible to touch (or overlap) the middle fingers of both hands. The distance between the fingers was then measured by the assessor.

After a demonstration by the assessor, the participant was asked about their dominant hand. They then performed one or two familiarization attempts, followed by two valid test attempts. Negative (-) values represent the shortest distance between the middle fingers, while positive (+) values represent the amount of overlap between the middle fingers.

e) Seated 2.44-Meter Walk and Return Test

The purpose of this test was to assess speed, agility, and balance. A stopwatch, measuring tape, a cone (or other marker), and a chair with a backrest approximately 43 cm in height were used. The chair was positioned against a wall or in a stable location, in an unobstructed area, facing a cone placed 2.44 meters away (measured from the front edge of the chair to the front of the marker). A free space of at least 1.22 meters was maintained around the cone to allow the participant to move around it without restrictions.

The participant began the test seated in the chair, hands resting on their thighs, and feet fully on the floor (one foot could be slightly ahead of the other). At the “go” signal, the participant stood up from the chair (pushing off the thighs or chair if necessary), moved as quickly as possible around the cone (from either side), and returned to the chair. The stopwatch was started at the “go” signal and stopped as soon as the participant was fully seated again.

After a demonstration by the assessor, the participant was asked about their dominant hand. They then performed one or two familiarization attempts, followed by two valid test attempts. The best result was recorded. Finally, the inertial sensor was placed on the lateral condyle of the right femur and on the right lateral malleolus.

f) Two-Minute Step Test

The purpose of this test was to assess cardiorespiratory fitness. A stopwatch, measuring tape, and a ribbon or cord were required. First, the midpoint between the kneecap (centre) and the iliac crest (top of the hip bone) was measured and marked on the wall or chair using the ribbon or cord. This point served as a reference for the minimum knee height that should be reached during the test.

After a demonstration by the assessor, the participant performed one or two familiarization attempts, followed by two valid test attempts. At the “go” signal, the participant marched in place, aiming to complete the maximum number of step cycles in 2 minutes. If the participant wished to rest, they could pause and resume later, although the stopwatch continued to run throughout the test period. Finally, the inertial sensor was placed on the lateral condyle of the right femur and on the right lateral malleolus.

Item 11: Description of internal facilitators and barriers that may influence the intervention, as revealed by the process evaluation

One of the main facilitators of the intervention was the qualification and availability of the professionals involved. The program was conducted by a physical exercise specialist with advanced academic training in physical activity and health and supervised by a PhD-qualified professional. The presence of qualified professionals not only ensured the correct execution of the exercises but also provided participants with a sense of safety and confidence, contributing to the success of the intervention. Continuous supervision during sessions, combined with positive and constructive feedback, enhanced adherence to the program, promoting participant engagement and motivation

Another important facilitator was the availability of adequate material and logistical resources. The infrastructure provided by the *Associação Cultural e de Apoio Social de Olhão*, including an indoor space with a non-slip floor, appropriate ventilation and acoustic conditions, as well as the necessary support equipment (such as a sound system, dumbbells, among others), created a suitable environment for the safe and efficient implementation of activities. These resources allowed participants to perform exercises comfortably, minimizing the risk of injury and promoting well-being.

Despite these identified facilitators, the intervention was potentially influenced by several internal barriers. One of the main barriers consisted of the physical limitations of participants resulting from the neurodegenerative diseases involved, namely Alzheimer’s Disease and Parkinson’s Disease.

Item 12: Description of external conditions or factors occurring during the study that may have influenced the implementation or mechanism of the intervention

Among the main external factors identified in this study, the influence of the institutional and community calendar stands out, namely national and regional holidays, as well as internal activities and events of the host institution, the ACASO.

Item 13: Description of costs or resources required for the intervention

The implementation of a structured and supervised physical exercise program aimed at older adults with neurodegenerative conditions, namely Parkinson’s Disease and Alzheimer’s Disease, required a clear estimation of the human, material, and financial resources involved, in order to ensure its feasibility, effectiveness, and medium- to long-term sustainability.

The intervention involved the regular presence of at least one qualified exercise professional with a bachelor’s degree and specific training in physical activity, responsible for conducting the sessions. Additionally, the program was supervised by a PhD-level coordinator with expertise in Human Motricity, ensuring methodological rigor, outcome evaluation, and overall intervention quality.

The materials required, as described in CERT Item 1, represented a low to moderate financial demand. The space needed for the intervention was provided by the

Associação Cultural e de Apoio Social de Olhão, with no direct rental costs. However, it was necessary to ensure that the space met appropriate conditions for the intervention.

In addition, other expenses were considered, such as:

- Assessment forms;
- Liability and personal accident insurance for both participants and professionals involved.

2.2.4. Discussion

The present study aimed to develop and validate a physical exercise program targeted at older adults with Alzheimer's Disease or Parkinson's Disease, using methodological frameworks (CREDECI2 and CERT). The discussion of the results focuses on the methodological robustness of the design process, expert validation, and the feasibility of the program in a real-world context.

Overall, the results of the questionnaire administered to the panel of specialists indicate a high level of agreement regarding the adequacy of the exercises, their potential to improve motor function, and the feasibility of implementing the exercise program in institutional settings. This validation process also made it possible to identify suggestions for improvement, particularly concerning the clarification of instructions, the need for individual adaptations, and attention to the functional heterogeneity characteristic of both conditions.

These contributions were incorporated into the final version of the program, representing a key strength of the study, as the systematic integration of expert feedback enhances the applicability, safety, and overall quality of the intervention.

The program structure, based on the recommendations of the American College of Sports Medicine, is aligned with current scientific evidence, which recognizes physical exercise as an effective strategy. The inclusion of aerobic, resistance, neuromotor, and joint mobility components is particularly relevant, given the multicomponent nature of the program.

2.2.5. Limitations

Despite the methodological rigor adopted in the development and validation of the physical exercise program, the present study has some limitations. First, the validation of the program was carried out by only nine experts, which represents a small sample size and limits the representativeness of different professional fields.

Additionally, there was no participation from professionals in the fields of Medicine, Psychology, and Neurology, which may restrict the diversity of clinical perspectives on the proposed intervention.

Second, the pilot test was conducted with only one participant with Parkinson’s Disease at an early stage, which prevents the generalization of the results to individuals at more advanced stages of the disease or to those with Alzheimer’s Disease.

These limitations do not compromise the relevance of the study but highlight the need for future research with larger samples and greater professional diversity.

2.2.6. Conclusion

The CREDECI2 and CERT instruments guide and support the development and validation of complex interventions. This study presents the design of a physical exercise program for older adults with Alzheimer’s Disease or Parkinson’s Disease.

The program was developed to promote the overall development of participants, with particular emphasis on motor function, and stands out for its pioneering nature for this target population. Furthermore, its detailed description enables replication by other professionals in the field of physical exercise.

2.3. Study 3 - Effects of Alzheimer´s Disease on Motor Function: a Case Study with the use of machine learning algorithms training

Abstract

Background: Alzheimer's disease (AD) is a neurodegenerative disorder associated with functional and cognitive decline. Physical activity has been identified as a strategy for improving functional capacity. Simultaneously, inertial measurement units (IMUs) and artificial intelligence (AI) approaches have emerged as promising tools for movement assessment.

Objective: To analyze the effects of Alzheimer's disease on motor function and intra-segmental motor coordination in an older adult diagnosed with AD, as well as to evaluate the sensitivity of machine learning models in reconstructing signals obtained from IMUs.

Methods: A case study was conducted with an 86-year-old female participant diagnosed with Alzheimer's disease (stage III/IV). Motor function was assessed using the Senior Fitness Test battery (Rickli & Jones, 2013).During task performance, two MEMS-type inertial sensors were used to record linear acceleration and angular velocity in the three planes of movement (sagittal, frontal, and transverse). The selected tests from the Senior Fitness Test battery included the Sit-to-Stand, Bicep Curl, Sit-and-Reach, Back Scratch, Seated 2.44-Meter Walk and Return, and Two-Minute Step Test. Incomplete IMU signals were reconstructed using a Temporal Convolutional Network (TCN), and model performance was evaluated using the RMSE, MAE, NRMSE, and Pearson correlation coefficient metrics. Motor coordination was analyzed through the smoothness and dispersion of phase plot trajectories.

Results: The results demonstrated the maintenance of motor function throughout the assessment period, with improvements particularly observed in the Bicep Curl Test. The AI-based reconstruction models were able to accurately estimate the missing data, with the subject-specific model outperforming the global model. Additionally, a trend towards improved intra-segmental motor coordination was observed, characterized by greater movement smoothness and lower trajectory dispersion in the phase plots, particularly in the sagittal plane.

Discussion and Conclusions: The findings suggest that regular physical activity may contribute to the maintenance of motor function in older adults with AD. Simultaneously, IMUs and AI-based approaches demonstrated potential as innovative tools for movement assessment, functional monitoring, and the personalization of biomechanical evaluations.

Keywords: Alzheimer's disease; Physical Activity; Motor Function; Inertial Measurement Units; Artificial Intelligence.

2.3.1. Introduction

Population aging is a growing phenomenon. Portugal has more than 2.5 million older adults, making it the 2nd country in the EU with the highest aging index (Pordata, 2024). Older adults experience a decline in muscle mass, strength, functional capacity (Suryadi et al., 2024) and power (Pontedeira, 2022) as they age progresses. Furthermore, the prevalence of neurodegenerative diseases, namely Alzheimer's disease (AD) and Parkinson's disease (PD), affecting over 100 million people worldwide. These pathologies compromise essential physical and cognitive capacities, significantly interfering with daily life activities (Gomes, 2015). AD is characterized by the progressive degeneration of functions such as memory, attention, and language (Gaitán et al., 2021). PD results from neuronal degeneration of the *substantia nigra,* manifesting as akinesia, rigidity, tremors, and gait alterations. Recent studies have demonstrated that physical activity bring benefits at both motor (strength, balance, mobility) and cognitive levels, reducing inflammation and oxidative stress while promoting neuroplasticity (Johansson et al., 2022; Serna-Orozco et al., 2025).Thus, physical activity emerges as a multifaceted approach essential for addressing the challenges posed by aging. The importance of physical activity extends far beyond disease prevention. Resistance training stands out among the various forms of physical activity due to its positive effects on muscular function, promoting gains in strength, power, and muscular endurance. Furthermore, this training modality has been associated with increases in muscle mass and bone mineral density, as well as the induction of neural adaptations, improvements in cardiometabolic health, and reductions in psychological symptoms, particularly anxiety and depression (Lopez et al., 2021; Serna-Orozco et al., 2025).

According to the literature, the positive effects of physical activity on the functionality of people with Alzheimer's Disease tend to be observed after interventions lasting more than 12 weeks (Zhou et al., 2022), performed approximately 3 to 4 times per week, with sessions of up to 30 minutes (Jia et al., 2019).

One way to assess the ability to maintain motor independence is through battery of tests such as the (Rickli & Jones, 2013) battery. This traditional battery provides a final score that depends of execution specific test such as Sit-to-Stand, Bicep Curl, Sit and Reach, Back Scratch, Seated Reach, 2.44 m Walk and Return, and Two-Minute Step Test However, this assessment is based in the final outcome by the number of repetitions or time of those specific tests, limiting the analysis of the process of motor control for each subject. In addition to functional performance, these tests can also be used to evaluate the motor function dynamically. One of the motor functions that can be assessed is motor coordination, which, according to (Bernstein, 1967), is "the process of mastering the redundant degrees of freedom of the moving organ, that is, its conversion into a controllable system.

On the other hand, inertial sensors (IMUs), lightweight and easily applicable devices such as wearables, allow the collection of continuous data throughout movement (Yin et al., 2025). IMUs collect three-dimensional (3D) data on acceleration (accelerometer), angular velocity (gyroscope), and the Earth's magnetic field orientation (magnetometer), with the ability to capture hundreds of data points per second (typically 100 to 200 Hz). These characteristics allow not only the analysis of the different dimensions of movement, but also a high degree of temporal and spatial precision. This means that, with these instruments, we can obtain 3D data every 5 milliseconds (in the case of recordings at 200 Hz), representing fine temporal resolution, as well as concrete data regarding the translations and rotations that occur during movement. For this reason, we can state that IMUs enable the analysis of the motor execution process. IMUs allow the evaluation of underexplored areas in the context of exercise and health, such as coordinative abilities, which are essential motor functions for autonomy and well-being in the elderly. Furthermore, this type of data has the potential to be used to train artificial intelligence models and machine learning algorithms, which in turn may be able not only to predict the effects of physical exercise on older people with these conditions, but also to predict the likelihood of an individual developing them or to prevent their progression. Consequently, the integration between inertial sensors and artificial intelligence represents a promising approach for the development of effective assessment, monitoring and intervention strategies.

2.3.2. Objectives

The main objective of the present longitudinal study is to analyze the effects of Alzheimer's disease on motor function in an older adult diagnosed with Alzheimer's disease.

In addition, this study also aims to verify the sensitivity of artificial intelligence (AI) methods in detecting individual subject characteristics through the analysis of acceleration and gyroscope time series collected using Inertial Measurement Units. Furthermore, the effects of Alzheimer's disease on intra-segmental motor coordination were evaluated during the following tasks: Bicep Curl Test, Seated 2.44-Meter Walk and Return Test, and Two-Minute Step Test.

2.3.3. Hypotheses

To address the objective of the study, the following hypotheses were formulated:

- H1: Alzheimer’s disease leads to deterioration in motor function. This hypothesis is supported by several studies demonstrating that individuals with Alzheimer's disease exhibit progressive impairments in gait, balance, functional mobility, and muscle strength (Cedervall et al., 2014; Hebert et al., 2010).
- H2: The machine learning model is sensitive enough to detect individual characteristics of the patient with Alzheimer’s disease. This hypothesis was formulated based on previous studies demonstrating that machine learning algorithms are capable of identifying disease-specific motor patterns from biomechanical data (Ghoraani et al., 2021)
- H3: Alzheimer’s disease impairs intra-segmental motor coordination in patient with Alzheimer’s disease. This hypothesis is based on previous evidence showing that individuals with Alzheimer's disease exhibit reduced gait speed, shorter step length, lower cadence, greater stride-to-stride variability, and increased postural sway, reflecting impairments in motor control and movement coordination (Sheridan & Hausdorff, 2007). These motor alterations are thought to result from the progressive degeneration of neural circuits involved in motor planning, execution, and coordination (Koppelmans et al., 2022).

2.3.4. Methods

2.3.4.1. Study Design

This case study was conducted at the *Associação Cultural e de Apoio Social de Olhão* (ACASO). The participant was evaluated at two distinct points in time: at the beginning of the study and after eight weeks, allowing the assessment of the participant's status.

2.3.4.2. Participant Characterization

The participant is an 86-year-old female diagnosed with Alzheimer’s disease (stage III/IV) and arterial hypertension. Despite her clinical conditions, she remains autonomous in performing activities of daily living and maintains an active lifestyle. She walks daily for at least 30 minutes. The participant takes her medication regularly, is 1.50 m tall, weighs 45.9 kg, and has a body mass index (BMI) of 20.4 kg/m².

2.3.4.3. Ethical Considerations

All procedures were conducted in accordance with the Declaration of Helsinki (1964). The study protocol was submitted for review by the Ethics Committee of the Polytechnic Institute of Santarém and received prior approval (appendix II). Data collection commenced only after obtaining written informed consent from all participants. Voluntary participation and agreement regarding the use and dissemination of data for scientific purposes were ensured. At all stages of the study, anonymity and confidentiality of information were guaranteed, in accordance with ethical principles.

2.3.4.4. Instruments

Motor function was assessed using the functional fitness testing protocol of the Senior Fitness Test battery (Rickli & Jones, 2013a). Data collection during task performance was carried out using two MEMS-type inertial sensors (TDK InvenSense ICM-20948 9-dof, Tokyo, Japan), which recorded linear acceleration and angular velocity across the three planes of motion (sagittal, frontal, and transverse). An Asus laptop computer (Windows 11 Home 24H2, Intel® Core™ M-5Y10c CPU @ 0.80 GHz) and the IMU DataService software were also used for data acquisition.

Data processing and analysis were performed using Microsoft Excel (version 2504, Build 16.0.18730.20122, 64-bit), MATLAB (The MathWorks, Inc, 2025) and Spyder Python (Raybaut, 2026).

2.3.4.5. Tests

The selected tests from the Senior Fitness Test battery were as follows: Sit-to-Stand, Bicep Curl, Sit-and-Reach, Back Scratch, Seated Reach, 2.44 m Walk and Return Test, and the Two-Minute Step Test. In all tests, except for the Bicep Curl, Sit-and-Reach, and Back Scratch tests the IMUs were positioned on the lateral condyle of the right femur and on the right lateral malleolus. During the Bicep Curl test, the IMUs were placed on the lateral epicondyle of the right humerus (Figure 3). No IMUs were used during the Sit-and-Reach and Back Scratch tests. These anatomical landmarks were selected because they are bony prominences that provide stable attachment sites, minimizing measurement errors associated with soft tissue artifact (STA). When IMUs are placed over regions with substantial muscle or adipose tissue, movement of the skin relative to the underlying bone may cause sensor displacement, thereby compromising the accuracy of the recorded kinematic data. Conversely, positioning the sensors over bony landmarks reduces relative motion between the sensor and the underlying skeletal segment, improving the reliability and validity of the kinematic measurements (Cereatti et al., 2024). For the exercises and movement segments analyzed, the IMUs orientations were defined such that the X-axis corresponded to the frontal plane, the Y-axis corresponded to the transverse plane, and the Z-axis corresponded to the sagittal plane.

a) b)

Figure 3 - Representation of the location and position of the IMUs: a) lateral condyle of the right femur and on the right lateral malleolus; b) lateral epicondyle of the right humerus.

The following tests are described below:

a) Sit-to-Stand

This test aimed to assess lower limb strength and endurance by measuring the maximum number of repetitions performed in 30 seconds. A stopwatch and a chair with a backrest approximately 43 cm in height were used for execution. Participants began the test seated in the center of the chair, with their back straight, feet shoulder-width apart and fully supported on the floor, and arms crossed over the chest. They were then instructed to stand up fully (to a vertical position) and sit back down completely.

Errors were recorded if the participant did not stand up fully, did not sit down completely, uncrossed their arms, or lifted their feet while sitting. Before the official test, participants were allowed to practice the procedure once or twice, and the test was repeated in case of mistakes or misunderstanding, after an adequate rest period.

b) Bicep Curl

The purpose of this test was to assess upper limb strength and endurance by counting the maximum number of repetitions performed in 30 seconds. The dumbbell used weighed 2.77 kilograms for females and 3.63 kilograms for males. A chair with a backrest approximately 43 cm high and a stopwatch were also required.

Participants began seated in the center of the chair, with their back straight and resting against the backrest, feet shoulder-width apart and fully supported on the floor, holding the dumbbell in their dominant hand at the side of the chair, perpendicular to the floor. The assessor kneeled beside the participant's dominant side, placing their fingers on the biceps to stabilize the upper arm and ensure a full flexion movement. The assessor could also place the other hand behind the elbow so that the participant could feel the full extension and avoid swinging movements of the forearm.

Before the official test, participants practiced the procedure once or twice, and the test was repeated in case of errors or misunderstanding, after an adequate rest period.

c) Sit-and-Reach

The purpose of this test was to assess lower limb flexibility. For its execution, a 45-centimeter measuring tape and a chair with a backrest approximately 43 cm in height were used. The participant began the test seated, with one leg bent at approximately 90 degrees and the foot in dorsiflexion, while the other leg remained extended with the foot fully supported on the floor. With both hands overlapped, the participant attempted to reach as close as possible to the dorsiflexed foot, and this distance was subsequently measured by the assessor.

After a demonstration by the assessor, the participant was asked about their dominant hand. They then performed one or two familiarization attempts, followed by two valid test attempts. The best result was recorded. The cutoff values were -10.16 cm for males and -5.08 cm for females.

d) Back Scratch Test

The purpose of this test was to assess upper limb flexibility, specifically the distance the hands can reach behind the back. A 45-centimeter measuring tape was used for this test. The participant performed the test standing, placing the dominant hand over the shoulder and reaching as far down as possible toward the middle of the back, with the palm facing down, fingers extended, and elbow pointing upward. The other hand was positioned behind and below, with the palm facing up, attempting to reach as far as possible to touch (or overlap) the middle fingers of both hands. The distance between the fingers was then measured by the assessor.

After a demonstration by the assessor, the participant was asked about their dominant hand. They then performed one or two familiarization attempts, followed by two valid test attempts. Negative (-) values represent the shortest distance between the middle fingers, while positive (+) values represent the amount of overlap between the middle fingers.

e) Seated 2.44-Meter Walk and Return Test

The purpose of this test was to assess speed, agility, and balance. A stopwatch, measuring tape, a cone (or other marker), and a chair with a backrest approximately 43 cm in height were used. The chair was positioned against a wall or in a stable location, in an unobstructed area, facing a cone placed 2.44 meters away (measured from the front edge of the chair to the front of the marker). A free space of at least 1.22 meters was maintained around the cone to allow the participant to move around it without restrictions.

The participant began the test seated in the chair, hands resting on their thighs, and feet fully on the floor (one foot could be slightly ahead of the other). At the “go” signal, the participant stood up from the chair (pushing off the thighs or chair if necessary), moved as quickly as possible around the cone (from either side), and returned to the chair. The stopwatch was started at the “go” signal and stopped as soon as the participant was fully seated again.

After a demonstration by the assessor, the participant was asked about their dominant hand. They then performed one or two familiarization attempts, followed by two valid test attempts. The best result was recorded.

f) Two-Minute Step Test

The purpose of this test was to assess cardiorespiratory fitness. A stopwatch, measuring tape, and a ribbon or cord were required. First, the midpoint between the kneecap (center) and the iliac crest (top of the hip bone) was measured and marked on the wall or chair using the ribbon or cord. This point served as a reference for the minimum knee height that should be reached during the test.

After a demonstration by the assessor, the participant performed one or two familiarization attempts, followed by two valid test attempts. At the “go” signal, the participant marched in place, aiming to complete the maximum number of step cycles in 2 minutes. If the participant wished to rest, they could pause and resume later, although the stopwatch continued to run throughout the test period.

2.3.4.6. Tasks, Procedures, and Protocols

Initially, an email was sent to schedule a meeting with day-care centers and nursing homes in the Algarve region in order to present the project and request authorization to conduct the study. After authorization was granted by one of the institutions, namely ACASO, informed consent was requested from the legal guardian of one of the institutionalized patients. At that stage, the objectives, procedures, and instruments used in the study were explained. Following authorization for participation in the study, an initial assessment was carried out using the functional fitness tests from the Senior Fitness Test battery (Rikli & Jones, 2013).

2.3.4.7. Variables

In this study, the level of Alzheimer´s disease was considered the independent variable, while the variables presented in the following table were considered dependent variables (Table 6).

Table 6. Operational table of variables.

Variable	Description	Type	Domain	Unit	Function
VA	Angular Velocity	Quantitative Continuous	Real numbers	Degrees/S	Dependent
Al	Linear Acceleration	Quantitative Continuous	Real numbers	m/s^2	Dependent
Reps	Repetitions	Quantitative	Natural numbers	-	Dependent
Cm	Centimeters	Quantitative	Natural numbers	-	Dependent
NDA	Level of Alzheimer´s Disease	Qualitative	-	-	Independent
RMSE	Root Mean Square Error	Quantitative Continuous	Real numbers	-	Dependent
MAE	Mean Absolute Error	Quantitative Continuous	Real numbers	-	Dependent
Coef-Correlation	Correlation Coefficient	Quantitative Continuous	Real numbers	-	Dependent
NRMSE	Normalized Root Mean Square Error	Quantitative Continuous	Real numbers	-	Dependent

2.3.4.8. Data Processing

Due to issues that occurred during the initial data collection sessions, gaps were identified in some of the time series recorded by the IMUs.

The .csv files generated by the IMU Data Service software were imported into the MATLAB environment, where different approaches for reconstructing the missing data were tested. Initially, mathematical interpolation methods were considered. However, due to the extent of the data acquisition failures, it became necessary to explore alternative reconstruction methods, specifically approaches based on artificial intelligence and machine learning. This approach involved the use of deep learning models to reconstruct incomplete signals. For this purpose, a Temporal Convolutional Network (TCN) was developed to estimate the missing data from the IMU signals. This choice was motivated by the sequential nature of the collected data, the temporal dependencies between consecutive samples, and the correlation among the different recorded channels, including linear acceleration, angular velocity, and orientation (Kazijevs & Samad, 2023; Yoon et al., 2017).

During the training process, complete datasets obtained during the second assessment were used. These time series were artificially degraded by removing segments of data, replicating the patterns of data loss observed in the actual incomplete files. This approach enabled the training and evaluation of different reconstruction models under conditions similar to those encountered experimentally. Since the original values of the removed samples were known, it was possible to directly compare the reconstructed signals with the original signals and calculate objective performance metrics.

Model performance was evaluated using the Root Mean Square Error (RMSE), Mean Absolute Error (MAE), Normalized Root Mean Square Error (NRMSE), and Pearson correlation coefficient, calculated exclusively on the artificially removed segments.

Following signal reconstruction, a digital low-pass filter was applied to the acceleration and angular velocity channels, using a cut-off frequency between 6 and 8 Hz (Winter, 1991). This step aimed to reduce high-frequency components potentially introduced during the reconstruction process while preserving the main characteristics of the movements performed during the different functional tasks. Subsequently, the reconstructed and filtered signals were used in the kinematic and statistical analyses presented in this study.

Regarding the motor coordination data, these were imported from .csv files to MATLAB environment. First, to the gyroscope data in degrees per second (deg/s), was applied a numerical integration to determine angular displacement, followed by the application of a correction to the angular displacement signal. Finally, phase plots were generated for each movement plane by plotting angular velocity against angular displacement on opposite axes of the plot (Lamba, P. F & Bartlett, R. M., 2018).

2.3.5. Results

2.3.5.1. Results of the Senior Fitness Test

Table 7 presents the results obtained from the Senior Fitness Test battery at two assessment time points. Performance in the Sit-to-Stand test remained unchanged, with 10 repetitions completed in both assessments. In the Seated 2.44-Meter Walk and Return Test, a slight improvement in performance was observed, as evidenced by a reduction in completion time from 16.95 s to 16.91 s. In the Bicep Curl test, the number of repetitions increased from 11 to 17, which may indicate an improvement in upper-limb muscular strength and endurance. Regarding the Sit and Reach test, the results remained unchanged, with a value of 0 cm recorded in both assessments, suggesting stable lower-limb flexibility. In the Back Scratch test, which assesses shoulder flexibility, a slight increase was observed, from 34 cm to 35 cm. In contrast, performance in the 2-Minute Step Test showed a small decrease, with the number of cycles completed declining from 49 to 47.

Table 7. Results of the Senior Fitness Test.

Sit-to-Stand (reps)	**Seated 2.44-Meter Walk and Return Test (sec)**	**Bicep Curl (reps)**	**Sit and Reach (cm)**	**Back Scratch (cm)**	**2-Min Walk (number cycles)**
10	16,95	11	0	34	49
10	16,91	17	0	35	47

2.3.5.2. Results of the AI

2.3.5.2.1. Results of the Reconstruction of the Bicep Curl Test data

The analysis provided relevant metrics for assessing the quality of signal reconstruction. It was found that the incomplete files contained, on average, approximately 22% observed data and 78% missing data. This high proportion of missing values highlights the complexity of the reconstruction task, therefore, the results obtained should be interpreted with caution.

Regarding the global model, evaluated using the leave-one-subject-out validation strategy, the overall performance was found to be moderate to poor. The largest reconstruction errors (NRMSE) were observed in the acceleration channels of the Y and Z axes. In contrast, the results obtained for the X-axis acceleration and the Z-axis of the angular velocity demonstrated more satisfactory performance, with lower error values and correlation levels considered acceptable for reconstruction purposes. These results are presented in greater detail in Table 8.

Table 8. Results of the global model of the bicep curl test.

Variable	RMSE	MAE	Correlation Coef.	NRMSE
Acc X	0.11	0.09	0.3	18.70%
Acc Y	0.21	0.19	0.3	46.70%
Acc Z	0.38	0.35	0.31	54.60%
Gir X	79.16	65.69	0.43	36.30%
Gir Y	51.24	41.62	0.19	28.20%
Gir Z	31.85	25.74	0.46	17.00%

Regarding the subject-specific fine-tuned model (Table 9), performance was clearly superior to that of the global model. Overall, consistent improvements were observed across the evaluation metrics for most of the analyzed channels, indicating a greater ability of the model to estimate missing data and to reconstruct signals more faithfully to their original characteristics. The channels that presented the greatest reconstruction challenges were the Y-axis acceleration and the Y-axis angular velocity, where the highest error values were recorded. In contrast, the angular velocity channels corresponding to the X and Z axes exhibited better performance, reflected by lower reconstruction errors and higher correlation coefficients.

Table 9. Results of the subject-specific fine-tuned model of the bicep curl test.

Variable	RMSE	MAE	Correlation Coef.	NRMSE
Acc X	0.05	0.04	0.75	11.6%
Acc Y	0.04	0.03	0.77	12.8%
Acc Z	0.06	0.05	0.78	11.5%
Gir X	15.50	12.20	0.90	9.3%
Gir Y	14.40	11.09	0.72	11.9%
Gir Z	11.66	9.00	0.88	10.1%

Figure 4 present the reconstructed acceleration and angular velocity signals and the original signals collected during the first assessment while performing the bicep curl exercise. The blue trace represents the reconstructed signal, whereas the orange trace corresponds to the original collected signal. A high level of agreement was observed between the two signals, demonstrating the ability of the reconstruction model to accurately capture the temporal pattern of the movement. The small differences observed in the amplitude of some peaks may be attributed to the application of a low-pass filter following the artificial intelligence-based reconstruction process.

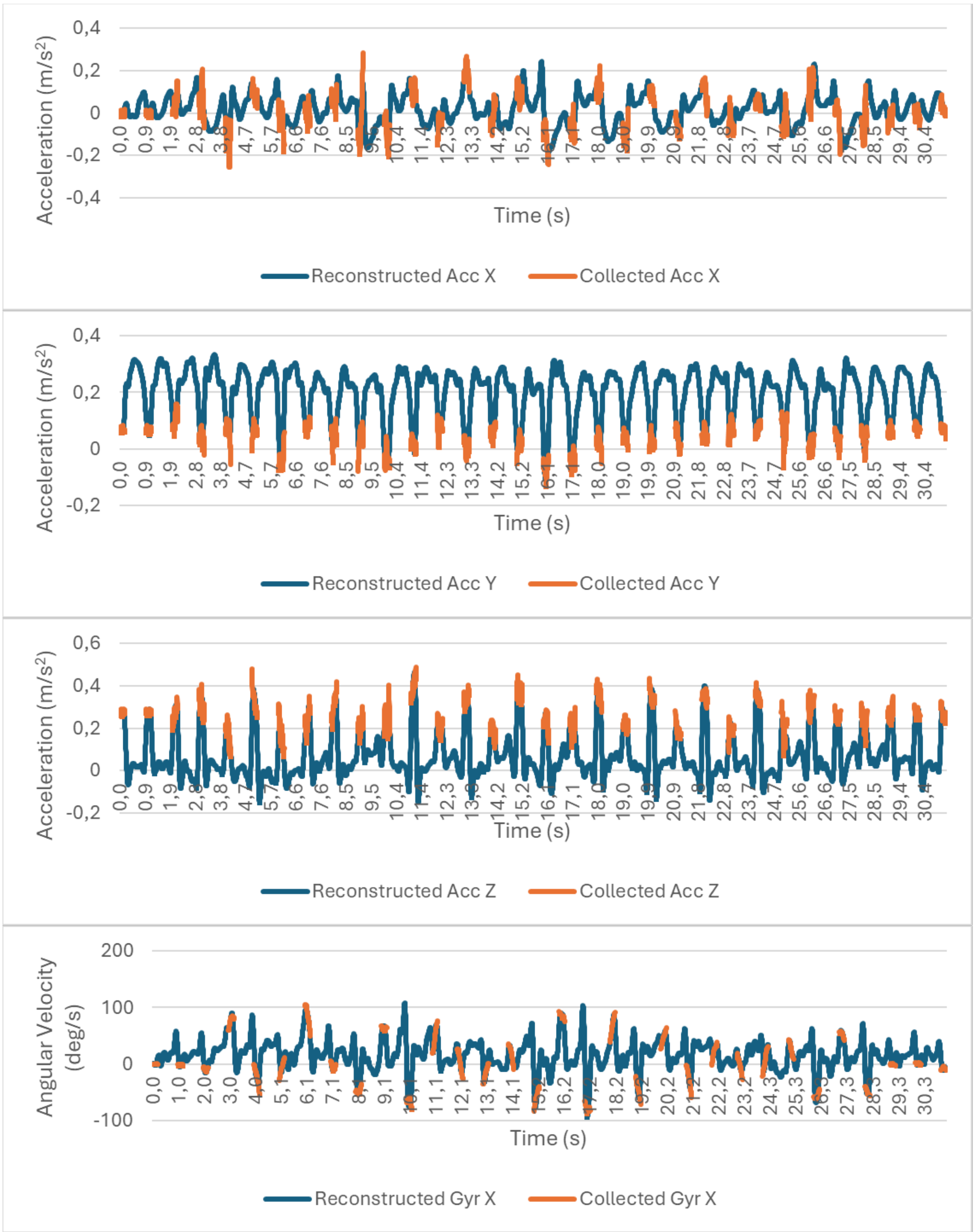


Figure 4 - Signal reconstructed for 3D acceleration and gyroscope data for the bicep curl test.

2.3.5.2.2. Results of the reconstruction of the Sit-to-Stand Test data

Regarding the global model, evaluated using the *leave-one-subject-out* validation strategy, an overall moderate performance was observed. The highest reconstruction errors were found in the acceleration channels of the Y and Z axes, indicating greater difficulty of the model in estimating these signals. In contrast, the results obtained for the angular velocity in the Y and Z axes showed more satisfactory performance, with lower errors and correlation values considered appropriate for reconstruction purposes. These results are presented in greater detail in Table 10.

Table 10. Results of the global model of the sit-to-stand test.

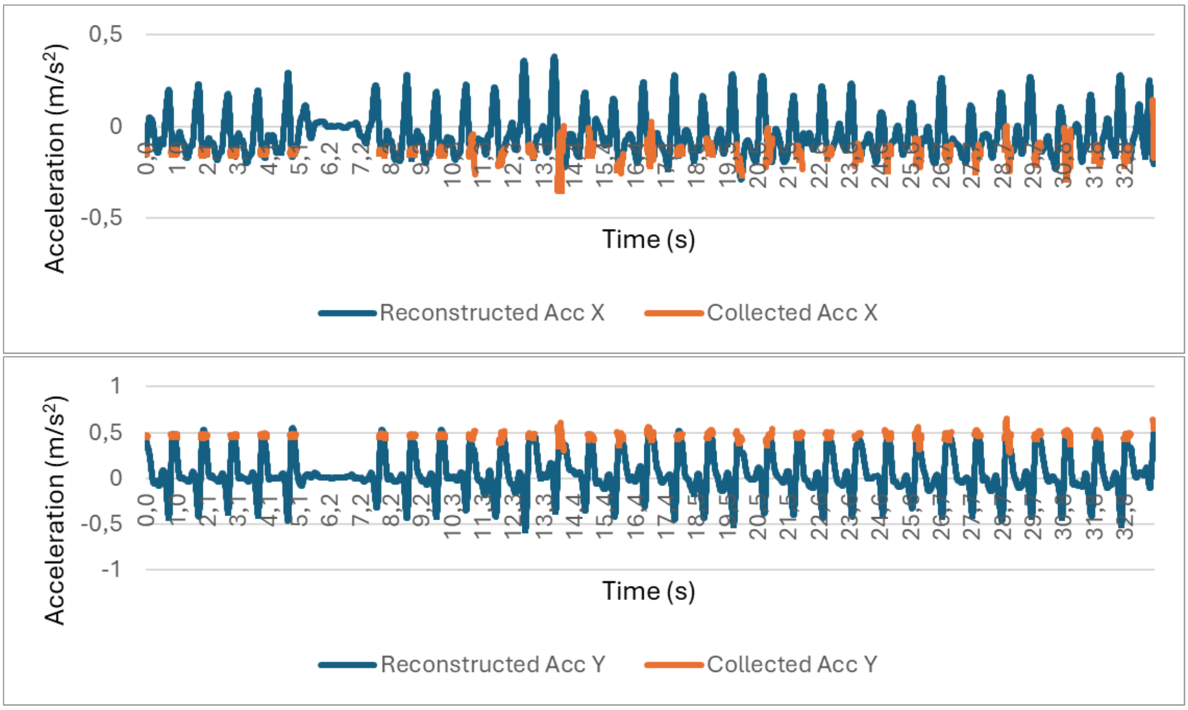
Variable	RMSE	MAE	Correlation Coef.	NRMSE
Acc X	0.23	0.18	0.22	23.64%
Acc Y	0.33	0.31	0.01	51.31%
Acc Z	0.25	0.24	0.06	57.51%
Gir X	13.00	10.45	0.26	18.73%
Gir Y	16.50	11.96	0.08	16.59%
Gir Z	25.85	20.16	0.28	14.22%

Regarding the subject-specific fine-tuned model, a clearly superior performance was observed compared to the global model. The highest reconstruction errors were found in the acceleration channels of the Z and Y axes. In contrast, angular velocity on the Z axis and acceleration on the X axis showed better results, with lower error values and overall acceptable metrics for reconstruction purposes (Table 11).

Table 11. Results of the subject-specific fine-tuned model of the sit-to-stand test.

Variable	RMSE	MAE	Correlation Coef.	NRMSE
Acc X	0.07	0.05	0.82	9.45%
Acc Y	0.05	0.03	0.62	12.71%
Acc Z	0.04	0.03	0.51	15.25%
Gir X	5.86	4.35	0.69	15.29%
Gir Y	7.47	5.37	0.75	11.49%
Gir Z	9.23	6.44	0.87	9.28%

Figure 5 present a comparison between the reconstructed acceleration and angular velocity signals and the original signals recorded over time during the Sit-to-Stand exercise. In this exercise, a substantial proportion of the signal consisted of reconstructed data, with approximately 78% of the signal being reconstructed and only 22% corresponding to originally recorded data. Despite the high proportion of reconstructed data, a strong agreement was observed between the reconstructed and original signals, suggesting good performance of the reconstruction model. The small differences observed in the amplitude of some peaks may be attributed to the application of a low-pass filter following the artificial intelligence-based reconstruction process.



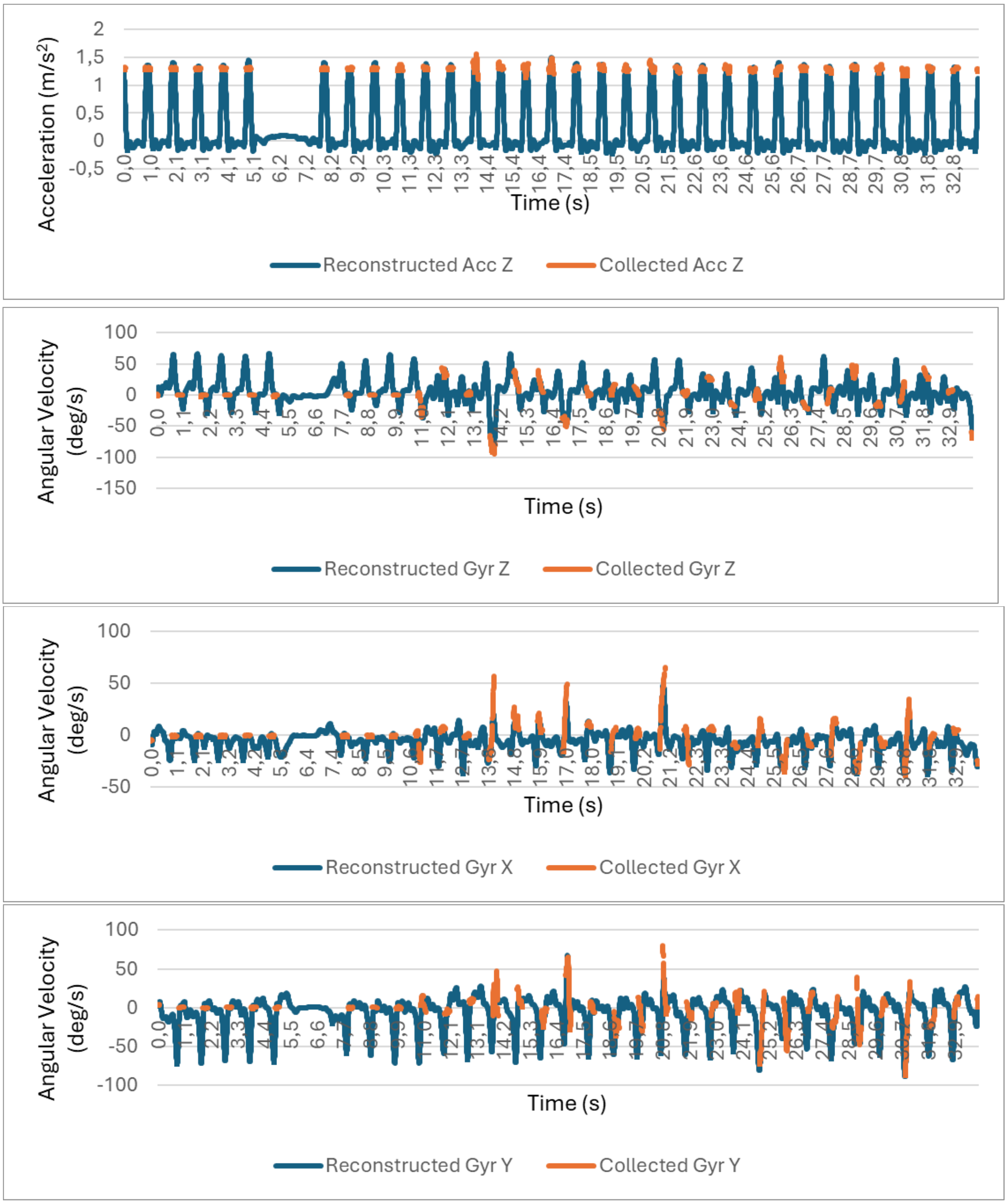


Figure 5 - Signal reconstructed of the 3D acceleration and gyroscope data for sit-to-stand test.

2.3.5.2.3. Results of the reconstruction of the 2-min walk test

In the gait exercise, the global model, evaluated using the leave-one-subject-out validation strategy, showed an overall moderate performance. The highest reconstruction errors were observed in the acceleration channels of the Y and Z axes. In contrast, angular velocity in the Y and Z axes showed more favorable results, with lower error magnitudes and metrics considered adequate for reconstruction purposes. These results are presented in greater detail in the following Table 12.

Table 12. Results of the global model of the 2-min walk test.

Variable	RMSE	MAE	Correlation Coef.	NRMSE
Acc X	0.19	0.13	0.09	11.97%
Acc Y	0.29	0.23	0.08	16.66%
Acc Z	0.21	0.19	0.07	28.41%
Gir X	22.35	17.63	0.05	15.88%
Gir Y	27.10	19.71	0.12	11.38%
Gir Z	35.65	27.00	0.12	18.33%

Regarding the subject-specific fine-tuned model (Table 13), substantially better results were observed compared to the global model. The highest reconstruction errors were recorded in the acceleration channels of the Z and Y axes. In contrast, angular velocity on the Z axis and acceleration on the X axis showed more satisfactory performance, with metrics considered acceptable for reconstruction purposes.

Table 13. Results of the subject-specific fine-tuned model of the 2-min walk test.

Variable	RMSE	MAE	Correlation Coef.	NRMSE
Acc X	0.09	0.06	0.70	9.95%
Acc Y	0.09	0.06	0.75	8.83%
Acc Z	0.05	0.03	0.60	11.68%
Gir X	7.33	5.17	0.75	11.37%
Gir Y	13.02	8.78	0.64	11.14%
Gir Z	10.42	7.38	0.83	9.55%

The Figure 6 comparison between the reconstructed acceleration and angular velocity signals and the original signals collected over time during the 2-Minute Walk Test. A high level of agreement was observed between the two signals, demonstrating the ability of the reconstruction model to accurately capture the temporal pattern of the movement. In this exercise, a substantial proportion of the signal consisted of reconstructed data, considerably exceeding the amount of originally recorded data. Despite this, the reconstructed signal remained highly consistent with the original signal, indicating good reconstruction performance. The small differences observed in the amplitude of some peaks may be attributed to the application of a low-pass filter following the artificial intelligence-based reconstruction process.

Figure 6 - Signal reconstructed for 3D acceleration and gyroscope data for 2-min walk test

2.3.5.3. Motor Coordination

The analysis was conducted based on the three anatomical planes of motion: sagittal, frontal, and transverse. The representative graphs depict the angular velocity of a joint as a function of that joint's angle, allowing for the assessment of the joint's coordination dynamics (Lamba, P. F & Bartlett, R. M., 2018). The interpretation focused on two key indicators: smoothness and dispersion, both of which are representative of the quality of intra-segmental motor coordination. Smoothness was interpreted as the oscillatory interaction between the agonist and antagonist muscles, reflecting the continuity and fluidity of movement. Dispersion, in contrast, was associated with the regularity of the motor pattern, the consistency of the movement trajectory, and the speed of movement execution (Lamba, P. F & Bartlett, R. M., 2018).

Frontal Plane

In the frontal plane, the results from the first assessment (top plots) revealed high dispersion and reduced movement smoothness across all tests performed. In contrast, during the second assessment (bottom plots), a trend toward greater movement organization was observed. Notably, the 2-min walk test was the only exercise to exhibit a smoother movement pattern with lower dispersion, suggesting an improvement in motor coordination within this plane of movement (Figure 7).

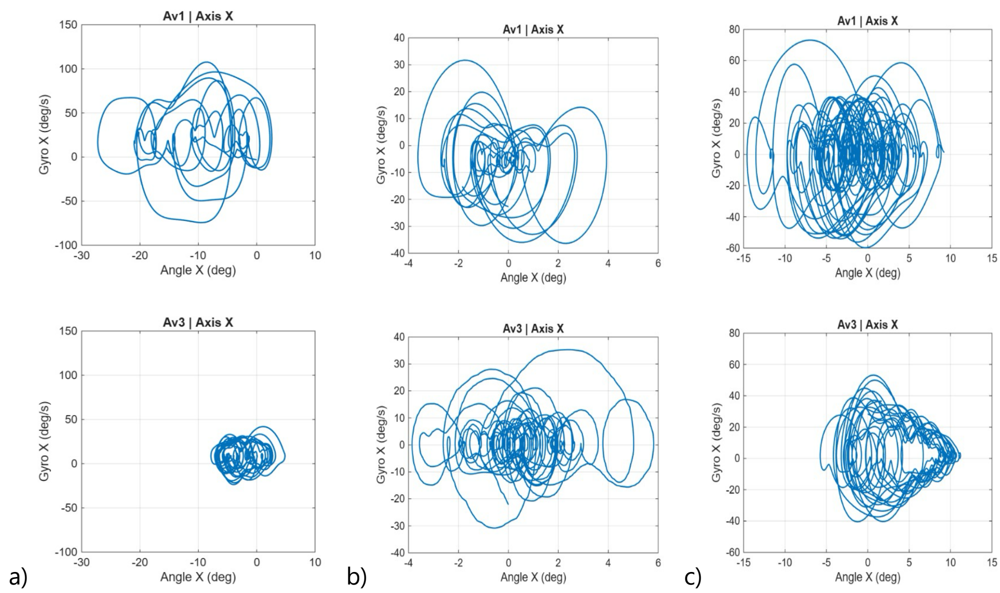


Figure 7 - Phase plots a): Frontal Plane the Bicep Curl Test. b): Frontal Plane the Sit-to-Stand Test. c) Frontal Plane the 2-min walk test.

Transverse Plane

In the transverse plane, the results from the first assessment showed reduced movement smoothness and high dispersion of the trajectories in the phase plots for the bicep curl, Sit-to-Stand Test, and 2-min walk test. In contrast, during the second assessment, an improvement in these parameters were observed. Notably, the Sit-to-Stand Test was the only exercise to exhibit a smoother movement pattern with lower dispersion, suggesting improved motor coordination within this plane of movement (Figure 8).

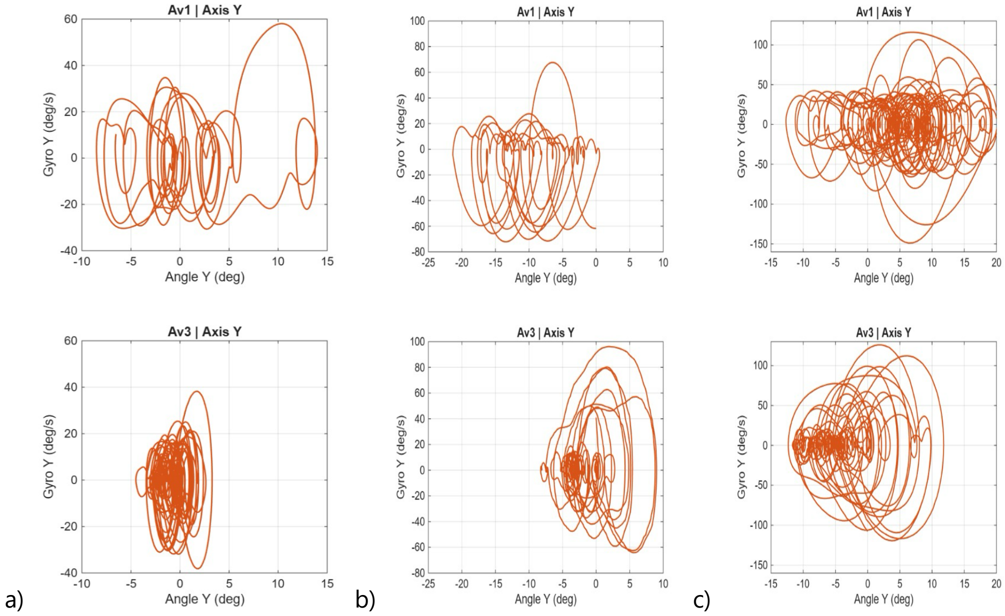


Figure 8 - Phase plots a): Transverse Plane the Bicep Curl Test. b): Transverse Plane the Sit-to-Sand Test. c): Transverse Plane the 2-min Walk Test.

<u>Sagittal Plane</u>

In the sagittal plane, the phase plots obtained during the first assessment revealed reduced movement smoothness and high dispersion of the trajectories across all tests performed. In contrast, during the second assessment, a more organized movement pattern was observed, characterized by greater smoothness and lower trajectory dispersion in all exercises. These findings suggest an overall improvement in motor coordination within this plane of movement (Figure 9).

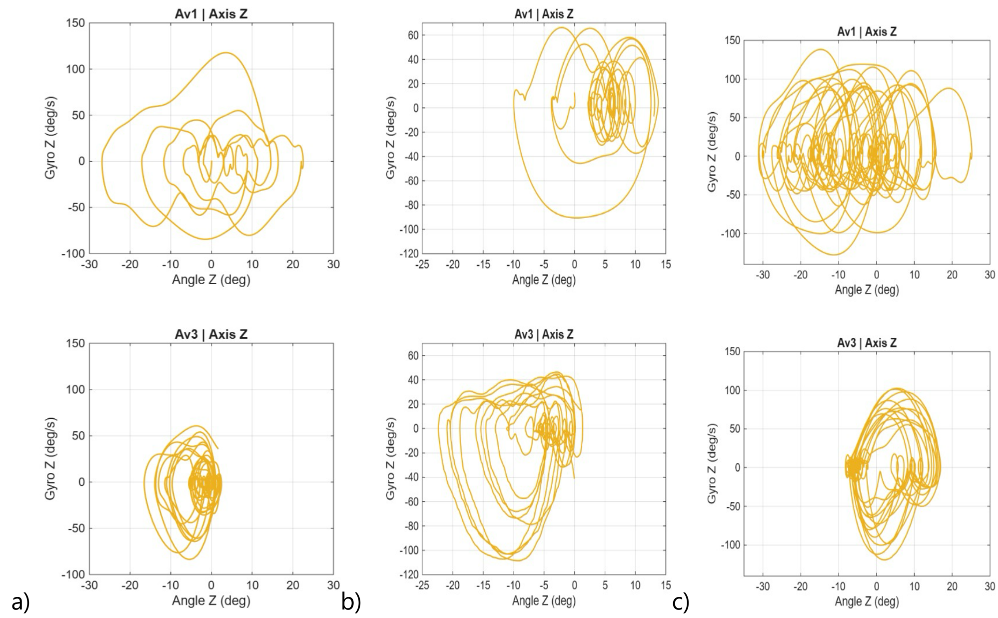


Figure 9 – Phase plots a): Sagittal Plane the Bicep Curl Test. b): Sagittal Plane the Sit-to-Stand Test. c): Sagittal Plane the 2-min Walk Test

2.3.6. Discussion

The main objective of the present study was to analyze the effects of Alzheimer's disease on motor function in older adults diagnosed with the condition. Regarding the results obtained, performance in the *Sit-to-Stand Test* remained unchanged between the two assessment points, with 10 repetitions completed in both evaluations. This finding suggests that lower-limb functional capacity remained stable throughout, with neither improvement nor deterioration being observed. However, considering the progressive nature of Alzheimer's disease, the maintenance of functional capacity over time may itself be regarded as a positive outcome. This pathology is associated with a progressive decline in cognitive abilities, functional capacity, and independence in activities of daily living (ADLs) (Serna-Orozco et al., 2025). Therefore, the absence of deterioration may indicate a potential protective effect of physical activity on motor function, which for this person her physical activity resumes to walking. In the *Seated 2.44-Meter Walk and Return Test*, a slight reduction in execution time was observed, decreasing from 16.95 to 16.91 seconds, suggesting a small improvement in walking speed, mobility, and functional agility. Although this difference is minimal and cannot be considered clinically meaningful, it may reflect a trend towards greater movement efficiency. The most notable result was observed in the *Bicep Curl Test*, in which the number of repetitions increased from 11 to 17. This finding suggests a possible improvement in upper-limb muscular strength and endurance. Resistance training is recognized as one of the most effective forms of physical activity for enhancing muscle function, promoting gains in strength, power, and muscular endurance (Lopez et al., 2021). With regard to flexibility, the results remained largely unchanged. In the *Sit-and-Reach Test*, no changes were observed, with a score of 0 cm recorded at both assessment points. Similarly, in the *Back Scratch Test*, only a marginal improvement was observed, with the score increasing from 34 cm to 35 cm. These findings may indicate that flexibility-related stimuli were insufficient within the participant’s exercise routine. Furthermore, flexibility is a physical capacity that tends to respond more slowly to training, particularly in very old adults and individuals with neurodegenerative diseases, who are frequently characterized by joint stiffness, postural alterations, and reduced range of motion (Gago et al., 2025). In the *2-Minute Step Test*, a slight decline in performance was observed, with the number of completed cycles decreasing from 49 to 47. This result may suggest a small reduction in cardiorespiratory fitness. However, performance in aerobic endurance tests may be influenced by several factors, including fatigue, motivation, daily clinical status, medication effects, and disease progression. Another important factor is the participant’s advanced age (86 years) and the presence of Alzheimer's disease at stages III/IV, which are often associated with reduced motivation, lower engagement in activities, and progressive functional decline. Consequently, maintaining overall physical performance throughout the assessment period may itself be considered a favorable outcome.

Regarding the results associated with the Artificial Intelligence model, the reconstruction models were able to successfully estimate missing data from the IMU signals. Across all exercises analyzed, the subject-specific fine-tuned model consistently outperformed the global model. This finding suggests that individualized machine learning approaches may be more effective in capturing the specific biomechanical characteristics of movements performed by older adults with neurodegenerative diseases. Furthermore, the comparison between reconstructed and original signals revealed a high level of agreement, supporting the reliability of the reconstruction process. These results point to another perspective, namely the usefulness of these trained AI/machine learning models, which relates to the possibility of exploring in greater detail the effects of both disease and/or physical exercise in different populations. This is because the introduction of subject-specific models into the AI model made it possible to highlight individual movement characteristics and enable movement reconstruction, in opposition to global models. Given the data used, there may be stemming variations based on the subject's condition or physical activity; however, it was still possible to reconstruct missing data with a high degree of consistency (correlation coefficient and NRMSE). This seems to reveal that there are subject-specific signatures embedded in the movements that can be detected and quantified by these AI methodologies, which should be considered in the future to detect the actual effects of diseases or physical exercise.

Finally, the analysis of intra-segmental coordination through phase plots revealed that the disease exhibited degenerative effects on motor coordination. According to the Constraints Theory proposed by Newell, (1986), motor coordination emerges from the continuous interaction between organism, task, and environmental constraints. Organism constraints correspond to the individual's inherent characteristics, such as somatotype, body weight, and height (Balagué et al., 2019; Newell, 1986). In Alzheimer's disease, these characteristics become progressively impaired due to memory loss, deficits in attention and orientation, motor decline, particularly gait disturbances, and impairments in executive functions (Andrade-Guerrero et al., 2024), as well as alterations in sensorimotor integration. Attention and executive functions play a fundamental role in safe walking, and their dysfunction has been identified as one of the main factors associated with early gait disturbances in individuals with Alzheimer's disease (S.-W. Kim et al., 2025). Environmental constraints refer to external characteristics that are beyond the individual's control, such as ambient temperature, natural lighting, and other contextual conditions (Newell, 1986). In this regard, the regular practice of walking in real-world environments, characterized by changes in direction, obstacles, interactions with other people, and different types of terrain, required continuous postural adjustments and movement adaptations. Consequently, these demands may explain the improvements observed in the frontal and transverse planes during tasks such as the 2-Minute Walk Test and the Sit-to-Stand Test. These continuous adaptations promoted greater recruitment of the stabilizing musculature and increased involvement of movements in the frontal and transverse planes, namely internal and external rotations, as well as abduction and adduction movements, respectively. Thus, repeated exposure to these demands may have facilitated motor adaptations and processes of self-organization within the motor system (Kelso, 1995), enabling the adoption of potentially more efficient movement strategies despite the limitations imposed by the disease. Nevertheless, improvements were also observed in the sagittal plane, not only during walking but also during the Sit-to-Stand and Bicep Curl tests. These improvements were evidenced by greater movement smoothness and reduced dispersion of the phase plot trajectories. These findings may also be related to the fact that walking and other functional movements predominantly involve flexion and extension movements, which are characteristic of this plane of motion. Therefore, the frequent repetition of these motor patterns may have contributed to a better organization of movement. As such, the demands imposed by the environment and by the regular practice of walking fit well within this category, as they represent external factors that modulate motor behavior. Task constraints correspond to the goals, rules, and specific demands of the activity being performed (Balagué et al., 2019; Newell, 1986). In Alzheimer's disease, gait is often impaired, as evidenced by reduced walking speed, increased double-support time (S.-W. Kim et al., 2025), and alterations in motor patterns. In this context, parameters such as gait speed, step length, and cadence (Lau et al., 2020) constitute important indicators of locomotor performance, reflecting how the individual responds to the demands of the task. In summary, Alzheimer's disease represents the primary organism constraint, environmental characteristics represent environmental constraints, and the demands inherent to the execution of the functional tests correspond to task constraints. The interaction among these three types of constraints helps explain the changes observed in motor coordination and movement patterns in the participant.

Overall, the findings allow for the partial acceptance of the hypotheses formulated at the beginning of the study. Concerning the second hypothesis, the results suggest that the machine learning model was sufficiently sensitive to detect the individual characteristics of the participant with Alzheimer's disease, as the subject-specific model consistently demonstrated superior performance compared with the global model. However, the findings do not support the hypothesis that Alzheimer's disease necessarily leads to a deterioration in motor function or impaired intra-segmental coordination over the assessment period considered in this study. Although the literature consistently reports that Alzheimer's disease is associated with progressive functional decline, no clear signs of motor deterioration were observed in this participant. On the contrary, performance was maintained across the tests included in the Senior Fitness Test battery, while indicators of motor coordination showed signs of improvement.

These findings suggest that, although Alzheimer's disease is a progressive neurodegenerative condition, regular participation in leisure physical activity may contribute to the preservation of motor function and movement coordination, even in the later stages of the disease.

2.3.7. Limitations

The present dissertation aims to investigate the benefits of physical exercise in individuals with neurodegenerative diseases, evaluating its impact on improving motor function, enhancing quality of life, and alleviating symptoms associated with these conditions. Additionally, the participant's clinical condition, characterized by the presence of a neurodegenerative disease and its corresponding stage of progression, may have influenced the individual response observed. It is also important to consider the participant's institutionalized living environment, as well as factors such as apathy, reduced motivation, difficulties in social interaction, and low adherence to activities, all of which may negatively affect engagement in and continuity of an active lifestyle (Mele et al., 2019). Furthermore, external factors, including medical appointments and family visits, may have contributed to interruptions in the participant's regular participation in physical activity, potentially affecting the consistency of the intervention and the outcomes observed. Given these limitations, future studies should include larger sample sizes and longer intervention periods. In addition, the implementation of structured exercise programs specifically tailored to older adults with neurodegenerative diseases may provide a more comprehensive understanding of the effects of physical activity on motor function, coordination, and overall functional capacity in this population.

3. General Discussion and Conclusions

3.1. Discussion

The present dissertation aimed to analyze the effects of physical exercise on motor function in older adults with neurodegenerative diseases, namely Alzheimer’s disease, Parkinson’s disease, and Multiple Sclerosis, as well as to understand the effect of Alzheimer’s disease on motor function. To achieve these objectives, three complementary studies were conducted, each contributing to a distinct stage of the research process. The first study, a systematic review (Chapter 2.1), provided the scientific foundation for the dissertation and synthesized the available scientific evidence regarding the effects of physical exercise in individuals with neurodegenerative diseases. The results demonstrated that, in Parkinson’s disease, multicomponent programs integrating aerobic exercise, strength training, balance training, and neuromotor training, performed predominantly two to five times per week with an average session duration of 45 to 60 minutes, represent the most frequently used approach and the one associated with the greatest benefits in mobility, balance, and quality of life. Regarding Alzheimer’s disease, despite the limited number of studies identified, programs based on dual-task motor-cognitive exercises performed regularly were found to enhance neural plasticity and improve functional capacity. On the other hand, the absence of eligible studies involving individuals with Multiple Sclerosis highlights a gap in the literature, reinforcing the need for future research in this population. Overall, these findings support physical exercise as an effective non-pharmacological strategy for preserving functional capacity and delaying the decline associated with the progression of neurodegenerative diseases.

Based on this evidence, the NeuroActive program (Chapter 2.2) was developed and validated to promote motor function in older adults with Alzheimer’s disease and Parkinson’s disease. The program, structured into four weekly sessions lasting 45 to 60 minutes, includes aerobic training, resistance training, and neuromotor training, in accordance with recommendations from the scientific literature. The multicomponent structure of the program, together with the recommendations provided by the expert panel, allowed the exercises to be adapted to the functional limitations and heterogeneity characteristic of these populations. Consequently, this study established a link between scientific evidence and professional practice by providing a structured, safe, and potentially applicable intervention for clinical, home-based, and community settings.

The third study (Chapter 2.3) complemented the previous studies by analyzing the motor function of a participant with advanced Alzheimer’s disease. Although this condition is characterized by a progressive decline in motor and cognitive abilities, the results of the *Senior Fitness Test* demonstrated the maintenance of motor function. However, the disease showed degenerative changes in motor coordination. These findings may be interpreted within the framework of the Dynamic Systems Theory and Newell’s Constraints Model (1986), according to which motor coordination emerges from the continuous interaction among organism, task, and environmental constraints. Despite the limitations imposed by Alzheimer’s disease, repeated exposure to functional tasks and regular physical activity may promote adaptation and self-organization of the motor system, enabling the adoption of more efficient movement strategies. These findings corroborate the evidence identified in the systematic review, reinforcing the importance of physical exercise as a means of attenuating disease progression. Furthermore, this dissertation highlights the potential of innovative methodologies for the assessment and monitoring of motor function through the use of inertial measurement units (IMUs) and artificial intelligence-based approaches, contributing to the development of more accurate monitoring strategies. In summary, the findings of the present dissertation address its overall objectives by demonstrating that physical exercise and/or physical activity constitute promising strategies for preserving motor function in older adults with neurodegenerative diseases. Furthermore, this dissertation contributes to the existing literature by integrating a multidisciplinary approach, bridging the gap between scientific research and clinical practice.

3.2. Implications for Professional Practice

The present dissertation has important implications for professional practice by providing scientific evidence, intervention strategies, and innovative assessment tools for working with older adults with neurodegenerative diseases. First, the findings of the systematic review highlight the importance of implementing structured physical exercise programs tailored to the individual needs of older adults with neurodegenerative diseases. In this context, exercise professionals can play a fundamental role in promoting functional independence, autonomy, and quality of life in this population. Building upon this evidence, the NeuroActive program represents a structured and evidence-based intervention specifically designed for older adults with Alzheimer's disease and Parkinson's disease. By integrating resistance training, cardiorespiratory training, balance exercises, and mobility exercises, the program offers a practical and multidisciplinary framework that can support exercise prescription in both clinical and community settings. Furthermore, the findings of the case study demonstrate the potential of inertial measurement units (IMUs) and artificial intelligence-based approaches as complementary tools for assessment and monitoring. Although their application in professional practice is still evolving, IMUs and artificial intelligence show considerable potential for monitoring participants' functional progression and contributing to the personalization of interventions.

Taken together, the findings suggest that combining evidence-based physical exercise programs, such as NeuroActive, with emerging assessment and monitoring technologies may enhance intervention effectiveness and promote more objective, individualized, and data-driven approaches to exercise prescription and supervision in older adults with neurodegenerative diseases.

3.3. Recommendations for Future Research

The recommendations presented below aim to guide future lines of research, contributing to the strengthening of the scientific evidence base and addressing the limitations identified throughout the present dissertation.

Based on the findings of the systematic review (Chapter 2.1), it is essential that future studies include larger and more representative samples, enabling subgroup analyses according to variables such as age, sex, type of neurodegenerative disease, and disease severity. Additionally, the adoption of standardized exercise protocols, accompanied by detailed descriptions of intervention characteristics, may facilitate study replication and the comparison of findings across investigations. The inclusion of follow-up assessments is also recommended to evaluate the sustainability of intervention effects over the medium and long term. Finally, there is a clear need for further research involving individuals with Multiple Sclerosis, as no eligible studies addressing this population were identified in the present review.

Regarding the development and validation of the NeuroActive program (Chapter 2.2), future research should focus on its implementation and evaluation of its effectiveness across different intervention settings. Furthermore, validation studies should involve a larger and more multidisciplinary panel of experts, including professionals from the fields of Medicine, Psychology, Neurology, and Exercise Science. The pilot-testing phase should also include participants at different stages of disease progression to ensure the program's applicability across varying levels of functional impairment.

With respect to the case study (Chapter 2.3), conducting longitudinal studies with larger samples is recommended to enable a more robust analysis of changes in motor function over time. In addition, more rigorous control of external factors and clinical disease progression should be ensured. Further research should also explore the integration of inertial measurement units (IMUs) and artificial intelligence-based approaches into physical exercise programs to evaluate their potential for monitoring motor function, assessing movement quality, and supporting personalized exercise prescription. These approaches may contribute to more objective assessments, as well as to the development of more individualized interventions tailored to the specific needs of each participant.

3.4. General Conclusion

The present dissertation made it possible to understand that neurodegenerative diseases have degenerative effects on motor function. However, the findings of the studies conducted suggest that both structured, formal exercise programs and moderate levels of physical activity may contribute to delaying the functional decline associated with disease progression. In this sense, physical exercise emerges as an effective strategy, supporting the principle advocated by the American College of Sports Medicine (ACSM, 2021) that "Exercise is Medicine." Although the implementation of the NeuroActive program was not feasible during the period in which the present study was conducted, the third study emerged from the dynamic system. Therefore, this dissertation not only addresses the Dynamic Systems Theory (Kelso, 1995) but also demonstrates it, as the study had to be continuously adapted to the context.

Overall, the findings support the adoption of multidisciplinary strategies enhanced by technology, with the potential to improve motor function, promote functional independence, and contribute to a better quality of life for older adults with neurodegenerative diseases.

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5. APPENDICES

Appendix I -Infographic

EFFECTS OF PHYSICAL EXERCISE on motor function

in older adults with Alzheimer´s Disease, Parkinson´s Disease, and Multiple Sclerosis

Systematic Review

1 OBJECTIVE

To evaluate the effects of physical exercise on motor function in older adults with Alzheimer's Disease (AD), Parkinson's Disease (PD), and Multiple Sclerosis (MS).

2 MEYHODS

Databases: PubMed, Web of Science, EBSCO
Search period: June and July 2025
Criteria (PICOS):

- **P: Older adults with AD, PD, and MS**
- **I: Physical exercise program**
- **C: Pre vs Post intervention**
- **O: Motor function**
- **S: RCTs and Clinical Trials**

3 RESULTS

Total articles: 14

DP:

- Improvement in cognitive and motor function, balance, gait, depression, and quality of life
- Integration of physical and cognitive components
- Frequency: 2–3 sessions per week
- Average duration: 40–60 minutes per session
- Total duration: 4 weeks to 1 year

DA:

- Only 1 study
- Motor-cognitive exercises (dual-task)
- Intervention started with 15-minute sessions, 5 times per week, progressing to 40 minutes, 4 times per week

MS:

- No eligible studies

4 LIMITATIONS

- High methodological heterogeneity among included studies
- Lack of standardization in intervention descriptions
- Small sample sizes
- Absence of studies related to MS

5 RECOMMENDATIONS

Future studies should include:

- Representative samples
- Well-defined and replicable protocols
- Targeted research focused on MS

Appendix II - Ethics Committee Approval of the Research Unit

POLITÉCNICO
DE SANTARÉM

PARECER

COMISSÃO DE ÉTICA DA UNIDADE DE INVESTIGAÇÃO DO IPSANTARÉM

EMISSÃO DE PARECER Nº30AB-2025ESDRM

Identificação do Investigador | Beatriz Rosa (ESDRM)

Identificação do Projeto | *Efeitos do Exercício Físico na Função Motora em doentes de Alzheimer e Parkinson: Estudo de intervenção longitudinal*

Constata-se que:

i. É um trabalho académico conferidor de grau de mestre.

ii. Apresenta fundamentação teórica, objetivos e a metodologia.

iii. O cronograma é esclarecedor quanto à calendarização das etapas do processo de investigação associado ao pedido.

iv. São cumpridas as condições de anonimato dos participantes.

v. No consentimento informado, livre e esclarecido:

   a. Recorre a uma linguagem acessível e compreensível para os participantes.
   b. Esclarece que os dados poderão ser usados para treinar programas de IA.
   c. Refere a existência de riscos mínimos para os participantes.
   d. Refere qual o tempo de posse dos dados até serem destruídos (5 anos). Inclusive esclarece quem será a pessoa responsável pela proteção dos dados.
   e. Inclui o logótipo institucional e da unidade orgânica.

Face ao exposto a Comissão de Ética emite parecer favorável porquanto nos documentos em apreciação são cumpridos todos os requisitos éticos.

Santarém, 14 de janeiro de 2026

Pedro Oliveira	Rafael Oliveira
(Coordenador)	(Subcoordenador)

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Appendix III- Informed Consent

POLITÉCNICO DE SANTARÉM
ESCOLA SUPERIOR DE DESPORTO DE RIO MAIOR

CONSENTIMENTO INFORMADO LIVRE E ESCLARECIDO PARA RECOLHA E UTILIZAÇÃO DE DADOS PESSOAIS EM INVESTIGAÇÃO

Enquadramento: Este estudo faz parte de um projeto de investigação desenvolvido no âmbito do Mestrado em Atividade Física e Saúde. O estudo é realizado pela estudante Beatriz Rosa, sob orientação do Professor Doutor Marco Branco, da Escola Superior de Desporto de Rio Maior – Instituto Politécnico de Santarém.

Explicação da investigação: A sua participação envolve a realização de um programa de exercício físico com cerca de 36 a 40 sessões, com duração aproximada de 45 a 60 minutos cada. Durante o estudo serão realizados testes simples para avaliar capacidades motoras como força, equilíbrio, flexibilidade, agilidade, resistência e coordenação. Serão também recolhidas algumas informações gerais, como idade e sexo.

Condições: A sua participação é voluntária. Pode desistir do estudo a qualquer momento, sem necessidade de justificar a sua decisão e sem qualquer prejuízo para si. Os riscos associados à participação são mínimos e semelhantes aos da prática habitual de exercício físico. Poderá sentir algum cansaço, fadiga ou ligeiro desconforto muscular, que são temporários.

Confidencialidade e utilização dos dados: Os dados recolhidos serão tratados de forma confidencial e codificada, garantindo o anonimato dos participantes. Os dados serão utilizados exclusivamente para fins de investigação científica. Poderão também ser utilizados, de forma anónima, para o desenvolvimento, treino e validação de programas de inteligência artificial (IA). Os dados serão conservados por um período máximo de 5 anos, após o qual serão eliminados.

Responsável pela proteção dos dados: O responsável pelo tratamento e proteção dos dados pessoais é a estudante Beatriz Rosa sob supervisão do orientador, podendo ambos serem contactados através do seu endereço institucional.

Declaração de consentimento: Declaro que li e compreendi as informações apresentadas. Foi-me dada a oportunidade de colocar questões e esclarecimentos. Aceito participar neste estudo e autorizo a recolha e utilização dos meus dados, nos termos acima descritos.

Investigador responsável

Assinatura:____ Data: ___/___/___

Participante do estudo

Assinatura:____ Data: ___/___/___

Este documento é composto por 1 página e elaborado em duplicado, uma via para o investigador e outra para a pessoa que consente.

Contactos:
Marco Branco, marcobranco@esdrm.ipsantarem.pt
Beatriz Rosa, 210500280@esdrm.ipsantarem.pt

NeuroActive

Activating the mind, body and autonomy

Physical Exercise Program for Older Adults with Alzheimer’s or Parkinson’s Disease

Beatriz Rosa

Marco Branco

GENERAL INDEX

LIST OF TABLES

NEUROACTIVE

Population aging has been increasing significantly, becoming one of the main current challenges for promoting health and quality of life among older adults. Regular physical exercise, combined with cognitive stimulation, has demonstrated proven benefits in maintaining functional autonomy, preventing functional and cognitive decline, and improving overall well-being.

However, the lack of structured and integrated programs adapted to the specific needs of this population may compromise the effectiveness of existing interventions.

In this context, the NeuroActive project emerges as a multidimensional response that combines physical exercise and cognitive stimulation, implemented in a residential care home. The intervention was designed, developed, and validated by specialized professionals, with the main objective of promoting functionality, autonomy, and well-being among older adults, contributing to more active and healthier aging.

EXERCISE IN OLDER ADULTS WITH ALZHEIMER'S OR PARKINSON'S DISEASE

Physical exercise refers to any type of planned, structured, and repetitive physical activity aimed at improving and/or maintaining physical fitness. This is defined as the ability to perform daily tasks with vigor and energy, without excessive fatigue (ACSM, 2021).

Recognizing the benefits of exercise, together with identifying appropriate types of physical activities for older adults, is essential to increase awareness and encourage physical activity in this population. Such encouragement can lead to a longer, healthier, and more active life. Considering the increased complexity of healthcare resulting from additional functional decline, older adults require specialized attention (Suryadi et al., 2024). Aging often results in a reduction in skeletal muscle mass, strength, and functional capacity, which reinforces the need for targeted exercise interventions to achieve these outcomes (Suryadi et al., 2024). This process is further aggravated by lifestyle factors, which increase the incidence of hypertension and contribute to a rise in degenerative diseases. The importance of physical activity goes beyond disease prevention. Studies highlight the role of exercise in improving health, increasing functional capacity, slowing the aging process, and delaying age-related decline. Thus, physical exercise is presented as a multifaceted approach to addressing the health challenges of the elderly population, reinforcing its relevance in building a healthier and more active community. Activities such as walking, cycling, practicing gymnastics, and/or yoga have proven beneficial, improving muscle strength, maintaining balance, and promoting cardiovascular health. Additionally, strength training, even with light loads, plays a key role in preventing sarcopenia (Suryadi et al., 2024).

Physical activity also has a positive influence on the mental well-being of older adults. Engaging in exercise can reduce the risk of depression, improve mood, and enhance cognition and brain function (Suryadi et al., 2024). As they age, many older adults develop a fear of falling, either due to a previous history or even without ever having experienced a fall. In this context, resistance training contributes to improvements in the sensory system, which consequently promotes greater stability, thereby improving balance and helping to reduce the number of falls (Pontedeira, 2022). Structured physical activity can benefit older adults at different stages of Alzheimer's disease (AD). In moderate stages, it helps maintain functional capacity; in advanced stages, fall prevention becomes particularly important. Thus, strength, endurance, and balance training—whether performed in combination or individually—have shown benefits for symptoms associated with AD (Adzhar et al., 2022).

Aerobic Training

(Johansson et al., 2022) demonstrated that aerobic exercise reduced overall brain atrophy and improved cognitive control, although it did not influence the integrity of substantia nigra tissue or localized gray matter volume. Specifically, it increased functional connectivity between the right dorsolateral prefrontal cortex and the right frontoparietal network, with greater increases in this connectivity being associated with improvements in physical fitness. Overall, these results suggest that aerobic exercise stimulates functional and structural neuroplasticity in motor and cognitive brain networks in Parkinson’s disease (PD).

Resistance Training

With aging, older adults lose muscle mass and power, which negatively affects physical performance. Resistance training is therefore essential to delay sarcopenia, promote strength gains, increase muscle contraction speed, and improve power. In addition, it helps reduce difficulty in performing daily tasks, increases energy expenditure, and improves body composition. It also has positive effects on insulin sensitivity, glycemic control, mitochondrial function, and cardiorespiratory capacity (Pontedeira, 2022). Another important aspect is falling prevention. Resistance training contributes to improvements in the sensory system, which in turn enhances postural stability and reduces the risk of falls (Pontedeira, 2022).

(Panza et al., 2018) conducted a meta-analysis and found that aerobic physical training interventions had a moderately favorable effect on cognitive function. On the other hand, training programs that combined aerobic and resistance exercises showed a small and non-significant effect. Additionally, improvements in cognitive function were greater in samples with higher adherence to the interventions—that is, among participants who attended exercise sessions more frequently.

Neuromotor Training

The risk of falls is higher in older adults with a reduced ability to generate strength in the lower limbs and greater accumulation of intramuscular adipose tissue in the hip adductors, factors that compromise gait stability and balance. Therefore, neuromotor training plays a crucial role in reducing this risk (Pontedeira, 2022).

(Öhman et al., 2016) analyzed the effects of an exercise program in older adults with dementia and found that participants with mild dementia experienced, on average, 1.24 falls per person per year in the intervention group, compared to 1.84 in the control group. Among participants with advanced dementia, the program reduced the risk of falling by half: 1.78 falls per person per year in the intervention group versus 3.76 in the control group.

EQUIPMENT

The NeuroActive program was designed to require simple and easily accessible material resources, allowing its implementation in different institutional contexts with low cost and high practicality.

For the sessions, only the following materials are required:

i. Speaker, for musical support and auditory stimulation;
ii. Balls of different sizes, suitable for various types of exercises and difficulty levels;
iii. Towel, used as support in mobility and resistance exercises, as well as for personal protection;
iv. Elastic bands, intended for strength and flexibility training;
v. Ankle weights, used to intensify lower limb muscle work.

Participants should wear appropriate, comfortable, and safe sports clothing and footwear to ensure efficient and safe practice of the proposed activities.

The indoor space designated for the sessions should have a non-slip floor and appropriate ventilation and acoustic conditions, ensuring a safe and functional environment.

Additionally, for the implementation of the functional assessment protocol based on the test battery (Rickli & Jones, 2013), the following materials were required: a stopwatch, a measuring tape 45 centimeters in length, a tape or cord, a chair with a backrest approximately 43 cm in height, dumbbells weighing 2.77 kilograms and 3.63 kilograms, and two inertial sensors of the MEMS type (TDK, TDK InvenSense, ICM-20948 9-Axis, Tokyo, Japan).

THE EXERCISE PROGRAM

Contextualization

The NeuroActive program was implemented in an institutional setting, specifically in a residential care home, and conducted by a professional with a degree in Sport, Physical Conditioning, and Health from the School of Sport of Rio Maior, currently pursuing advanced studies in Physical Activity and Health. The physical exercise program was designed to be delivered in a group setting, with in-person sessions lasting 45 to 60 minutes and a weekly frequency of four sessions. The main objective of the program is to optimize and preserve participants' motor function, while simultaneously promoting functional autonomy, motor coordination, and overall well-being. In this way, it aims to contribute to the maintenance of physical capacities and the improvement of quality of life in these populations.

Session Structure

Each NeuroActive session consisted of three main phases:

a) warm-up;
b) main phase;
c) cool-down and stretching.

The methodological structure of the session included the following components:

1. SESSION OPENING

ENGAGEMENT (2–3 minutes)

Objective: To promote behavioral, motivational, and organizational preparation for the session. This included:

- Creating a relaxed, motivating, and welcoming environment;
- Encouraging integration and active participation of older adults;
- Reinforcing guidelines regarding intensity control, safety, and hydration;
- Recording attendance and checking the general condition of participants.

2. WARM-UP

ACTIVATION EXERCISES (5–10 minutes)

Objective: to prepare the body for exertion, promoting a gradual transition from rest to exercise. This phase included:

- Body awareness exercises, promoting posture and segmental alignment;
- Breathing exercises, stimulating respiratory control;
- Joint mobilization through smooth, wide movements of the main joints;
- Gradual increase in body temperature and joint range of motion, preparing muscles and tendons for subsequent effort.

3. MAIN PHASE

A) CARDIOVASCULAR COMPONENT (20 minutes)

Objective: to improve cardiorespiratory capacity through rhythmic, continuous, and moderate-intensity activities.

B) RESISTANCE COMPONENT (20 minutes)

- Resistance strength exercises (10 minutes)
    - Focus on strengthening large muscle groups, using equipment;
- Neuromotor exercises (10 minutes)
    - Integration of coordination, balance, agility, and dual-task activities, combining physical movements with cognitive stimuli for greater neuromuscular integration.

4. COOL-DOWN AND STRETCHING

A) STRETCHING (5 minutes)

Objective: To promote recovery and relaxation after exertion.

Includes:

- Stretching of the main muscle groups exercised during the session;
- Breathing and relaxation exercises;
- A reflective moment to reinforce the importance of physical exercise in maintaining quality of life and functional autonomy.

B) SESSION CLOSURE

This final moment was intended to strengthen the social and motivational bond among participants and to organize the equipment used.

Periodization

General Objectives

- Improve and/or maintain muscle strength, locomotion, balance, and cardiorespiratory endurance, contributing to participants' functional autonomy and quality of life.

The training sessions of the NeuroActive program were structured according to a periodization organized into mesocycles, based on specific and progressive objectives, ensuring a gradual and safe adaptation of participants, as illustrated in Table 1.

The intervention plan was divided into three mesocycles, as follows:

- 1st Mesocycle: first 4 weeks;
- 2nd Mesocycle: first 3 weeks;
- 3rd Mesocycle: first 3 weeks.

Table 1 - Mesocycle objectives

	1st Mesocycle	2nd Mesocycle	3rd Mesocycle
Duration	4 weeks	3 weeks	3 weeks
Objectives	Postural awareness: □ Understanding the positioning of body segments; □ How to activate deep muscles; □ Activation consistent with agonist muscles; • Inter- and intramuscular coordination: understanding what and how to stabilize to ensure safe movement and more efficient execution; • Range of motion: performing movements at maximum amplitude safely; • Breathing: maintaining constant breathing throughout exercises, avoiding the Valsalva maneuver whenever possible, and correctly coordinating inhalation and exhalation phases with movement; • Technical mastery of fundamental aspects: execution technique does not need to be perfect at this stage, but it is essential to ensure a level of execution	• All objectives from the previous microcycle should continue to be addressed in this mesocycle; • Good stabilization ability when performing basic exercises with a reduced base of support or a reduced number of support points; • In terms of technique, the objectives remain the same but at a higher level, particularly with increased balance challenges.	• All objectives from the previous microcycle should continue to be addressed in this mesocycle; • Development of muscular endurance strength.

	and minimum intensity to guarantee safety and effectiveness in achieving exercise goals; • Development of work habits: □ Hydration and hygiene habits (towel, clean clothing); • Safe execution: □ Safe use of equipment (dumbbells, etc.); □ Proper posture in different positions (standing, quadruped, prone, etc.); □ Correct execution technique of basic exercises; □ Breathing; □ Association of the exercise with its name.		

Training Sessions

1st Mesocycle (4 weeks)

Table 2 - Specific objectives for Mesocycle 1

<table>
<tr><th colspan="4">1st Week</th><th colspan="4">2nd Week</th><th colspan="4">3rd Week</th><th colspan="4">4th Week</th></tr>
<tr><td>1</td><td>2</td><td>3</td><td>4</td><td>1</td><td>2</td><td>3</td><td>4</td><td>1</td><td>2</td><td>3</td><td>4</td><td>1</td><td>2</td><td>3</td><td>4</td></tr>
<tr><td colspan="4">Develop mobility with stretching, body awareness, and stimulate breathing patterns.</td><td colspan="4">Develop joint mobility, inter- and intramuscular coordination, and enhance control of materials.</td><td colspan="4">Develop functional mobility, improve control of materials, and muscular dexterity.</td><td colspan="4">Develop functional mobility, improve control of materials, and muscular dexterity</td></tr>
<tr><td colspan="2">Equipament</td><td colspan="2">No equipament</td><td colspan="2">Equipament</td><td colspan="2">Ball</td><td colspan="2">Equipament</td><td colspan="2">Towel</td><td colspan="2">Equipament</td><td colspan="2">Resistance Band</td></tr>
</table>

<u>Type of Exercises:</u>

General Recommendations:

Body awareness exercises: 3 to 4 per class – decrease throughout the mesocycle

Basic exercises: 4 to 8 per class – increase throughout the mesocycle

Microcycles:

- Microcycle 1 and 2 – Postural awareness exercises (3 to 4 exercises); Basic exercises (4 to 6 exercises)
- Microcycle 3 and 4 – Postural awareness exercises (2 to 3 exercises); Basic exercises (6 to 8 exercises)

Exercise Organization:

General Recommendations:

- Postural awareness exercises should precede a basic exercise.
- Untrained students have low endurance, and fatigue will interfere with proper technique. Therefore, in this initial subphase, we should reduce class intensity, allowing greater muscle recovery time through exercise organization. This can be done in three ways:
    - For unilateral exercises, alternate the limb/side between sets;
    - For extremely untrained students, consider organizing sets in a circuit format;
    - Alternation of Body Segments
- In this phase, where the focus should be on technique and posture, the work performed must allow for muscular adaptation, and progression should aim to safely reach the minimum recommended limits for resistance training according to the guidelines.

Microcycles:

- Microcycle 1 and 2 – Circuit sets
- Microcycle 3 – Consecutive sets, but for unilateral exercises, sets are alternated
- Microcycle 4 – Consecutive sets, regardless of whether exercises are unilateral or not

Intensity:

General Recommendations: 40–50% of 1RM

Microcycles:

- Microcycles 1 to 4: 40–50% of 1RM

Number of Sets:

General Recommendations: 1 to 3 per exercise

1 Set:

- Postural awareness exercises
- Unilateral exercises

2 Sets:

- Basic exercises
- Unilateral exercises

3 Sets:

- Exceptional situations where the number of repetitions or isometric work time is extremely low.

Microcycles:

Microcycle 1 to 2: 1 set (body awareness exercises, unilateral exercises); 2 sets (basic exercises); 3 sets (exceptional situations)

Microcycle 3 to 4: 1 set (body awareness exercises); 2 sets (unilateral exercises, basic exercises); 3 sets (exceptional situations)

<u>Number of Repetitions:</u>

General Recommendations: 10 to 15 reps

Microcycles:

- Microcycle 1 to 4: 10 to 15 reps

<u>Rest Time Between Exercises:</u>

General Recommendations: 1 to 2 minutes

Note: General recommendations apply equally to all microcycles.

Microcycle 1 - Session 1

Engagement:

1 A) Introduction Activity (only in Session 1 of Microcycle 1)

Warm-up:

1 B) Joint Mobility and Breathing

Main Part:

2A) Cardiovascular Component

2B) Upper Limb Resistance Component

2C) Lower Limb Resistance Component

Cool-Down and Stretching

3A) Stretching and Relaxation

Table 3 - Session1 of Microcycle 1, Mesocycle 2

PHASE	EXERCISE	FUNCTIONAL MOVEMENT
1 a.	Introduction activity	Introduction of the instructor – name, where they are from Participants introduce themselves – passing a ball and saying: name, age, where they are from Session presentation – how it will work, objectives, and importance of attendance
1 b.	1.Breathing	Hands on the belly: inhale and exhale Thoracic expansion and breathing through the nose (like smelling a flower) Open arms while inhaling and bring arms together while exhaling
	2. Fingers and hands	Flexion and extension Abduction and adduction
	3. Cervical (neck)	Flexion, rotation, and lateral inclination of the head
	4. Shoulders	Elevation and depression of shoulders and scapula External rotation of the shoulders
	5. Trunk	Lean back and return from the chair Spinal flexion and extension
	6. Knees	Unilateral extension and flexion
	7. Ankle (tibiotarsal)	Dorsiflexion and plantar flexion Weight distribution and foot alignment
2 a.	8. Walking in the courtyard	With walker support, for 20 minutes (divided into 5-minute blocks with 1-minute rest)
2 b.	9.Unilateral raise	10–15 reps right side and 10–15 reps left side
	10. Elbow flexion and extension	10–15 reps right side and 10–15 reps left side

	11. Horizontal abduction and adduction	10 - 15 reps
2 c.	12. Knee extension	10–15 reps right side and 10–15 reps left side
	13. Kness flexion	10–15 reps right side and 10–15 reps left side
	14. Abduction and adduction	10–15 reps right side and 10–15 reps left side
	15. Seated marching	Lift feet off the ground
3a.	16. Lower limbs	Stretching of hamstrings, quadriceps, and calves
	17. Upper limbs	Stretching of biceps and chest
	18. Trunk	Roll the back forward and retur

2nd Mesocycle (3 weeks)

Table 4 - Specific objectives of Mesocycle 2

1st Week				2nd Week				3rd Week			
1	2	3	4	1	2	3	4	1	2	3	4
Strengthen basic motor coordination patterns, stimulate static and dynamic balance, and introduce simple dual-task activities.				Work on dynamic balance in different directions, intensify dual-task exercises, and stimulate functional agility through adapted circuits.				Consolidate gains in coordination and balance, integrate more demanding dual-task exercises, promote transfer to activities of daily living, and foster autonomy and confidence.			
Equipament		No equipament		Equipament		No equipament		Equipament		No equipament	

Type of Exercise:

General Recommendations:

- Body awareness exercises: 3 to 4 per class
- Basic exercises: 6 to 10
- Introduction of basic exercises with a reduced base of support or reduced number: 2 to 3 to 6–8 exercises – start with fewer and gradually increase throughout the mesocycle

Microcycles:

- Microcycle 1 and 2 – More technical body awareness exercises (1 exercise); Basic exercises (6 to 8 exercises, of which 2 to 3 are with reduced base of support)
- Microcycle 3 – Basic exercises (8 to 10 exercises, of which 3 to 6 are with reduced base of support)

Exercise Organization:

General Recommendations:

For exercises introducing instability, it is recommended:

- That they are distributed throughout the class;
- Adjust the organization of exercises to allow more recovery time if the introduction of instability proves too demanding (in this case, follow the recommendations from the initial mesocycles of the TEB);
- In an initial phase, alternate instability exercises with the others;

- In the final phase of the mesocycle, consecutive instability exercises may be performed, considering that:
    - It is possible to maintain the distribution of instability exercises throughout the class;
    - Consecutive exercises targeting the same instability position should be avoided in case of joint pain or discomfort.

Microcycles:

Microcycle 1 to 3 – Distributed throughout the class (groups of 2 to 3 instability exercises interspersed with other exercises in Microcycles 1 and 2; groups of 3 to 5 instability exercises interspersed with other exercises in Microcycle 3)

<u>Intensity:</u>

General Recommendations: N/A

<u>Number of Sets:</u>

General Recommendations: 2 to 3 sets in total, and 1 to 3 sets specifically for instability exercises

Total Sets per Exercise:

2 Sets: Preferred option

3 Sets:

- Exceptional situations where the intensity from introducing instability requires reducing the duration of each set;
- Large muscle groups performing instability exercises at the end of the mesocycle, to increase instability work time;
- Avoid for unilateral exercises due to time demands and potential monotony.

Total Sets of Instability:

1 Set:

- In an initial adaptation phase, only the first set may be performed;
- In bilateral exercises where instability is unilateral.

2 Sets:

- Two sets can be used in the early phase of this mesocycle if the introduction of instability represents low complexity and/or intensity;
- Each set can be performed at a different level of instability. In this case, it is suggested that the 1st set uses a lower complexity level, and the 2nd set increases in complexity.

3 Sets:

- Large muscle groups performing instability exercises at the end of the mesocycle, to increase instability work time;
- Not recommended for unilateral exercises due to time demands (would imply a total of 6 sets, 3 for each side);
- Not recommended for bilateral exercises with unilateral instability (would imply a total of 6 sets for the muscle group worked bilaterally).

Microcycles:

- Microcycle 1 to 2 – 2 sets in total; 1 set of instability
- Microcycle 3 – 2 sets in total; 2 sets of instability

<u>Number of Repetitions:</u>

General Recommendations: More than 12 reps to achieve results in muscular endurance.

Total Repetitions per Set:

- Whenever possible, continue the previous microcycle in terms of both number of repetitions and work duration;
- The number of repetitions or duration should be reduced whenever intensity is increased by manipulating other variables (e.g., introduction of instability, increase in the number of sets) to ensure gradual progression.

<u>Total Repetitions in Instability (per set):</u>

Instability can be applied throughout the set or only in part of it, following this suggested progression:

- Introduce low/medium-level instability only in the last repetitions of the set;
- Perform the entire set with low/medium-level instability;
- Perform the first repetitions of the set with low/medium-level instability and increase the level in subsequent repetitions;
- Perform the entire set with medium/high-level instability.

Microcycles:

- Microcycle 1 – 1st set: introduce low/medium-level instability only in the last repetitions of the set
- Microcycle 2 to 3 – 1st set: no instability; 2nd set: perform the entire set with low/medium-level instability

Rest Time Between Exercises:

General Recommendations: 1 to 2 minutes

Note: General recommendations apply equally to all microcycles.

Microcycle 1 – Session 1

Engagement:

1A) Introduction Activity (only in Session 1 of Microcycle 1)

Warm-up:

1B) Joint Mobility and Breathing

Main Part:

2A) Cardiovascular Component

2B) Upper Limb Resistance Component

2C) Lower Limb Resistance Component

Cool-Down and Stretching:

3A) Stretching and Relaxation

Table 5 - Sessions 1 of Microcycle 1, Mesocycle 2

PHASE	EXERCISE	FUNCTIONAL MOVEMENT
1 a.	Introduction activity	
1 b.	1.Breathing	Hands on the belly: inhale and exhale Thoracic expansion and breathing through the nose (like smelling a flower) Open arms while inhaling and bring arms together while exhaling
	2. Fingers and hands	Flexion and extension Abduction and adduction
	3. Cervical (neck)	Flexion, rotation, and lateral inclination of the head
	4. Shoulders	Elevation and depression of shoulders and scapula External rotation of the shoulders
	5. Trunk	Lean back and return from the chair Spinal flexion and extension
	6. Knees	Unilateral extension and flexion
	7. Ankle (tibiotarsal)	Dorsiflexion and plantar flexion Weight distribution and foot alignment
2 a.	8. Low step up and down	Slowly and steadily, with side support, for 20 minutes (divided into 5-minute blocks)
2 b.	9. Arm and leg coordination (Touch your right hand to your left knee and vice versa)	12 or more reps; 2 sets
	10. Chair support with shoulder tap	12 or more reps; 2 sets
2 c.	11. Sit to stand from the chair	12 or more reps; 2 sets
	12. Standing single-leg weight transfer	30 seconds ; 2 sets
	13. Standing march in place	30 seconds ; 2 sets

	14. Dual task (During the march, say the names of fruits/colors)	30 seconds ; 2 sets
3a.	15. Lower limbs	Stretching of hamstrings, quadriceps, and calves
	16. Upper limbs	Stretching of biceps and chest
	17. Trunk	Roll the back forward and retur

3rd Mesocycle (3 weeks)

Table 6 - Specific objectives of Mesocycle 2

<table>
<tr><th colspan="4">1st Week</th><th colspan="4">2nd Week</th><th colspan="4">3rd Week</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th><th>1</th><th>2</th><th>3</th><th>4</th><th>1</th><th>2</th><th>3</th><th>4</th></tr>
<tr><td colspan="4">Enhance functional movements for the upper and lower limbs, and strengthen muscles.</td><td colspan="4">Enhance functional movements for the upper and lower limbs, strengthen muscles, and improve motor coordination.</td><td colspan="4">Functional exercises: pulling, pushing, lifting</td></tr>
<tr><td colspan="2">Equipament</td><td colspan="2">Ball/ resistance band</td><td colspan="2">Equipament</td><td colspan="2">Dumbbells</td><td colspan="2">Equipament</td><td colspan="2">Dumbbells/ball/resistence band</td></tr>
</table>

Type of Exercises:

General Recommendations:

- Number of basic exercises: 6 to 10
- Exercises should provide balanced work across all muscle groups

Microcycles:

- Microcycle 1 – Basic exercises (6–8 exercises)
- Microcycle 2 to 3 – Basic exercises (8–10 exercises)

Exercise Organization:

General Recommendations:

- Agonist–Antagonist Supersets
- Agonist–Antagonist
- Pre-Fatigue
- Consecutive exercises (for the same muscle group)
- Agonist–Agonist Supersets

Microcycles:

- Microcycle 1 – Alternation of body segments
- Microcycle 2 to 3 – By body segment (agonist–antagonist; agonist–synergist)

Intensity:

General Recommendations: Light intensity for beginners (30–60% 1RM), progressing to moderate to vigorous intensity (60–70% 1RM)

Microcycles:

- Microcycle 1 to 2: 30–60% 1RM
- Microcycle 3: 60–70% 1RM

Number of Sets:

General Recommendations:

- For beginners: 1 to 3 sets

Microcycles:

- Microcycle 1 and 2: 1 set
- Microcycle 3: 2 to 3 sets

Number of Repetitions:

General Recommendations:

- 8 to 12 repetitions
- The number of repetitions should allow completion of the set within the intended intensity range for this mesocycle, meaning:
  - Repetitions or work duration do not need to be identical for all exercises;
  - For large muscle groups, more repetitions may be necessary to reach the goal.

Microcycles:

- Microcycle 1 to 3: 8 to 12 repetitions

Rest Time Between Exercises:

General Recommendations: 1 to 2 minutes

Note: General recommendations apply equally to all microcycles.

Microcycle 1 – Session 1

Warm-up:

1B) Joint Mobility and Breathing

Main Part:

2A) Cardiovascular Component

2B) Upper Limb Resistance Component

2C) Lower Limb Resistance Component

Cool-Down and Stretching:

3A) Stretching and Relaxation

Table 7 - Session 1 of Microcycle 1, Mesocycle 3

PHASE	EXERCISE	FUNCTIONAL MOVEMENT
1 a.	Introduction activity	
1 b.	1.Breathing	Hands on the belly: inhale and exhale Thoracic expansion and breathing through the nose (like smelling a flower) Open arms while inhaling and bring arms together while exhaling
	2. Fingers and hands	Flexion and extension Abduction and adduction
	3. Cervical (neck)	Flexion, rotation, and lateral inclination of the head
	4. Shoulders	Elevation and depression of shoulders and scapula External rotation of the shoulders
	5. Trunk	Lean back and return from the chair Spinal flexion and extension
	6. Knees	Unilateral extension and flexion
	7. Ankle (tibiotarsal)	Dorsiflexion and plantar flexion Weight distribution and foot alignment
2 a.	8. Walking the yard	With walker support, for 20 minutes (divided into 5-minute blocks with 1-minute rest).
2 a.	9. Chest Press	8 - 12 reps
	10. Low Row	8 - 12 reps
	11. Bicep Curl	8–12 reps right arm and 8–12 reps left arm; 2 sets

	12. Tricep Dips	8-12 reps; 2 sets
	13. Shoulder Press	8-12 reps; 2 sets
2 b.	14. Sit to stand from chair	8-12 reps; 2 sets
	15. Heel raises	8-12 reps; 2 sets
	16. Hip abduction and adduction	8-12 reps; 2 sets
3a.	17. Lower limbs	Stretching of hamstrings, quadriceps, and calves
	18. Upper limbs	Stretching of biceps and chest
	19. Trunk	Roll the back forward and retur

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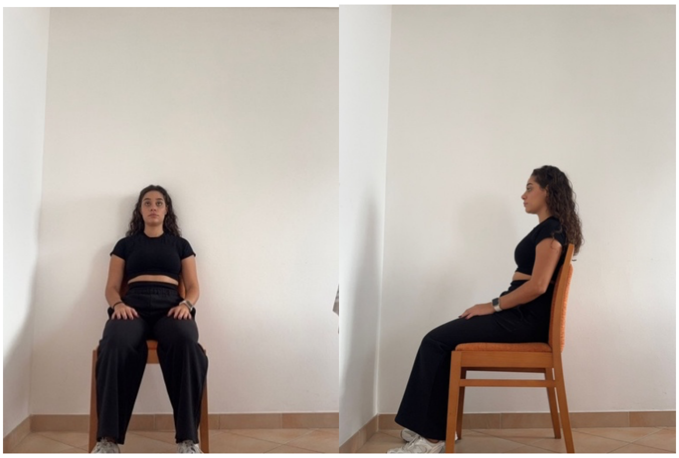
APPENDICES

Exercise Description

Alignment and stability in the neutral

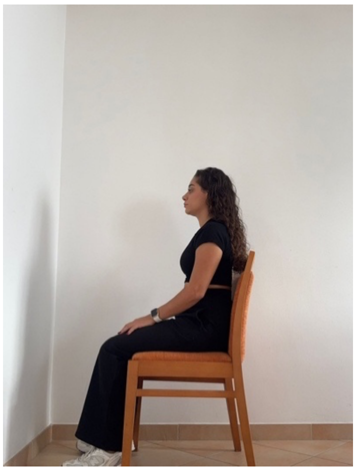


Objectives	Alignment and stability in the neutral trunk position
Main Muscles	Muscles of the common mass, abdominal wall
Movement	Maintain the trunk in a neutral position, with the hands resting on the seat of the chair. Perform anterior trunk tilt, keeping alignment with the pelvis and moving away from the backrest of the chair. Identify core activation and support points as a basis for initiating and sustaining the movement.
Critical Points	Foot positioning on the floor and the distance from the backrest of the chair should allow freedom of movement. Lifting the feet off the floor to generate movement. Excessive anterior tilt of the body.
Variations	In cases of balance or strength deficits, the individual may maintain contact with the backrest. Vary the supports — hands on the seat, on the legs, or without support.

Stand Up and Sit Down on the Chair

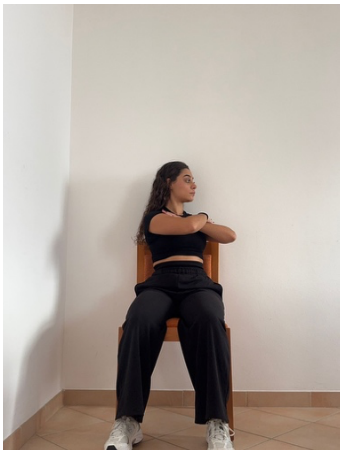
Objectives	Lower limb strength
Main Muscles	Gluteus, quadriceps, hamstrings, calves
Movement	1. Starting Position (Seated): Sit on a sturdy chair or bench, feet flat on the floor at shoulder width. Knees bent at approximately 90°. Spine upright, shoulders relaxed. Arms can be crossed over the chest, resting at the sides, or on the knees (depending on the difficulty level). 2. Drive Phase (Standing Up): Lean the trunk slightly forward (hip flexion) — this shifts the center of gravity forward. Activate the gluteus, quadriceps, and core muscles. Push the floor with your feet until the knees and hips are fully extended, standing up. 3. Control Phase (Standing): Keep the body aligned: hips, shoulders, and head in a straight line. Distribute weight evenly between both legs. 4. Descent Phase (Sitting Down): Begin by slowly flexing the hips and knees. Control the movement until you touch the seat, avoiding “falling” into it. Keep the trunk slightly leaned forward and the core active.
Critical Points	Lifting the feet off the floor to initiate the movement. Dropping’ the body onto the seat during descent. Excessive forward lean of the body.
Variations	For individuals who are not independent or require assistance to assume a standing position, use a chair or walker for support.

Breathing



Objectives	Postural alignment awareness
Main Muscles	Deep trunk stabilizers, shoulder girdle stabilizers, diaphragm
Alignment	Position the arms and shoulders relaxed along the trunk, avoiding tension in the cervical and scapular muscles. Promote axial elongation of the spine, imagining the top of the head growing toward the ceiling. Perform a controlled posterior tilt of the pelvis, feeling the sit bones resting on the support base. Keep the lower limbs parallel, with the feet spaced at hip width. Unlock the knees, maintaining joint alignment between the knees and feet. Expand the ribcage, allowing the chest to open. Keep the chin parallel to the floor, with a neutral cervical spine and gaze directed forward, in line with the spine.
Breathing pattern	Inhale through the nose, promoting expansion of the abdominal and ribcage regions, as if the air is inflating a balloon. Exhale slowly through the mouth, guiding the air toward complete emptying while perceiving the activation of the deep abdominal muscles (particularly the transversus abdominis). You may place your hands on the sternum, ribcage, or abdominal area to feel the expansion during inhalation and the contraction during exhalation, enhancing respiratory awareness and motor control.
Critical Points	Foot planted on the floor, trunk leaned forward and flexed, shoulders rolled forward.

Shoulder Stretch



Objectives	Shoulder Stretch
Main Muscles	Posterior Deltoid
Movement	Maintain the trunk in a neutral position, ensuring axial alignment and scapular stability. Place the hand on the opposite elbow, crossing the arm in front of the body. Apply gentle horizontal pressure to promote stretching of the posterior shoulder muscles (mainly the posterior deltoid). Hold the position for 15 to 30 seconds, breathing in a controlled manner. Slowly return to the starting position, maintaining control of the movement
Critical Points	Respect individual joint range limits at the elbow and shoulder. Bring the arm closer to the trunk using the opposite hand, without creating excessive tension. Avoid trunk rotation. Keep the elbow below shoulder height if discomfort or pain occurs, adjusting the position according to tolerance.
Variations	Hold at different points (wrist, forearm, upper arm, or elbow) to adjust stretch intensity. Maintain an active stretch by slightly contracting stabilizing muscles.

Cervical Mobility

Objectives	Cervical mobility
Main Muscles	Sternocleidomastoid, scalenus, trapezius
Movement	Align the head with the continuation of the spine, keeping the trunk neutral and the shoulders away from the ears, in a scapular depression position. Perform cervical joint movements: Flexion and extension (looking down and up), Rotations (right and left), Lateral tilts (ear toward shoulder). Exhale during flexion and inhale during extension, synchronizing breathing with the movement. Perform the exercise slowly, in a controlled and mindful manner.
Critical Points	Avoid leaning the trunk while moving the head; the movement should occur exclusively in the cervical spine. Prevent cervical hyperextension by respecting joint limits. Maintain scapular stability, ensuring the shoulders remain in a neutral and depressed position.
Variations	Place the hands on the head to gradually increase the intensity of the stretch during cervical flexion. Combine with imaginary daily movements, such as “nodding yes and no” or “waving to someone from side to side,” to facilitate coordination and natural mobility.

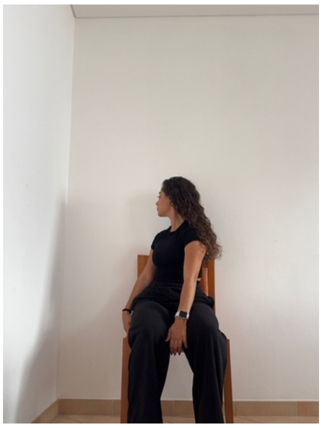
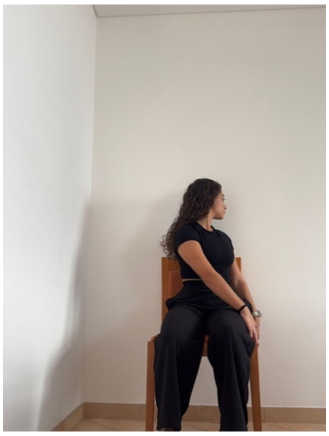
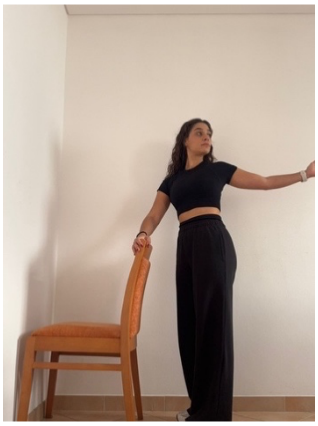
Flexion and Extension of the Spine

Objectives	Spinal mobility with trunk control during movement
Main Muscles	Rectus abdominis, internal and external obliques, gluteus maximus, erector spinae, quadratus lumborum, and thoracic extenso-rectus abdominis, internal and external obliques, gluteus maximus, erector spinae, quadratus lumborum, and thoracic extensors
Movement	Perform gradual flexion, starting with the cervical spine (head), followed by the shoulder girdle (shoulders) and the upper thoracic portion of the trunk. Unroll in the reverse order: slowly return to a neutral upright position, beginning with lumbar extension, followed by thoracic extension, and finishing with cervical repositioning. Breathing coordination: Exhale during flexion (rolling phase). Inhale during extension (unrolling phase).
Critical Points	Avoid compensations in the cervical spine and shoulders. Perform the movement slowly, smoothly, and in a controlled manner, coordinating breathing (exhale during flexion and inhale on the return). Maintain light abdominal activation to promote stability and protect the lumbar spine.
Variations	With or without the backrest against the wall/chair. Place the hands on the legs/table/walker and ask the individual to slide the hands forward while flexing the trunk.

Lateral Flexion of the Spine

Objectives	Spinal mobility with trunk control during movement
Main Muscles	Internal and external abdominal obliques
Movement	Start from the initial position with the trunk in neutral alignment, maintaining an upright posture and the upper limbs relaxed along the sides of the body. Perform lateral flexion of the trunk to one side, imagining the homolateral hand sliding down the lateral thigh toward the floor, without performing pelvic rotations or compensations. Return in a controlled manner to the neutral starting position.
Critical Points	Avoid excessively shifting body weight toward the side of the flexion, which may compromise the base of support and overall postural alignment. Do not roll the trunk or project the shoulders forward, as this disrupts the frontal plane movement axis.
Variations	Contralateral support: Keep the hand on the side opposite the flexion resting on the waist or thigh to aid trunk support and control. Arm extended overhead: Perform the movement with the arm on the same side as the flexion extended next to the head, increasing leverage and stability challenge. Use of props: Hold sticks, towels, or other light accessories to promote alignment, control, and range of motion. Version without the arm elevated: Recommended for practitioners with shoulder limitations or discomfort.

Trunk Rotation

Objectives	Trunk Mobility: Rotation
Main Muscles	Internal and external abdominal obliques
Movement	Start the exercise with the spine in a neutral position, trunk upright, shoulders relaxed, and gaze directed forward. From this position, rotate the trunk to one side, keeping the chest open. Return to the neutral starting position and repeat the movement to the opposite side in a controlled and symmetrical manner. Throughout the exercise, focus on initiating the rotation from the trunk, especially the thoracic spine.
Critical Points	Avoid compensating with the lower limbs, which can shift the rotation axis of the trunk. Do not perform excessive range of motion in individuals with dorsal spine pathologies (e.g., disc herniations, protrusions, or other vertebral dysfunctions); in these cases, reduce the range and prioritize postural control. Avoid neck rotation, keeping the gaze aligned with trunk movement.

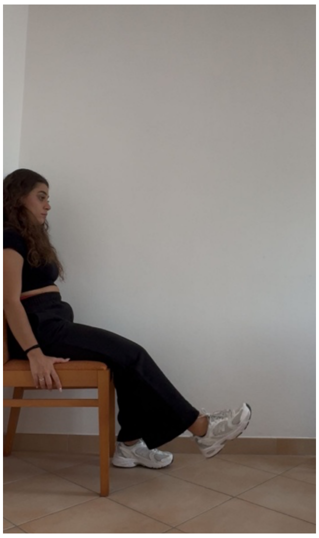
Marching

Objectives	Marching
Main Muscles	Quadriceps, psoas-iliacus, calves
Movement	Begin the exercise seated on a chair or stable support, keeping the trunk in a neutral position and the supporting foot firmly on the floor. Lift one foot off the ground in a controlled manner, keeping the other foot as a stable base to ensure balance and proper weight distribution. Return the elevated foot to the floor, always maintaining one foot as the support base. Alternate the feet rhythmically, ensuring the trunk remains upright and neutral, and the weight stays well distributed over the seat and/or hands supporting the walker or chair.Evitar inclinar ou deslocar o tronco lateralmente durante a elevação do pé.
Critical Points	Always keep one foot firmly on the floor, avoiding lifting the heel of the foot that remains as the base. Avoid excessive weight shifting between the feet, preventing trunk sway or postural compensations. In case of imbalance, ensure the trunk remains supported on the backrest of the chair or auxiliary support, maintaining safety and stability.
Variations	Heel Raise: Start the movement by lifting only the heel, keeping the sole of the foot in contact with the floor; recommended for individuals who cannot lift the entire foot. Types of Marching: Vary the direction of movement by marching forward, backward, or performing side-to-side steps, stimulating coordination and mobility. Integration with Upper Limbs: Perform marching while moving the arms, promoting bilateral coordination and functional activity.

Hamstring Strength – Knee Flexion

Objectives	Hamstring Strength – Knee Flexion
Main Muscles	Hamstrings, gluteus maximus, quadriceps
Movement	Start with the feet apart and slightly forward, keeping the trunk upright, spine in neutral alignment, and a firm base of support (seat or feet on the floor, depending on the position). Posterior Foot Slide (Seated): Slide one foot backward in a controlled manner, avoiding movement of the hips or trunk. Knee Flexion (Standing): If performed in a standing position, flex the knee of the leg being moved backward, maintaining weight distributed over the supporting leg. Return to Starting Position: Bring the foot back to the starting position in a controlled manner. Alternate Legs: Repeat the movement alternately, ensuring stability and postural control throughout the exercise.
Critical Points	Keep the trunk neutral, avoiding leaning forward or to the sides during the movement
Variations	Alternating or Unilateral: Perform the exercise alternately between the legs or repeat unilaterally to focus on a specific side. Reduced Manual Support: Gradually decrease hand support on the seat or walker, increasing the demand for postural control. Additional Resistance (Seated): Place objects under the foot (such as ankle weights) to increase resistance and stimulate strength.

Quadriceps Strength – Knee Extension



Objectives	Quadriceps Strength – Knee Extension
Main Muscles	Quadriceps
Movement	Sit or support yourself with the trunk in neutral alignment, keeping the supporting foot firmly on the floor. Knee Extension: Lift one leg, fully extending the knee within each individual's safe range of motion, focusing on quadriceps contraction. Controlled Return: Lower the leg back to the starting position, keeping the trunk stable and the supporting foot firm. Alternation: Repeat with the other leg, ensuring symmetry and postural control.
Critical Points	Keep the supporting foot fully in contact with the floor to ensure trunk stability and balance. Reduce repetitions and range of motion for individuals with knee pathologies, such as osteoarthritis or joint injuries, prioritizing safety. Avoid trunk swaying during leg lift, maintaining a stable and neutral trunk to maximize quadriceps activation and minimize postural compensations.
Variations	Reduced Support: Gradually remove support from the chair or walker, increasing the challenge for balance and stability. Use of Equipment: Add accessories such as ankle weights for progressive resistance, enhancing quadriceps strength and motor control.

Strength of the lower limb abductors and adductors

Objectives	Strength of the lower limb abductors and adductors
Main Muscles	Gluteus medius and minimus, tensor fasciae latae, adductors
Movement	1Starting Position: Sit upright. Spine straight. Feet and knees pointing forward. 2. Execution: Move the legs outward laterally, maintaining control of the movement. Focus on contracting the lateral hip muscles (gluteus medius and minimus). Avoid leaning the trunk or rotating the feet. 3. Return: Slowly return to the starting position, without fully touching the legs together (maintaining slight tension).
Critical Points	Keep the abdomen engaged to stabilize the trunk. Distribute weight evenly over the pelvis to ensure stability during abduction. Maintain a neutral trunk, avoiding leaning or swaying to the opposite side during the movement. Exhale during abduction and inhale during adduction.
Variations	Unilateral or Alternating Repetitions: Perform the exercise unilaterally or alternate between right and left legs, depending on training goals and muscular balance. Use of Equipment: Incorporate accessories such as elastic bands or ankle weights

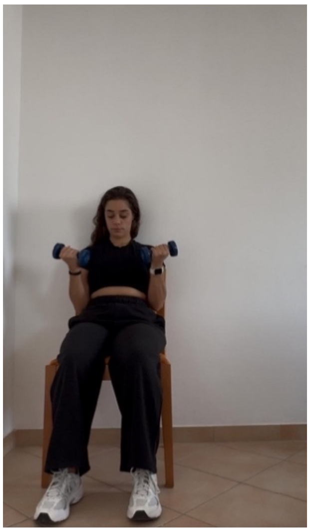
Back Strength

Objectives	Back Strength
Main Muscles	Latissimus dorsi, middle and lower trapezius, biceps brachii
Movement	Keep the trunk neutral, upright, or slightly leaned forward. Elbow Flexion: Bend the elbows backward and upward, keeping them close to the trunk. Scapular Activation: During the movement, gently squeeze the shoulder blades backward, promoting scapular stabilization and retraction. Controlled Return: Extend the elbows and return to the starting position, keeping the trunk stable and aligned.
Critical Points	Maintain scapular stabilization, avoiding internal shoulder rotation during elbow flexion. Avoid trunk sway while the arms move, ensuring postural control. Flex the trunk only from the hip joint if the trunk is slightly leaned forward, keeping the spine neutral.
Variations	Unilateral or Simultaneous: Perform the movement with one arm at a time or both arms simultaneously, depending on goals and available equipment. Trunk Inclination: Increase forward trunk lean to vary range of motion and muscle recruitment. Use of External Load: Add elastic bands, dumbbells, or other equipment for strength progression.

Triceps Strength

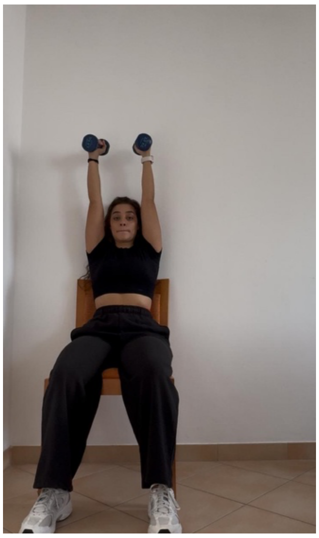
Objectives	Triceps Strength
Main Muscles	Triceps brachii, posterior deltoid
Movement	Keep the trunk neutral, in a vertical position or slightly leaned forward, with feet firmly on the floor or on a stable support. Initial Elbow Flexion: Pull the elbow backward, keeping it fixed close to the trunk throughout the movement. Forearm Extension: Extend the forearm backward, keeping the elbow close to the trunk and controlling the range of motion. Controlled Return: Flex the elbow again, returning to the starting position without leaning or rotating the trunk.
Critical Points	Perform segmented elbow movement, avoiding swinging the entire arm; extension should be controlled and localized at the elbow joint. Keep the chest open, avoiding internal shoulder rotation to ensure proper alignment and joint safety.
Variations	Unilateral or Simultaneous: Perform the movement with one arm at a time or both simultaneously, depending on training goals and available equipment. Use of External Load: Add elastic bands, dumbbells, or other accessories for progressive strength training.

Biceps Strength



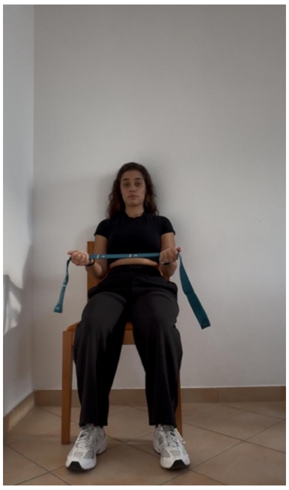
Objectives	Biceps Strength
Main Muscles	Biceps brachii, brachioradialis
Movement	Keep the spine in neutral alignment and the shoulders retracted, with the arms extended along the sides of the body. Elbow Flexion: Bend the elbows, bringing the hands toward the shoulders, keeping the elbows close to the trunk and maintaining postural control of the trunk. Rotation: Perform forearm rotation during flexion, as needed or according to the goal. Controlled Return: Extend the elbows and return to the starting position, keeping the spine neutral and shoulders retracted.
Critical Points	Avoid moving the trunk to assist the arms; the movement should be controlled and isolated at the elbow. Start the movement from full elbow extension to ensure full biceps recruitment and joint control. Keep the shoulders down and retracted, avoiding elevation or internal rotation during execution.
Variations	Alternating or Simultaneous Arm Movement: Perform the exercise one arm at a time or both simultaneously, depending on training goals and coordination. Additional External Load: Add dumbbells, elastic bands, or other accessories for progressive strength training. Grip Variation: Perform the movement with different hand grips: Supinated: Palm facing up Hammer: Palm facing inward

Shoulder Strength – Shoulder Press



Objectives	Shoulder Strength – Shoulder Press
Main Muscles	Anterior deltoid, middle deltoid, triceps brachii
Movement	Keep the trunk neutral, spine aligned, shoulders retracted, and feet firmly on the floor or a stable support (if seated). Arm Position: Hold the weight (dumbbells, barbell, or functional objects) close to the shoulders, elbows flexed and aligned with the trunk. Execution: Extend the arms upward, fully straightening the elbows at the top of the lift without excessively arching the spine. Functional Movement: Simulate lifting objects overhead, promoting shoulder strength and control. Controlled Return: Lower the arms slowly and in a controlled manner back to the starting position, maintaining a neutral trunk and stabilized shoulders.
Critical Points	Maintain scapular stability, avoiding shoulder elevation toward the ears during the movement. Avoid projecting the head forward, keeping the cervical spine neutral and aligned throughout the exercise.
Variations	Unilateral or Bilateral: Perform the movement with one arm at a time or both simultaneously, depending on training goals and coordination. Use of Equipment: Add dumbbells, barbell, elastic bands, or functional objects for progressive strength. Trunk Off the Chair: Perform the exercise without leaning on the chair. Standing Version: Perform the exercise while standing.

Shoulder External Rotator Strength



Objectives	Shoulder External Rotator Strength
Main Muscles	Infraspinatus, teres minor, posterior deltoid
Movement	Keep the trunk neutral and spine aligned, with the elbow flexed at 90° and supported close to the body (arm at the side of the trunk). Execution: Rotate the forearm outward, moving the hand away from the trunk while keeping the elbow close to the body and controlling the movement. Controlled Return: Return to the starting position, keeping the trunk stable and without shoulder displacement.
Critical Points	Keep the elbow close to the trunk throughout external rotation, avoiding lateral drift or projection. Trunk control: avoid leaning forward or projecting the abdomen, maintaining a neutral and stable posture. Proper breathing: exhale during external rotation, keeping the rib cage low and promoting greater abdominal activation for stability.
Variations	Combination with Forearm Pronation and Supination: Perform external rotation while pronating or supinating the hands, enhancing shoulder and forearm muscle coordination and activation. Unilateral or Bilateral Execution: Perform the exercise with one arm at a time or both simultaneously, depending on the goal and motor control. Integration with Lower Limbs: Combine external rotation with alternating leg lifts, promoting overall coordination, core activation, and postural stability.