Boxe4Ageing: Investigando los Efectos del Boxeo y Entrenamiento Multicomponente en la Salud de los Adultos Mayores – Protocolo de Estudio Cuasi-Experimental

Boxe4Ageing: Investigating the Effects of Boxing and Multicomponent Training on Health of Older Adults – A Quasi-Experimental Study Protocol

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Abstract

Introduction: Physical exercise is essential for maintaining functionality and independence in later life. However, the specific benefits of boxing as a form of exercise remain unclear.
Objective: To describe the protocol of Boxe4Ageing, a program designed to compare the effects of boxing (BT) and multicomponent training (MT) on cognitive performance, brain activity, physical fitness, and fall risk in community-dwelling older adults in Portugal.
Methodology: This quasi-experimental study protocol will include participants aged ≥60 years, assigned to one of three groups: BT, MT, or a control group (CG). The exercise programs will run for 24 weeks, with two sessions per week. CG participants will maintain their usual activities. Assessments will occur at baseline, mid-intervention (12 weeks), post-intervention (24 weeks), and after a 12-week detraining period.
Results: Primary outcomes include cognition, brain activity, physical fitness, and fall risk; secondary outcomes are quality of life and exercise satisfaction.
Discussion: If successful, this study could provide evidence supporting the inclusion of boxing in community health programs aimed at preventing falls, improving cognitive health, and enhancing physical fitness in older adults. It may offer a low-cost, accessible intervention with significant potential benefits for older adults.
Trial Registration: ClinicalTrials.gov – Identifier NCT05826314, registered April 24, 2023.

Keywords

Boxing training; Clinical impact; Falls prevention; Methodological innovation; Older adults.

Resumen

Introducción: El ejercicio físico es esencial para mantener la funcionalidad y la independencia en la edad avanzada. Sin embargo, los beneficios específicos del boxeo como forma de ejercicio siguen siendo poco claros.
Objetivo: Describir el protocolo de *Boxe4Ageing*, un programa diseñado para comparar los efectos del entrenamiento de boxeo (BT) y el entrenamiento multicomponente (MT) sobre el rendimiento cognitivo, la actividad cerebral, la condición física y el riesgo de caídas en adultos mayores que viven en la comunidad en Portugal.
Metodología: Este protocolo de estudio cuasi-experimental incluirá participantes de ≥60 años, asignados a uno de tres grupos: BT, MT o un grupo control (GC). Los programas de ejercicio se desarrollarán durante 24 semanas, con dos sesiones por semana. Los participantes del GC mantendrán sus actividades habituales. Las evaluaciones se realizarán al inicio, a mitad de la intervención (12 semanas), al finalizar la intervención (24 semanas) y después de un período de desentrenamiento de 12 semanas.
Resultados: Los resultados primarios incluyen cognición, actividad cerebral, condición física y riesgo de caídas; los resultados secundarios son la calidad de vida y la satisfacción con el ejercicio.
Discusión: Si tiene éxito, este estudio podría proporcionar evidencia que respalde la inclusión del boxeo en programas comunitarios de salud destinados a prevenir caídas, mejorar la salud cognitiva y aumentar la condición física en adultos mayores. Podría ofrecer una intervención de bajo costo, accesible y con beneficios potenciales significativos para esta población.
Registro del ensayo: ClinicalTrials.gov – Identificador NCT05826314, registrado el 24 de abril de 2023.

Palabras clave

Entrenamiento de boxeo; Impacto clínico; Prevención de caídas; Innovación metodológica; Adultos mayores.

Introduction

Aging leads to physiological, psychological, and socio-cultural changes, compromising functional capacity and independence later in life (Dharmarajan, 2021). Regular physical exercise has been emphasized as a non-pharmacological intervention (Izquierdo et al., 2021) to counteract age-related deleterious effects. This is due to its capacity to improve functional capacity (Izquierdo et al., 2021), prevent falls (DiPietro et al., 2020; Miranda et al., 2021), and enhance cognitive function (Cerda-Vega et al., 2024), thereby preventing or postponing the onset and progression of dementia (Carvalho et al., 2021).

Among older adults, multicomponent training (MT) is the most common and extensively studied mode of physical exercise (DiPietro et al., 2020). This approach combines aerobic, strength, balance, and flexibility exercises into a single session, significantly improving functional fitness among older adults (Rodrigues et al., 2023).

Nonetheless, complementary forms of exercise might also be effective for health maintenance and improvement (DiPietro et al., 2020). Among these, combat sports stand out for their potential to improve physical function and quality of life in older adults (Valdes-Badilla et al., 2021), as they integrate multiple exercise components similar to MT, including aerobic, strength, balance, and flexibility exercises, along with additional elements such as muscular power and motor agility (Muñoz-Vásquez et al., 2023).

Boxing, as a form of combat sport, combines these benefits with distinctive features. Its practice involves coordinated movements of the limbs, rapid arm actions, trunk rotation, and anticipatory postural adjustments (Ersoy & Iyigun, 2024). Additionally, it serves as a form of dual-task training, requiring participants to memorize sequences, make quick decisions, and synchronize upper and lower body movements (Domingos et al., 2019). These attributes make boxing a promising exercise to enhance cognition, functionality, mobility, and fall prevention in later life.

The benefits of boxing have been well-documented in individuals with Parkinson's disease, highlighting its positive effects on quality of life and fall risk (Dawson et al., 2020; Shearin et al., 2021). However, despite these promising results, there is a significant lack of studies examining the effects of boxing on health outcomes in healthy older adults (Morris et al., 2019; Valdes-Badilla et al., 2021).

Therefore, this study aims to describe the protocol of Boxe4Ageing, which aims to compare the effects of boxing (BT) versus multicomponent training (MT) on cognitive performance, brain activity, physical fitness, and risk of falls in older Portuguese adults from the community.

We hypothesize that BT will trigger comparable positive effects to those induced by MT on cognitive performance, brain activity, physical fitness, and risk of falls in older adults.

Method

Study Design and Participants

This is a protocol study for a quasi-experimental controlled trial with a parallel design. Participants will be recruited from local community programs in the Porto metropolitan area (Portugal) and through social media platforms using virtual advertisements. A preliminary meeting with prospective participants will be conducted to address intervention concerns and encourage participation. The study aims, associated risks, and procedures will be outlined during this session. The potential participants will sign an informed consent form and undergo an initial screening to assess their eligibility. Those who will be eligible will be scheduled for the baseline assessments, consisting of three days of measurements spaced seven days apart. Specific measurements for each of the baseline assessment days are in Figure 1.

After the baseline assessments, participants will be assigned to the BT, MT, or control group (CG) based on availability (Figure 2). They will then begin the 24-week intervention period, which will include an intermediate evaluation. Following the completion of the protocol, post-intervention and detraining assessments will be conducted according to the outlined timeline (Figure).

Data collection will be conducted by researchers who are skilled and seasoned. The same evaluator will be responsible for performing the same procedures during the assessment moments. The number of participants assigned to each intervention group will be documented for the allocation process, along with explanations for any nonadherence to the assigned group. Additionally, the number of participants lost to follow-up (dropouts) and those who discontinue the intervention, including reasons for discontinuation, will be recorded. Finally, the number of participants included in the study will be detailed based on the intention-to-treat and per-protocol approaches, with explanations for any exclusions from the analytical dataset.

Figure 1. Timeline of Evaluations and Intervention Sessions

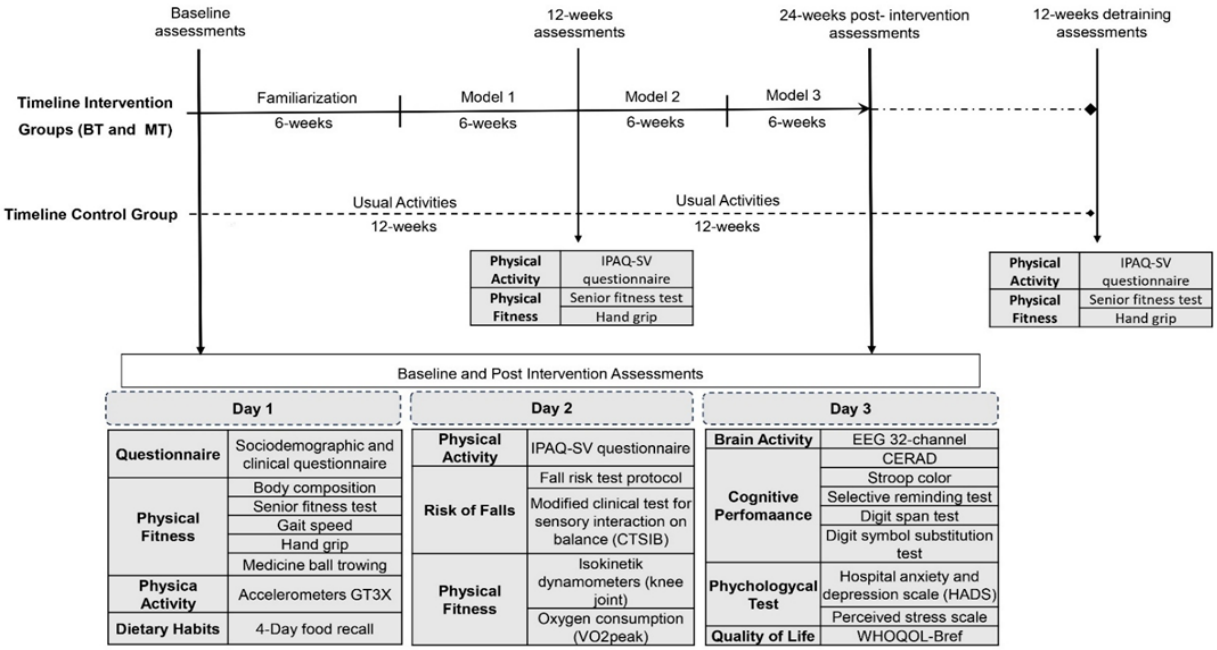
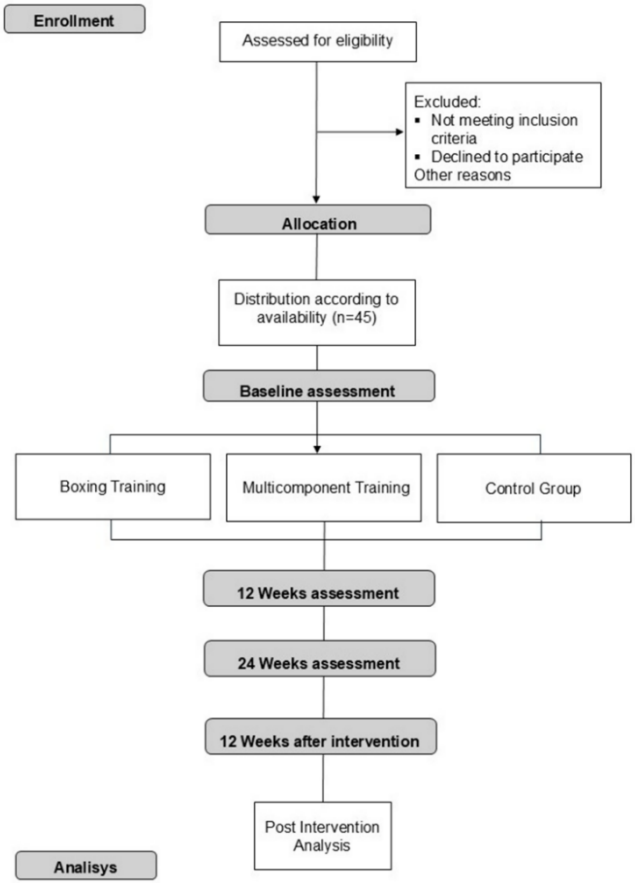


Figure. 2: Flowchart of the participant selection process and protocol stages, following the Consolidated Standards of Reporting Trials (CONSORT 2010).



Eligibility criteria

Eligible participants will be those (i) aged ≥60 years, (ii) non-institutionalized, and (iii) without participation in any physical exercise program in the previous three months. Exclusion criteria will include (i) dementia, defined by a neuropsychological assessment using the Montreal Cognitive Assessment (MoCA) with a threshold of <17 points. This cut-off was chosen due to its higher specificity in detecting advanced cognitive impairment, as supported by Freitas et al. (2012), who demonstrated its diagnostic accuracy, particularly considering cultural and educational factors; (ii) unstable cardiovascular disease or musculoskeletal dysfunction that makes it impossible to participate in moderate-intensity exercise.

Ethics Approval and Data Management

The study protocol has been approved by the Faculty of Sport Ethics Committee of the University of Porto (CEFADE 26.2022). The project procedures will follow all ethical standards and the 1964 Declaration of Helsinki. The trial is registered in the US National Institutes of Health Clinical Trials Registry NCT05826314.

Before data collection, all participants will be asked to sign an informed consent form. Data confidentiality and anonymity will be guaranteed at all stages of the study. Any significant changes to the protocol will be reported to the Clinical Trials website for approval by the Research Ethics Board, except when necessary to eliminate apparent immediate hazard(s) to humans. There will be no financial rewards for participants for their involvement in the study.

Sample Size

The G*Power software (University of Düsseldorf, Germany) was used to calculate the study sample size using F-tests (ANOVA between factors), considering an effect size of f = 0.60, α = 0.05, statistical power = 0.95, number of groups = 3, number of measurements = 3; a correlation between repeated measures = 0.5 (Monteiro et al., 2023). Thus, the calculations suggested a minimum of 33 participants (11 participants per group) for the results to be valid and reliable. In line with previous studies, the number of recruited participants will be increased to cover an expected 25% drop-out rate (Carvalho et al., 2021). Therefore, the target sample size will be increased to 45 participants (15 per group).

A post hoc analysis will be conducted at the end of the study to adjust the calculations based on the entire data set, ensuring the results' accuracy and robustness.

Blinding

Given the nature of the interventions, blinding will not be feasible, as the participants will inevitably know which group they belong to due to the lack of randomization. However, the principal investigator (PI) and research team members who will not be involved in post-intervention assessments or exercise session supervision will remain blinded to group allocation. Group identities will only be disclosed in the event of an unexpected adverse event involving a participant, and such disclosure will be made solely by the PI or a physician.

Study Interventions

As mentioned above, physical exercise protocols will span 24 weeks and be equally divided into familiarization, model 1, model 2, and model 3. Exercise groups will have two non-consecutive weekly sessions that will last 45 minutes. The general structure of exercise sessions will be identical for both physical exercise groups, consisting of a 10-minute warm-up, a 25-30-minute main workout, and a 5-10-minute cool-down. Irrespective of the exercise group, the warm-up and cool-down exercises will be the same. Marked differences will be evident in the main workout routines, although exercise intensity will be uniform across the exercise groups. Individual monitoring of exercise intensity will be conducted using the self-perceived exertion scale (6-20 scale). Participants in the exercise groups will be questioned about any osteoarticular and skeletal muscle discomfort they have experienced since their last training session. In the event of affirmative responses, a pain scale will be administered.

Boxing training (BT)

The main characteristic of the BT protocol in the Boxe4Ageing project is the inclusion of non-contact physical exercises, ensuring no physical contact is involved. This approach is based on the protocol proposed by Domingos et al. (2019).

In boxing, an important concept is a round. Here, a round is defined as a time frame during which boxing exercises are performed. In the familiarization phase, the aim is to acquire desirable technical execution of the boxing exercises. Therefore, the intensity during this period will be low (rated 9-12 on a 6-20 self-perceived exertion scale). In the subsequent models, exercises will progressively increase in intensity and complexity.

The BT program periodization, session structure, and specific aims will be detailed in Table 1**.** A succinct description of the exercises that will be included in the BT sessions is as follows:

Neuromotor exercises: These exercises will primarily be performed through circuit training, incorporating directional changes such as forward, sideways, and backward movements. The goal is to enhance agility, coordination, and balance. Foam training sticks will be used to guide movement patterns and improve coordination. Exercises with balloons and balls will be included to develop reaction time, hand-eye coordination, and dynamic balance. Additionally, footwork drills using agility ladders and/or cones will focus on improving speed, precision, and overall agility.

Shadowboxing exercises: The aim of this part of the exercise session will be the development of muscular fitness, coordination, balance, and attention. Exercises will progress in terms of motor learning, starting with: i) a stable task (i.e., stance and guard) and advancing to a variable task (stance, guard, and attacks); ii) a single task (jab followed by a cross) to a double task (performing the jab and cross while verbalizing the names of the opposite blows, i.e., cross and jab or footwork and attacks). Initially, shadowboxing exercises will be performed with a boxing bandage, gradually transitioning to exercises with light elastic bands or dumbbells weighing 1kg/1.5kg.

Punching bag exercises: This part of the exercise session will aim to improve aerobic and muscular fitness and reaction time. Participants will perform combinations of arm movements integrated with trunk and lower limb rotation. As participants progress, agility and power movements will also be introduced. Each punching bag will accommodate three to four participants, who will receive verbal exercise instructions from the coach.

To illustrate the planned BT exercises and their progression throughout the study protocol, Figure 3 will depict the key technical fundamentals of the modality, as well as the punch combinations and circuits.

Figure3. Overview of Key Technical Fundamentals and Main Workout Models in the Boxe4Ageing Protocol

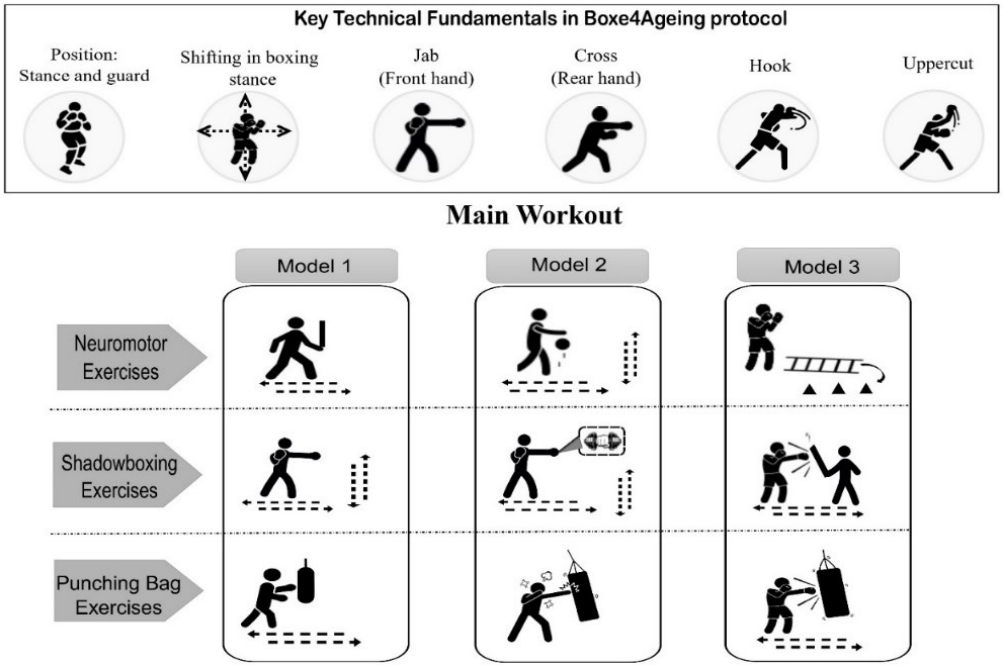


Table 1. Boxing Training protocol

	Warm-up 10min	Main Workout 25-30min			Cool down 5 - 8min Aim: flexibility	Exercise Intensity 6-20 RPE
		Neuromotor Exercises *Aim: Agility, coordination and balance*	Shadowboxing Exercises *Aim: muscular fitness, coordination, balance and attention*	Punching Bag Exercises *Aim: Aerobic and muscular fitness, and reaction time*		
Familiarization - 12 Sessions	-Walking (self-selected speed) -Joint mobility -Dynamic Stretching	1º round: 3min exercise+1min rest Walking around following the coach instructions. For example, when signaled, everyone must go to a designated arch with a specific color. 2º round: 3min exercise+1min rest Forward and backward movement in the basic boxing position (i.e., shifting in boxing stance)	1º round: 5min exercise+1min rest In pairs, assume the stance without lateral movement, and practice throwing a ball with jab and cross punches alternately. Once coordination is mastered, introduce shifting in the boxing stance. 2º round: 5min exercise+1min rest During the rest period, participants must wrap their hands for boxing. Individual motor learning of boxing punches such as jab, cross, hook, and uppercut, through static exercises that gradually incorporate shifting in the boxing stance.	1º and 2º round: 2min exercise+1min rest In pairs, perform sequences of punches with progressive complexity, simulating boxing combinations. Note: During the familiarization phase, the punching bag will not be used. Instead, sticks will be utilized for adapted exercises. One participant will hold the sticks while the other executes punch combinations.	Stretching for the main muscle groups of the trunk and extremities.	Very light (RPE <9)
Model 1 - 12 Sessions	-Walking (self-selected speed) -Joint mobility -Dynamic Stretching	1º and 2º round: 2min exercise+1min rest Double task - involving shifting in boxing stance with 2 to 3 steps in each direction while simultaneously balancing the stick or hitting the balloon/ball.	One round: 10min exercise+4min rest During the rest period, participants must wrap their hands for boxing. The coach will assign numbers to movements involving changes in boxing stance, requiring participants to memorize and concentrate to remember the corresponding movement for each number: 1 – Step forward 2 – Step back 3 – Step to the left 4 – Step to the right In addition to movements, punches such as the jab and cross will be gradually incorporated.	1º round: 2min exercise+1min rest Under the supervision of the coach, practice shifting in boxing stance. Execute straight punches (i.e., jab and cross), followed by two steps back. Upon the command to return to the front, execute the punches again and then retreat once more. Gradually incorporate more straight punches; instead of two punches, perform four. 2º round: 2min exercise+1min rest Open round: Participant-selected sequences of punches (ranging from 2 to 6 punches).	Stretching for the main muscle groups of the trunk and extremities.	Very light to light (RPE 9-11)
Model 2 - 12 Sessions	-Dynamic Stretching -Walking (self-selected speed)	1º round: 2min 30sec exercise+1min rest Double task - shifting in boxing stance and forcefully dribble a ball onto the ground using both hands. 2º round: 2min 30sec exercise+1 min rest Move in pairs, maintaining a safe distance, and shift forward in a boxing stance. Advance while throwing a small ball with the lead arm (jab - 5reps) and then with the rear arm (cross – 5reps). The partner catches and returns the ball. Alternate roles in the next round.	One round: 8min exercise+4min rest (During rest period, boxing hand wrapping) Perform up to four-move sequences created by participants (e.g., cross, hook, cross) or the coach (e.g., jab, cross, step back, cross). Follow the coach's commands to repeat the sequence until it changes, or a new participant creates one. Gradually integrate resistance bands or dumbbells into the participants' hands while maintaining range of motion and the boxing stance.	1º round: 2min 30sec exercise+1min rest The punching bag is divided into four sections with two participants on each side, labeled A and B. When the coach calls "A, 1-2-3," only participants A from both sides attack the indicated numbers on the bag. The numbers are affixed to the punching bag. 2º round: 2min 3sec exercise+1min rest In boxing guard position, participants execute a continuous series of straight punches, for 20 seconds, gradually increasing speed. Followed by 20seconds of rest for recuperation before the next cycle of punches.	Stretching for the main muscle groups of the trunk and extremities.	Fair light to somewhat hard (RPE 12-13)

Model 3 - 12 Sessions	-Dynamic Stretching -Walking (self-selected speed)	1º and 2º round: 3min exercise+1min rest After the exercise, boxing hand wrapping (3min) Circuit: -Agility ladder footwork -Shifting in boxing stance through a slalom course between cones -Throwing a medicine ball with both hands for maximum distance (women: 3kg; men: 4kg) -Sprinting back to the end of the line	1º round: 3min exercise+1min rest In pairs: one participant adopts a boxer's stance with gloves, while the other acts as the coach using a stick. The exercise focuses on footwork and decision-making, with the boxer executing punch combinations in response to the coach's stick signals. 2º round: 3min+1min rest The roles will switch. The participant who was previously in the boxer's stance will now take on the coach's role, and vice versa.	1º round: 3min exercise+1min rest Open round: Participants perform self-selected punch sequences (2 to 6 punches). After one minute, the coach instructs them to do 10-12 squats in a side stance, then return to the boxing stance to resume punching. Squats are repeated twice. 2º round: 3min+1min rest In the boxing guard position, participants execute a continuous series of straight punches, for 30seconds, gradually increasing speed. Followed by 15seconds of rest for recuperation before the next cycle of punches.	Stretching for the main muscle groups of the trunk and extremities.	Somewhat hard to very hard (RPE 14-17)

RPE = Perceived Exertion Rating

Multicomponent Training (MT)

The MT program was designed to be similar to the BT program in volume and intensity, and the exercise session structure was adapted according to previously published protocols (Gouveia et al., 2020; Rodrigues et al., 2023).

In line with what is planned for the BT program, the familiarization phase of the MT program aims to acquire desirable technical execution of the exercises. Therefore, the intensity during this period will be low (rated 9-12 on a 6-20 self-perceived exertion scale). Subsequently, exercise periods will become progressively more intense and complex. Table 2 shows the MT program periodization, with a detailed overview of the training structure, aims, and the progression of intensity duration. The main MT structure is planned as follows:

Neuromotor exercises: Exercises involving static and dynamic balance will be implemented, progressively increasing task complexity, such as introducing visual and proprioceptive conflicts. These exercises will be structured in a circuit training format, utilizing various equipment, including agility ladders, cones, and balance pads, among others. The neuromotor exercises will develop agility, coordination, and balance.

Resistance exercises: Exercises will be carefully selected to target the major muscle groups, encompassing knee flexors/extensors, shoulder abductors/adductors, elbow flexors/extensors, pectoral/back muscles, and abdominals. The external load will comprise body weight, ankle weights, elastic bands, and dumbbells. Furthermore, resistance training intensity will be adjusted throughout the program based on the participants' progression. Resistance exercises will improve muscular strength, coordination, and balance.

Aerobic exercises: Exercises will encompass walking, running, and choreographed movements. Regarding choreographies, participants will receive instructions to synchronize their movement pace with the rhythm of the provided music (ranging from 100 bpm to 120 bpm), tailored to the progression of each training model. Participants will be involved in the selection of the music repertoire. The aerobic exercise section will improve aerobic and muscular fitness and reaction time.

Table 2. Multicomponent Training Protocol

		Main Workout 25 – 30min				
	Warm-up 10min	Neuromotor exercises *Aim: Agility, coordination and balance*	Resistance exercises *Aim: muscular strength, coordination and balance*	Aerobic exercises *Aim: Aerobic and muscular fitness, and reaction time*	Cool down 5 - 8min *Aim: Flexibility*	Exercise Intensity 6-20 RPE
Familiarization - 12 Sessions	-Walking (self-selected speed) -Joint mobility -Dynamic Stretching	1º and 2º set: 2min exercise (each exercise lasts for 30sec) +1min rest/set - *Static*: Bipedal; Semi-tandem; Tandem; One leg stance 1º and 2º set: 2min exercise (ach exercise lasts for 30sec) +30sec rest/set - *Dynamic:* Normal gait; Narrow gait; Overlapping gait; Tandem gait	1º and 2º set: 15rep/set+30sec rest/set Execution velocity: 1:3 -Squats -Shoulder press (unloaded) -Calf raises (body weight) -Isometric shoulder lateral raise (unloaded) -Seated one-leg extension (unloaded)	1º and 2º set: 1min/set+1min rest/set Stationary knee elevation (Slow). 1º and 2º set: 2min/set+1min rest/set Choreography (100 bpm).	Stretching for the main muscle groups of the trunk and extremities.	Very light (RPE <9)
Model 1 - 12 Sessions	-Walking (self-selected speed) -Joint mobility -Dynamic Stretching	1º and 2º set: 2min exercise (each exercise lasts for 45sec) + 30sec rest/set - *Static:* Bipedal (With/without vision); Semi-tandem; Tandem; One leg stance (With balance pads) 1º and 2º set: 2min exercise (each exercise lasts for 30sec) +30 sec rest/set - *Dynamic:* Normal gait; Narrow gait; Overlapping gait; Tandem gait	1º and 2º sets: 12 - 15rep/set+1min rest/set Execution velocity: 1:3 -Squats (4kg kettlebell) -Biceps curls (2kg Resistance Band) -Calf raises (2kg Ankle Weight) -Shoulder frontal raises (2kg resistance band) -Wall Push-Ups -Reverse pec deck (2kg resistance band)	One set: 2min+1min rest Stationary knee elevation (1min slow+1min fast) One set: 2min+1min rest Choreography (100 bpm)	Stretching for the main muscle groups of the trunk and extremities.	Very light to light (RPE 9-11)
Model 2 - 12 Sessions	-Dynamic Stretching -Walking (self-selected speed)	1º and 2º set: 45sec/sets+30sec rest/set *Static:* Primary task (maintaining postural control over a foam mattress) while performing a secondary task (manual task such as holding a dumbbell) *Note:* Increase task complexity by adjusting load or changing upper limb task (example, arm movements) 1º and 2º set: 2min/set+30sec rest/set *Dynamic:* Complete a circuit by performing a slalom, overcoming an agility ladder, and sprinting back to the starting point	1º and 2º set: 15rep+45sec rest/set Execution velocity 1:3 Circuit: -Squats (4kg kettlebell) -Bicep curls (2kg dumbbell) -Standing knee flexions (2kg ankle weights) -Incline push-ups -Reverse pec deck (2kg resistance band) -Unilateral standing cross crunches - 15 rep per side	1º and 2º set: 2min/set+30sec rest/set Stationary knee elevation (1min) +Stationary Running (1min). 1º and 2º set: 2min/set+30sec rest/set Choreography (110 bpm).	Stretching for the main muscle groups of the trunk and extremities.	Fair light to somewhat hard (RPE 12-13)

Model 3 - 12 Sessions	-Dynamic Stretching -Walking (self-selected speed)	1º and 2º set: 2min30 sec/set+30sec rest/set *Dynamic:* Complete a circuit by performing a slalom, overcoming Agility ladder, and sprinting back to the starting point	1º, 2º and 3º set: ≥15rep+30-45sec rest/stations Execution velocity 1:3 Circuit: -Squats (4kg or 6kg kettlebell) -Bicep curls (2kg and 3kg dumbbell) -Standing knee flexions (2kg and 3kg ankle weights) -Incline push-ups -Reverse pec deck (2kg and 3kg -resistance band) -Standing Cross Crunches	1º and 2º set: 2min/set+30sec rest/set Stationary knee elevation (1min fast) + Stationary Running with Knee lifts (1min fast). 1º and 2º set: 2min/set+30sec rest/set: Choreographies (120 bpm).	Stretching for the main muscle groups of the trunk and extremities.	Somewhat hard to very hard (RPE 14-17)

RPE = Perceived Exertion Rating; Bpm: beats per minute

Control Group (CG)

Participants in the CG will be assessed at the same time as the MT and BT groups (baseline, 12 weeks of intervention, post-intervention, 12 weeks of detraining) (Figure 1). During the intervention, participants will maintain their usual activities. All control group participants will be offered the possibility to commence a multicomponent physical exercise program after the conclusion of the detraining assessments.

Statistical analysis plan

All statistical analyses will be conducted using SPSS IBM Statistical Software version 29.0 for Windows (SPSS, Inc., Chicago, IL, USA). The significance level will be set at 95%. Normality of distribution and homoscedasticity for outcome measures will be assessed using the Shapiro-Wilk test and Mauchly and Levene test, respectively. Results will be presented as absolute frequencies N (%) for categorical variables, means and standard deviations for continuous variables with normal distribution, and medians and interquartile range for continuous variables with non-normal distribution.

The main effects of training within and between groups will be evaluated by repeated measures ANOVA (time [baseline vs. week 24] × 3 groups [BT vs. MT vs. CG]). The time course of the effects within and between groups will be assessed by a mixed model ANOVA (time [baseline vs. week 12 vs. week 24] × 2 groups [BT vs. MT]). Bonferroni post hoc procedures will determine the paired differences between the different time points and the groups if a significant F value is obtained.

Test-retest reliability will be determined by calculating the intraclass correlation coefficients with a two-way mixed effects model of absolute agreement to determine whether there is a significant difference between the two tests for a variable at baseline. The Friedman test will be applied to analyze the differences between the experimental groups to assess the subjective perception of effort.

The effect size will be used to quantify the meaningfulness of any differences, and it will be calculated using η^2p, defined as trivial (< 0.1), small (0.1–0.29), moderate (0.3–0.49), or large (≥ 0.5) (Hopkins et al., 2009). Both intention-to-treat and per-protocol procedures will be performed.

Data Governance and Privacy Protection

To clarify, each participant will be assigned a unique identification code applicable to both intervention and control groups. The correlating names and IDs lists will be securely stored in a lockable cabinet in the Principal Investigator's office at the Research Centre, kept separate from report forms and evaluation tools. No personal information such as names, addresses, or other identifying details will be collected or recorded. Two authorized researchers will enter the data into an electronic database. Data management and statistical analyses will commence only after obtaining authorization from the Principal Investigator. All data will be destroyed ten years after the conclusion of the intervention, with electronic data being deleted five years after the last related scientific publication.

Primary Outcome Measure

Neurocognitive assessment

Neurocognitive assessments will be conducted to evaluate different cognitive functions. Verbal memory will be assessed using the Word List Test from the Consortium to Establish a Registry for Alzheimer's Disease (Morris et al., 1989) and the Selective Reminding Test (Buschke et al., 1995), which also measures multi-trial verbal learning. Response inhibition and cognitive flexibility will be examined with the Stroop Color and Word Test. Short-term verbal memory and attention will be assessed using the Digit Span Test (Strauss et al., 2006), while high-level information processing speed will be evaluated through the Digit Symbol Substitution Test (Strauss et al., 2006). Additionally, psychological tests will be administered to assess anxiety, depression, and stress.

Brain activity

Brain activity will be assessed using an electroencephalography system (EEG; ActiCHamp®, Brain Products, GmbH). EEG Signals will be acquired with an international 10-20 system with a standardized 32-channel electrode arrangement with reference and ground electrodes. The system will comprise Ag/AgCl active electrodes, a cap – actiCAP or EASYCAP (Brain Products, GmbH) – electrolyte gel, and straps to keep the cap in place. The ground electrode will be placed on the forehead, and the reference electrode will be the Cz channel of the ActiCHamp® equipment. The same equipment will be used for each participant's session.

Physical Fitness

Physical fitness will be assessed using different measurements. Firstly, the Senior Fitness Test (SFT) will be employed, which will include evaluations of lower and upper-body strength (sit-to-stand test and arm curl, respectively) and flexibility (sit and reach and back scratch, respectively), aerobic endurance (6-minute walk test), and agility/dynamic balance (8-foot up-and-go test) (Rikli & Jones, 2013).

Additionally, gait speed measurements (4-meter walk test) and handgrip strength (Lee et al., 2020; Patrizio et al., 2021) will be obtained. Upper body muscle power will be assessed using the 3-kg medicine ball throw test (Ø 0.60 m) (Pereira et al., 2012).

The isokinetic strength of knee extensors and flexors will be evaluated at 60º/s and 180º/s using an isokinetic dynamometer (Biodex System 3, Biodex Corp., Shirley, NY, USA) (Nagata et al., 2023).

Finally, oxygen consumption (VO2 peak) will be measured through an incremental treadmill test using a modified Bruce protocol designed for older individuals (Fleg et al., 2005).

Body composition

A portable stadiometer will measure the Participants' height (Seca®, Baystate Scale & Systems, USA). Body mass, fat-free mass, fat mass, and body mass index will be obtained by bioimpedance (InBody 120®, Body Composition Analyzers, Seoul, Korea). Overweight and obesity will be defined using the international criteria (World Health Organization, 2021). The appendicular skeletal mass index and bone mineral density will be performed using dual-energy x-ray absorptiometry (QDR 4500/A, Hologic Explorer, version 12.4, Bedford, MA, USA).

Risk of falls

The Biodex ® Balance System (Biodex, Shirley, NY, USA) (Biodex Medical Systems, 2014), employing the Fall Risk Test protocol, will be performed with participants standing on an unstable platform with both eyes open and closed. Additionally, a modified version of the Clinical Test of Sensory Interaction and Balance will be administered, deliberately inducing conflicts between visual (eyes open and closed) and proprioceptive inputs (on a foam platform). This specific test is renowned for its efficacy in identifying individuals with a spectrum of balance impairments ranging from mild to severe.

Secondary Outcome Measure

Quality of Life

Quality of life will be tested using the World Health Organization assessment tool (WHOQOL-Bref) (THE WHOQOL GROUP, 1998). The WHOQOL-Bref consists of 26 items, answered on a Likert scale ranging

from 1 to 5, with higher scores reflecting a higher quality of life. Quality of life will be categorized into physical, psychological, social relationships, and environmental domains.

Physical Activity Enjoyment Scale (PACES)

The physical activity enjoyment scale (PACES) (Mullen et al., 2011; Teques et al., 2020) will assess satisfaction with the physical exercise programs. PACES comprises eight items, and participants are requested to rate "how they currently feel about the physical activity they have been engaging in" using a 7-point Likert scale (1= unpleasant; 7= pleasurable). The total score of all items provides a one-dimensional measure of enjoyment, with higher values indicating higher levels of pleasure. The PACES has already demonstrated satisfactory psychometric properties for assessing enjoyment in physical activity (Mullen et al., 2011), with acceptable internal consistency in studies conducted in Portugal (Teques et al., 2020).

Confounders

Physical Activity

Daily physical activity will be objectively measured with accelerometry (Actigraph GT3X, Pensacola, FL). Devices will be positioned on the right hip to record movements during waking hours over seven consecutive days, excluding water-related activities. The data will be processed using Actilife software (v6.13.5) and categorized into sedentary, light, and moderate-to-vigorous activity levels.

Self-reported physical activity will be collected through the short form of the international physical activity questionnaire (Rosa et al., 2015). Participants will provide details on the frequency and duration of walking, moderate and vigorous activities, and their average daily sitting time. All activity data will be analyzed following the methods outlined by Craig et al. (2003).

Dietary Habits

Dietary habits will be assessed through the 4-day food record (three weekdays and one weekend). Participants will be asked to record all daily food and drink consumed on a paper sheet. The food will be properly encoded and analyzed using the adapted Food Processor Plus® software (ESHA Research Inc., Salem, Oregon, USA) (Wanderley et al., 2013).

Discussion

This study presents the protocol of the Boxe4Ageing program, a quasi-experimental controlled trial designed for older Portuguese adults living in the community. The Boxe4Ageing aims to verify the effectiveness of two physical exercise regimes (BT and MT) with a CG on cognitive performance, brain activity, physical fitness, and risk of falls. Both exercise programs will last 24 weeks (2 sessions per week), and participants from the 3 groups (BT, MT, and CG) will be assessed at baseline, 12 weeks after the beginning of the exercise sessions, post-intervention, and after 12 weeks of detraining. We hypothesized that both physical exercise programs will prompt similar positive changes in the outcomes (i.e., cognitive performance, brain activity, physical fitness, and risk of falls) compared to CG.

It is well-established that older adults should engage in physical exercise programs to sustain and improve their physical fitness and general health (DiPietro et al., 2020; Lima et al., 2025). MT has been the exercise regime most recommended by the World Health Organization for older adults (DiPietro et al., 2020).

Evidence coming from other physical exercise regimes such as BT has also revealed promising results in different outcomes in clinical conditions such as Parkinson's disease (Domingos et al., 2019), cancer (Doherty et al., 2021) , and stroke survivors (Ersoy & Iyigun, 2024). However, there is still a lack of evidence regarding the effectiveness of BT in apparently healthy older populations and whether the potential benefits are comparable to those from MT. Combs et al. (2011), and Domingos et al. (2019) showed that BT improved neuromotor skills, balance, and functional mobility, which are critical for reducing the risk of falls in populations with neurodegenerative conditions. Yusuf et al. (2024) showed that boxing intervention enhanced the quality of life and emotional well-being of Parkinson's disease patients by fostering motivation and engagement in exercise routines. Doherty et al. (2021) showed that

8 weeks of BT improve physical fitness and quality of life in women with breast and ovarian cancer. All the studies summarized above did not have CG or an MT.

The scope of the benefits from BT may extend beyond clinical populations, suggesting a broader applicability of boxing for older adults without underlying health conditions. The application of BT for healthy older adults, particularly its potential to improve general physical fitness, cognitive function, and psychosocial health, remains underexplored, and the Boxe4Ageing program will provide valuable insights in this regard. Importantly, we expect boxing interventions to provide health-related benefits comparable to MT, but to our knowledge, no studies have done this before in healthy older adults. Rapid decision-making, complex motor patterns, and high-intensity aerobic activity simultaneously target multiple physical and cognitive health domains (Morris et al., 2019). For example, learning sequences of punches and defensive movements may stimulate cognitive processing and executive function, while the physical demands of boxing improve cardiovascular fitness, muscular strength, and coordination (Muñoz-Vásquez et al., 2023). These dynamic demands align with findings from other neuromotor interventions, which highlight the importance of integrating cognitive and physical challenges for promoting neuroplasticity and reducing age-related declines in cognitive function (Gajewski & Falkenstein, 2016). In the context of aging, these multidimensional benefits align closely with strategies for maintaining independence and quality of life (DiPietro et al., 2020).

Despite its promise, boxing as a structured intervention for older adults faces several challenges. Existing studies often lack detailed protocols, making it difficult to replicate interventions or evaluate their safety and efficacy across different populations (Domingos et al., 2019). Essential components, such as the types of punches (jab, cross, hook, and uppercut), the positioning of participants (e.g., sitting *versus* standing), and whether exercises involve the use of a punching bag or are limited to shadow boxing, are inconsistently reported (Morris et al., 2019). Additionally, there is a paucity of guidelines addressing contraindications and precautions, which are critical for ensuring the safe participation of older adults in BT (Morris et al., 2019).

The Boxe4Ageing protocol aims to fill these gaps by providing a standardized and replicable framework tailored to the needs of healthy older adults. The protocol targets various health-related outcomes by incorporating neuromotor, resistance, muscular power, and aerobic components, including balance, strength, functional capacity, and cognitive performance. Furthermore, the comprehensive evaluation plan, which includes physical, cognitive, and psychosocial assessments, allows for a complete analysis of the intervention's impact.

Future results from this study have the potential to substantiate the growing body of evidence supporting boxing as a viable exercise modality for older adults. If the Boxe4Ageing protocol induces health-related improvements comparable to those from MT, it will represent an alternative physical exercise approach for aging populations.

Boxe4Ageing has many strengths. It is described in detail, allowing the replication of its methods in future research. The study outcomes will be ascertained with validated and reliable laboratory and field tests that will allow researchers to ensure the effectiveness of both physical exercise regimes. Results from BT will be compared against those of MT and CG. The protocol will last 24 weeks, which is longer than other studies, and include a detraining period, which is novel in this research field (BT in older adults). This protocol study also has some limitations that must be acknowledged. It is a quasi-experimental design, meaning that participants will not be randomly assigned to one of the 3 study arms. The participants will remain unaware of their specific physical exercise intervention group until the beginning of the exercise sessions, which can lead to an initial rejection of the older adults who will be allocated to BT. The weekly frequency will be 2 times per week, which is lower than the international physical activity recommendations for older adults. These limitations must be considered when the study results are interpreted.

Conclusions

This study aims to contribute to bridging significant gaps in literature. It underscores the importance of developing a safe, engaging, and effective exercise program for older adults, grounded in evidence and

supported by detailed methodologies. The anticipated outcomes have the potential to inform future guidelines, providing a scalable and impactful intervention for promoting healthy ageing.

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