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ORIGINAL RESEARCH

The Efficacy of a Multicomponent Functional Fitness Program Based on Exergaming on Cognitive Functioning of Healthy Older Adults: A Randomized Controlled Trial

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Background and Objectives: Regular physical exercise can attenuate age-related cognitive decline. This study aimed to investigate the effect of a physical exercise multicomponent training based on exergames on cognitive functioning (CF) in older adults. ***Research Design and Methods:*** This randomized controlled trial included older adults aged 61–78. Participants were randomly allocated to an intervention group (IG; $n = 15$) or active control group (CG; $n = 16$). The IG was exposed to a combined training with traditional exercise and exergaming, twice a week over a period of 12 weeks. The CG performed only traditional sessions. CF was assessed by the Cognitive Telephone Screening Instrument. The time points for assessment were at zero (pretest), 12 (posttest), and 17 weeks (follow-up). ***Results:*** Active CG and IG increased from pretest to posttest in short-term memory (STM), long-term memory (LTM), and Cognitive Telephone Screening Instrument total score $1.98 > Z < 3.00$, $ps < .005$, with moderately large positive effects ($.36 > r < .54$). A significant increase was seen from posttest to follow-up in STM, Z = 2.74, p = .006, and LTM, Z = 2.31, $p < .021$, only in IG. Across the two time periods posttest to follow-up, there were significant interaction effects between program type and time for STM ($p = .022$, $\eta_p^2 = .17$) and LTM ($p = .004$, $\eta_p^2 = .25$), demonstrating a more beneficial effect of the exergames intervention compared to the CG. ***Discussion and Implications:*** The integration of exergaming in a multicomponent functional fitness exercise might have the potential to maintain and improve CF (in particular, STM and LTM) in older adults.

Keywords: cognition, exercise/physical activity, memory

Background and Objectives

Cognitive functioning (CF) declines with age. There is evidence that regular physical exercise (Bherer, Erickson, & Liu-Ambrose, 2013; Northey, Cherbuin, Pumpa, Smee, & Rattray, 2018) and cognitive training (Ballesteros, Kraft, Santana, & Tziraki, 2015; Ihle, Albiński, Gurynowicz, & Kliegel, 2018) are nonpharmaceutical interventions that attenuate age-related cognitive decline and improve CF in older adults.

The biological mechanisms by which physical exercise and cognitive training favor improvements in CF are not completely clarified. Studies with animals indicate that the neurobiological mechanisms associated with the benefits of physical exercise could be explained at two levels: supramolecular (an increase of the neuronal network that becomes more functional) and molecular (induced changes based on brain-derived neurotrophic factor and increased production of insulin-like growth factor 1; Bherer et al., 2013). In humans, the findings suggest that physical exercise is associated with changes in brain structures like increases in gray and white matter in the frontal, prefrontal, and temporal regions (Colcombe et al., 2003) and a larger left and right hippocampus (Erickson et al., 2009). Complementary benefits through brain structural and functional changes have been also seen as a result of cognitive training (such as increased brain volume, cortical thickness, density, coherence of white-matter tracts, and increased task-related activation; Belleville & Bherer, 2012). Nonetheless, there is still an open question about the training intensity, duration, frequency, and type of exercise and cognitive activities most efficient to stimulate CF in older adults.

With the focus on preventing age-related cognitive declines and stimulating different CF domains, much attention has been given to combined physical and cognitive training programs, since those have shown larger effects than a single-domain training module (Karssemeijer et al., 2017; Stojan & Voelcker-Rehage, 2019). The recent literature shows that interventions based on multiple activities combining physical exercises and cognitive training seem to be generally more effective in improving cognition in older adults (Bruderer-Hofstetter, Rausch-Osthoff, Meichtry, Münzer, & Niedermann, 2018). Currently, exergames (i.e., physically active video gaming) have been proposed as a novel technological solution to assist older adults in improving their general functional ability (Muñoz, Gonçalves, Gouveia, Cameirão, & Bermúdez i Badia, 2019). Exergaming combines physical and cognitive exercise in an interactive

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digital, augmented, or virtual game-like environment. Some examples of commercial exergame systems are Nintendo, Wii, Xbox Kinect, or Dance Revolution (Stojan & Voelcker-Rehage, 2019). Besides the known barriers related to cost, availability, setup, and need of expertise in using technology, it is believed that using exergames to combine physical activity and cognitively demanding tasks may result as an effective strategy to improve CF, particularly in older adults (Stanmore, Stubbs, Vancampfort, de Bruin, & Firth, 2017).

Although there is some reluctance in using new technology solutions due to the lack of capabilities of older adults, exergaming seems to be at least equally or even more effective than other isolated physical interventions on CF in healthy older adults (Stojan & Voelcker-Rehage, 2019). Yet, despite these findings, the effects of exergaming on cognitive and brain function are still poorly understood. So far, few studies have also analyzed the retention of the gains in CF domains in the follow-up of exergaming interventions. It also remains unclear which cognitive domains (such as short-term memory [STM] and long-term memory [LTM], working memory, executive functioning, inductive reasoning, etc.) may benefit most from exergaming interventions. Moreover, to the best of our knowledge, no other single study has described the effectiveness of purposely developed user-centered designed exergames for older adults, taking into consideration the most relevant functional fitness components, as well as meaningful environments for this population (i.e., local-related cultural and traditional activities covering several touristic activities in different places).

Based on previous studies using exercise programs with exergames, we hypothesized that a 12-week exercise multicomponent training composed of two different sessions (i.e., a group traditional training session and another session based on exergames) has greater potential to improve overall CF than a group traditional training exercise program only. It is expected that the results of this study support the utilization of the multicomponent exercise based on exergames by kinesiologists and sport sciences professionals. Therefore, this study aimed to investigate the effect of an exercise multicomponent training program based on exergames (compared to an active control condition) on the different cognitive abilities (i.e., STM, LTM and working memory, verbal fluency, and inductive reasoning) of a group of healthy community-dwelling older adults from Madeira Island, Portugal.

Research Design and Methods

Study Design

A randomized controlled trial (RCT) was conducted to assess the effect of a multicomponent functional fitness program based on exergaming on CF of healthy older adults from Madeira Island, Portugal. In the active control group (CG), the exergaming component was replaced by traditional training activities.

Participants

Participants were recruited from a local senior gymnasium in Funchal, Portugal, by invitation of the sports science professionals that work at this gymnasium, considering their regularity in attending the training sessions and their availability for the study. One research assistant followed the entire selection process, presented the main goals of the project, and scheduled all the baseline assessments.

A trained group of assessors evaluated participants for eligibility criteria in the local gymnasium. Key inclusion criteria were as follows: (a) seniors in a range of age from 60 to 80 years old; (b) voluntary motivation to participate in the study; (c) no cardiac diseases based on self-reports and historical data in the gym; (d) sufficient CF to understand the procedure, game rules, and study goals assessed by the Mini-Mental State Examination [Folstein, Folstein, and McHugh, (1975); Guerreiro et al. (1994); for cognitive impairment screening, a cut-off score of 15 was considered for those who were illiterate, 22 for those with 1–11 years of education, and 27 for those with higher education]; and (e) to present no balance impairments, compatible with scoring 10–16/16 in the short version of the Fullerton Advanced Balance scale.

The optimal sample size calculation was based on results of previous research (Gouveia et al., 2016), using G*Power3 (Faul, Erdfelder, Lang, & Buchner, 2007). A priori, repeated-measures analysis of variance indicated that a total sample size of 32 was needed to achieve 95% power to detect an interaction effect size of 0.30 at the .05 level of significance. A potential 15% attrition rate was considered for the RCT, and a total of 37 participants were targeted in this study.

A simple randomization process was used to allocate the eligible participants into one of the two groups, defined as the intervention group (IG) and the active CG. Numbers were randomly selected to form the two groups, using a random number generator software (Excel, Microsoft Corporation, Redmond, WA). Clusters (of two participants) were only used in the randomization for special situations (couples or relatives), in order to prevent contamination. Blinding was used in the generation of the allocation sequence and in the assignment of the participants to one of the two groups. These tasks were carried out by an independent person. The independent person was part of the research laboratory, but did not take part in any other task related to the present study.

The intervention protocol was implemented by two research assistants with professional experience in teaching special populations and academic education in physical education and sports. Training for the intervention implementation included theoretical discussions, lab demonstrations, and pilot sessions with older adults not included in this study. The research assistants were full-time dedicated to the preparation of the intervention for 1 month. Process evaluation was conducted during the intervention through individual observation/supervision by a senior researcher.

In terms of the overall organization of the study, the recruitment and baseline assessments were done at Week #–2 and Week #–1. Randomization to conditions was done at Week # –1 after finishing all assessments. Finally, Week #0 was used to familiarize the groups of older adults with the new exercise routines.

Ethical approval of this study was granted by the Ethics Committee of the Faculty of Human Kinetics, University of Lisbon, CEFMH No:14/2017, Project: "AHA: Augmented Human Assistance." Informed consent was provided by all participants during the enrollment phase, before any assessment. Written and verbal information about the study was given to all volunteers. All data collection and management procedures took into account the participants' right to privacy and confidentiality.

Exercise Program Intervention

The eligible participants allocated to the IG and the CG were submitted to an equivalent fitness training routine: frequency, intensity, time, and type (Heyward & Gibson, 2014). Exercise frequency was defined as twice per week, while the intensity was intended to keep users exercising at moderate to vigorous physical activity levels. The Borg Rating Scale (Borg, 1982) was used to monitor perceived exertion during the classes. The time or duration of the training was defined as 45 min/session. Finally, the type of training routine was designed considering a multidimensional and multistage workout (Bushman & American College of Sports Medicine, 2017) structured into three main components: (a) 5–10 min of warming up (stretching, muscular preparation); (b) 20–25 min of multidimensional physical training (intense exercise); and (c) 10 min of cooling down and stretching (muscle relaxation). In particular, the multidimensional physical training stage (20–25 min) followed the American College of Sports Medicine guidelines for older adults (Bushman & American College of Sports Medicine, 2017) considering a training that covers three key fitness areas: (a) cardiorespiratory, which represents 50% of the total session time; (b) muscle strength/endurance, ranging between 20% and 30% of the total session time, depending on the week plan; and (c) motor ability (neuromotor training), with the same preponderance. A total of 24 sessions were delivered over 12 consecutive weeks (i.e., 90-min duration, 2 days per week) between February and May 2018. The adherence level of IG and active CG was 100%.

The difference between groups (i.e., IG vs. active CG) lies in the exercise modality chosen for the multiple activities physical training stage, as described. For the active CG-specific functional fitness, exercises were chosen to be performed via group training sessions led by a sports science professional. The exercises covered (but were not limited to) marching in place, step touches, stepping on pads, and squats. No additional equipment (i.e., air pads, resistance bands, weighted balls) was used in the training. The CG and IG were exposed to similar conditions in the group traditional training exercise sessions. The IG was exposed to a combined training program with traditional exercise and exergaming. The group traditional training exercises addressed the same exercise routine as in the active CG, and it was delivered with a frequency of once per week. In addition, a training regime with exergames was delivered with the same frequency and duration, therefore completing a combined workout program of 45 min + 45 min weekly (time-matched with the Control condition). This group-based intervention, as well as individual exergaming lessons, was administered by two sport science professionals, who were responsible for delivering all exercise sessions, giving instructions on each exercise, controlling the number of repetitions and the duration of the exercise, and controlling the reaction to the training. Over the exergame training program, the duration of the interaction with the system and the game parameters introduced by the sport science professional were tailored to the participant, taking into consideration the following indicators: (a) participants' perceived exertion and (b) performance achieved during the preceding games.

System Setup and Exergames

A set of five customized exergames (i.e., "grape stomping," "rabelos," "exermusic," "toboggan," "ride," and "exerpong," see descriptions below) for older adults were used to provide a multidimensional functional fitness training program. The exergames contain local motives to trigger memories from the past and other gamification techniques that keep the users involved (Gonçalves, Muñoz, Gouveia, Cameirão, & Badia, 2017; Muñoz et al., 2019). Although each exergame has been designed to cover a main training domain (e.g., aerobic endurance, upper/lower strength, and motor ability), several game parameters were used to aid the content personalization in meeting seniors' needs. The "grape stomping" that is based on the stepping exercises recreates the environment of grape stomping aimed at producing virtual wine. This exergame covers the aerobic parameter. The "rabelos" exergame encourages people to row in a virtual boat to create an upper-body strength training experience. The "exermusic" aims to exercise the lower-limb strength and flexibility. The "toboggan ride" exergame aims to train overall balance by exercising postural stability and trunk muscular strength. Finally, the "exerpong," where players have to control a virtual paddle using lateral movements while a ball is bouncing around, aims to train aerobic endurance and general motor ability. A detailed description about the gaming system, steps taken in game development, game parameters, configurations, main objectives, punctuations and bonus, and other relevant features related to cognitive load can be found elsewhere (Muñoz, 2018, and Muñoz et al., 2019).

To create a digital playground able to demand measurable amounts of exertion in older users, we used a floor projection setup on a white 2.5 m × 3.0 m PVC surface. Player's position tracking was performed by using the KinectV2 sensor (Microsoft, Washington), which captures 25 joints anatomically distributed. Each exergame utilizes a different combination of joints for tracking body gestures that are used in the game mechanics (Gonçalves et al., 2017; Muñoz et al., 2019). The exergames were installed at the facilities of the local senior gymnasium. In this study, Week #0 (right after the baseline assessment) was used to familiarize the groups of older adults with the new exercise routines, set a rating of perceived exertion, and fix some possible technical bugs in the exergames. Mainly, we were interested in having an introductory session with the participants of the exergaming group to formally explain to them the particularities of each game.

Outcome Measures

The primary outcome in this study was CF, assessed using the Portuguese-validated version of the Cognitive Telephone Screening Instrument (COGTEL; Ihle, Gouveia, Gouveia, & Kliegel, 2017). The COGTEL consists of six subtests covering prospective memory, verbal STM and LTM, working memory, verbal fluency, and inductive reasoning, as described previously (Kliegel, Martin, & Jäger, 2007). The scores of the six subtests can be combined into a weighted total score (7.2 × prospective memory + 1.0 × verbal STM + 0.9 × verbal LTM + 0.8 × working memory + 0.2 × verbal fluency + 1.7 × inductive reasoning score); see Kliegel et al. (2007). Since prospective memory is a binary variable, it was only used in the equation that allows the calculation of the COGTEL total score. The time points for assessment were at Week #0 (pretest), Week #13 (posttest), and Week #17 (follow-up). Participants were evaluated by an independent assessor who was blinded to group assignment.

Baseline Assessments

In this study, baseline characteristics were assessed, namely (1) demographic characteristics; (2) clinical characteristics (number of medications and number of risk factors for CVD); and (3) cognition, assessed by the Mini-Mental State Test (Folstein et al., 1975). The test consists of five subsections covering orientation (0–10 points), immediate and recent memory (0–3 points each), attention capacity and counting backwards calculation (0–5 points), language (0–3), and constructive capacity (0–9 points). A total score is derived from the sum of the scores of the five subsections. (4) Balance, assessed by the Fullerton Advanced Balance scale (Rose, Lucchese, & Wiersma, 2006), includes the following 10 items: (a) standing with feet together and eyes closed, (b) reaching forward to retrieve an object (pencil) held at shoulder height with outstretched arm, (c) turning 360° in a right and left direction, (d) stepping up and over a 15-cm bench, (e) tandem walking, (f) standing on one leg, (g) standing on foam with eyes closed, (h) jumping for distance, (i) walking with head turns, and (j) recovering from an unexpected loss of balance. Each test item is scored using a 4-point ordinal scale (0–4), resulting in a maximum score of 40 possible points, representing an optimal balance performance. (5) Functional fitness components, upper and lower body strength (chair stand and arm curl tests), lower body flexibility (sit and reach test), agility and dynamic balance (8 foot-up-and-go test), and aerobic endurance (6-min walk test) were assessed. A detailed description of the evaluation procedures (namely, equipment, procedure, scoring, and safety precautions) are detailed in the senior fitness test manual (Rikli & Jones, 2001). (6) Habitual physical activity was assessed using the Baecke questionnaire (Baecke, Burema, & Frijters, 1982). With reference to the last year, this questionnaire includes a total of 16 questions organized in three domains: PA at work/housework, sport and leisure time, and the latter excluding sports.

If the subjects were not employed or if they were retired, their occupation was coded as homemaker. The questionnaire also provides a measure of total PA, which is the sum of these three specific domains.

Statistical Analysis

Statistical analyses included descriptive statistics, the Mann–Whitney *U* Test, and the Wilcoxon Signed-Rank Test to assess the differences between pretest to posttest and posttest to follow-up. The effect size was calculated based on z values. In addition, a mixed between-within subjects' analysis of variance was conducted to assess the impact of the intervention/control on participants' total scores on the COGTEL and across the three time periods (pretest, posttest, and follow-up). Data-analysis assumptions were verified. The level of confidence was set at 95%. Data were analyzed using IBM SPSS statistics (version 25; SPSS Inc., an IBM Company, Chicago, IL).

Results

Advertisements in a senior gymnasium from the Funchal city started in November 2017. Recruitment started in January 2018 and was completed at the beginning of February 2018. A total of 233 older adults were recruited and assessed for potential enrollment. Of these, according to previous sample size calculations, 37 older adults were eligible and randomly allocated to the IG ($n = 19$) or to the active CG, which performed a group traditional exercise training program ($n = 18$). A total of 31 participants completed the study (IG; $n = 15$; CG; $n = 16$). The intervention protocol was fully applied during the course of the study, as planned. Adherence for the participants who completed the study, assessed by the proportion of sessions attended, was between 79% and 89%. No adverse events (i.e., falls) or side effects were associated with the exercise intervention or the assessments. However, other events led to attrition, as described in Figure 1.

Participants' characteristics at baseline are summarized in Table 1.

Pretest to Posttest

Descriptive statistics for median, minimum, and maximum for all cognitive domains at baseline and immediately following the intervention are presented in Table 2. For the active CG, a statistically significant increase was observed from pretest to posttest in STM, LTM, and COGTEL total score following the participation in the training program, $2.81 > z < 3.00$, $ps < .005$, with a large effect size ($.50 > r < .53$). No other statistically significant differences were seen. Similarly, for the IG, a statistically significant increase was seen from pretest to posttest in STM, LTM, and COGTEL total score following the participation in the training program with the exergames, $.198 > z < 2.98$, $ps < .047$, with an effect size ranging between medium and large ($.36 > r < .54$). No other statistically significant differences were seen (Table 2).

Posttest to Follow-Up

All participants were assessed again 4 weeks after the completion of the intervention (detraining period). Descriptive results related to the follow-up are presented in Table 3. In the CG, there were no significant differences between posttest and follow-up in the cognitive domains. For the IG, a statistically significant increase was seen from posttest to follow-up in STM, $z = 2.74$, $p = .006$, and LTM $z = 2.31$, $p < .021$, both with a large effect size ($r = .50$ and $r = .42$, respectively; Table 3).

Effect Size Estimates

A mixed between-within subjects' analysis of variance was conducted to assess the impact of the IG versus active CG on participants' scores on COGTEL total score, across the three time periods (pretest, posttest, and 4-week follow-up). This analysis revealed a nonsignificant interaction effect (Wilk's Lambda = .91, $F(2, 28) = 1.36$, $p = .27$, $\eta_p^2 = .09$). There was a statistically significant main effect for time (Wilk's Lambda = .25, $F(2, 28) = 42.86$, $p < .001$, $\eta_p^2 = .75$). The COGTEL total score increased across the three time periods. There was a significant main effect for group, $F(1, 29) = 5.03$, $p = .033$, Partial Eta Squared = .15, showing that the IG exposed to the exergaming program revealed a significantly higher CF when compared to the CG, which was exposed to a group traditional exercise training program only (see Figure 2).

Following the significant results regarding STM and LTM previously outlined, we additionally conducted explorative analyses for these cognitive domains. Across two time periods (posttest and follow-up) in STM, there was a significant interaction between program type and time, Wilk's $\lambda = .83$, $F(1, 29) = 5.88$, $p = .022$, Partial Eta Squared = .17. We also found a substantial main effect for time, Wilk's $\lambda = .87$, $F(1, 29) = 4.50$, $p = .043$, Partial Eta Squared = .13. Similar results were seen for the interaction between program type and time on LTM, Wilk's $\lambda = .75$, $F(1, 29) = 9.62$, $p = .004$, Partial Eta Squared = .25. There was no significant effect for time. Finally, the main effect comparing the two types of intervention was not significant for both STM and LTM. Moreover, a detailed analysis in LTM across the three time periods showed a significant interaction between program type and time, Wilk's $\lambda = .73$, $F(2, 28) = 5.32$, $p = .011$, Partial Eta Squared = .28, as well as a substantial main effect for time, Wilk's $\lambda = .54$, $F(2, 28) = 12.18$, $p < .001$, Partial Eta Squared = .47. No significant effect was seen comparing the two types of intervention on LTM.

Discussion and Implications

The two groups evaluated in this RCT (i.e., IG and active CG) showed significant gains in the main score of CF right after the intervention, with a large positive effect. There was a significant

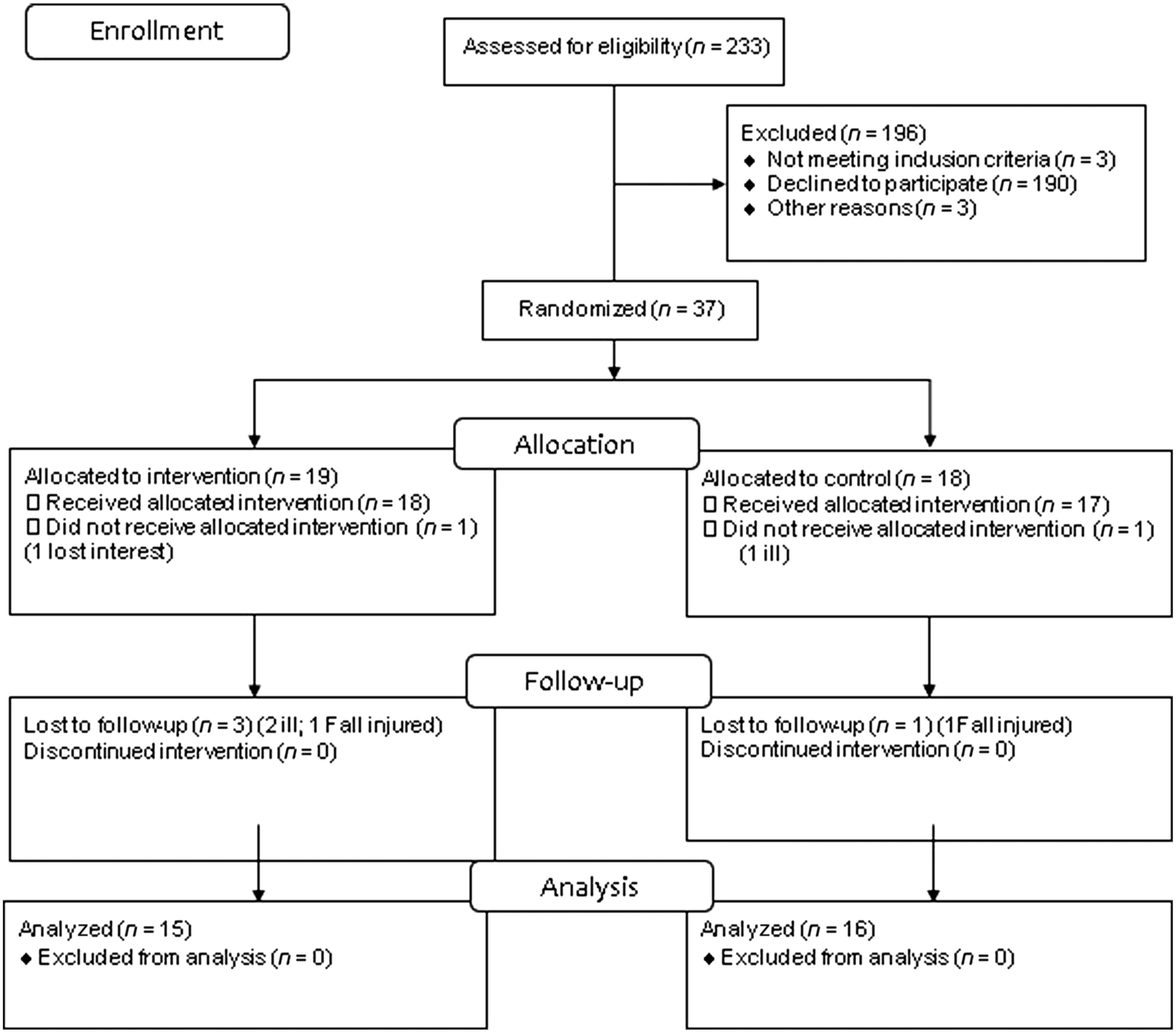

Figure 1 — Participant flow through the phases of the randomized controlled trial.

main effect for group, showing that the IG revealed a higher CF when compared to the active CG. A detailed analysis through the dimensions of the COGTEL showed significant increases in STM and LTM, with a moderately large positive effect. Most importantly, across the two time periods posttest to follow-up, there were significant interaction effects between program type and time for STM and LTM, demonstrating a more beneficial effect of the exergames intervention when compared to the CG.

Our results support the idea that the use of a physical exercise multicomponent training intervention based on exergames and group traditional training exercise may have more benefits on CF than a single-module program. One possible explanation for the greater cognitive benefit found in IG compared with CG could be the effect of added mental stimulation exposed on the exergames condition. Given that both groups exerted similar effort over 12 weeks, the main difference between the two interventions was the exergaming experience. In terms of cognitive load, the set of five customized exergames used in this study requires additional focus, expanded divided attention, enhanced decision making, and higher memory training (Muñoz, 2018).

Currently, a growing literature has been developed to better understand the effectiveness of using exergames. Several RCTs have found moderate to large positive effects on CF of exergame interventions in comparison to control conditions (Stanmore et al., 2017). Other studies have found benefits in executive functioning, specifically inhibitory control and cognitive flexibility (Anderson-Hanley et al., 2012; Barcelos et al., 2015; Kayama et al., 2014). More recently, significant positive changes were found in general memory, visual memory, verbal memory, and attention in those who were exposed to the intervention with physical games (Hedayati,

Table 1 Participants' Characteristics at Baseline: Sociodemographic, Clinical, Cognition, Functional Fitness, and Physical Activity

Variables	Control group (*n* = 16)	Intervention group (*n* = 15)
Sociodemographic		
Female *n* (%)	12 (75%)	10 (67%)
Age in years (*SD*)	69.1 (4.2)	67.6 (5.0)
Education in years (*SD*)	2.3 (1.1)	2.3 (1.2)
Cognitive function		
STM	3.6 (1.1)	3.8 (1.1)
WM	4.4 (1.6)	4.8 (2.0)
VF	16.7 (9.3)	21.9 (5.5)***
IR	1.3 (1.2)	2.1 (1.6)
LTM	4.4 (1.1)	4.4 (1.2)
COGTEL total score	18.3 (6.0)	23.0 (5.6)
MMSE *n* (*SD*)	28.1 (1.2)	27.5 (1.4)
Functional fitness		
Chair stand test *n* (*SD*)	17.6 (4.1)	17.3 (2.9)
Arm curl test *n* (*SD*)	18.9 (3.5)	17.0 (3.4)
Chair reach test in cm (*SD*)	6.9 (8.6)	6.9 (9.7)
8 foot-up-and-go test in s (*SD*)	4.2 (0.6)	4.2 (0.5)
6-min walk test in m (*SD*)	596.6 (91.8)	609.0 (63.5)
FAB *n* (*SD*)	13.1 (2.2)	13.6 (2.3)
Physical activity		
Household score *n* (*SD*)	3.0 (0.4)	2.9 (0.3)
Sports score *n* (*SD*)	2.5 (0.5)	2.5 (0.7)
Leisure time score *n* (*SD*)	2.6 (0.5)	2.6 (0.4)
Total score *n* (*SD*)	8.0 (0.9)	8.0 (1.0)
Clinical parameters		
Medication *n* (*SD*)	3.1 (1.6)	3.3 (2.4)
RF-CDV *n* (*SD*)	4.0 (0.9)	3.7 (1.1)

Note. CVD = cardiovascular disease; STM = short-term memory; WM = working memory; VF = verbal fluency; IR = inductive reasoning; LTM = long-term memory; COGTEL = cognitive telephone screening instrument total score; MMSE = Mini-Mental State Examination; FAB = Fullerton Advance Balance Scale; Medication = number of medications; RF-CDV = number of risk factor for CVD. ***$p < .05$ Mann–Whitney *U* Test.

Sum, Hosseini, Faramarzi, & Pourhadi, 2019). Another similar intervention study showed retention and improvement in attention, working, visual, and implicit memories, and processing speed (Eggenberger, Schumacher, Angst, Theill, & de Bruin, 2015; Nouchi et al., 2014; Vaughan et al., 2014). The most recent systematic review on the topic has confirmed the beneficial effects of exergaming on overall CF, but regarding individual cognitive domains, the review's authors concluded that there is no consistency yet due to the heterogeneous results (Stojan & Voelcker-Rehage, 2019).

Several factors may induce these heterogeneous results. First, the covered physical and cognitive components of the gaming situations that are highly correlated to the demands of each task present a great variability across the studies. Future studies should follow specific guidelines on the frequency, intensity, time, and type of intervention programs to better clarify the features of the most effective interventions, as well as for replication purposes. A second issue concerns the meaningful environments of the game situation for this specific population. This aspect has a huge impact on the adherence and the motivation to engage. Most of the studies did not address this issue. The present study overcame this challenge by designing game-oriented activities based on local cultural traditions and relating them to the most important functional fitness parameters to keep people's independency (Gonçalves et al., 2017; Muñoz et al., 2019). A further issue concerns the different instruments used to assess performance in cognitive domains across prior studies that, in some cases (due to ceiling effects, especially in healthy older adults), are less sensitive to access training program-induced changes. In this study, we used the COGTEL that has been demonstrated to allow a more fine-grained differentiation between individuals within the healthy range of functioning in a broad set of cognitive domains (Ihle et al., 2017; Kliegel et al., 2007).

Surprisingly, in our study, performance kept increasing in STM and LTM from the posttest to follow-up, but only for the group that was exposed to exergaming sessions. This is an important, promising result that may reflect a longer prolongation of the response to the intervention with exergaming in older adults. From a neuroscience perspective, the benefits found in STM and LTM in our study can be explained by a set of changes related to brain structure, brain function, and brain connectivity. Regarding the brain structure, an increase in the volume in the hippocampus following physical exercise has been seen, which has an important role in memory functions (Erickson et al., 2009; Nouchi et al., 2014). As for the brain

Table 2 Findings on the Outcome Measure at Baseline and After the Intervention by Group: Control and Intervention

	Control group (*n* = 16)						Intervention group (*n* = 15)					
	Pretest		Posttest				Pretest		Posttest			
Cognitive domains	Median	Min–max	Median	Min–max	*p*	*r*	Median	Min–max	Median	Min–max	*p*	*r*
STM	4.0	1.0–5.0	5.0	3.0–8.0	.005	.50	4.0	2.0–6.0	5.0	2.0–8.0	.003	.54
WM	4.5	2.0–7.0	4.0	1.0–9.0	.695	.07	5.0	2.0–10.0	6.0	2.0–10.0	.287	.19
VF	13.5	8.0–45.0	15.5	5.0–45.0	.637	.08	22.0	13.0–31.0	25.0	11.0–51.0	.059	.34
IR	1.5	0.0–4.0	2.0	0.0–4.0	.235	.21	2.0	0.0–7.0	2.0	0.0–7.0	.437	.14
LTM	4.0	3.0–7.0	5.5	3.0–8.0	.005	.50	4.0	3.0–7.0	6.0	2.0–8.0	.047	.36
COGTEL	18.2	10.8–30.1	26.2	8.5–45.4	.003	.53	22.3	15.0–33.4	29.7	13.8–44.5	.005	.52

Note. STM = short-term memory; WM = working memory; VF = verbal fluency; IR = inductive reasoning; LTM = long-term memory; COGTEL = cognitive telephone screening instrument total score; *r* = effect size (by dividing the *z* value by the square root of *n*).

Table 3 Findings on the Outcomes Measure at Posttest and Follow-up by Group: Control and Intervention

	Control group ($n = 16$)						Intervention group ($n = 15$)					
	Posttest		Follow-up				Posttest		Follow-up			
Cognitive domains	Median	Min–max	Median	Min–max	*p*	*r*	Median	Min–max	Median	Min–max	*p*	*r*
STM	5.0	3.0–8.0	5.0	2.0–8.0	.712	.07	5.0	2.0–8.0	6.0	4.0–8.0	.006	.50
WM	4.0	1.0–9.0	5.0	2.0–8.0	.376	.16	6.0	2.0–10.0	5.0	2.0–8.0	.647	.08
VF	15.5	5.0–45.0	17.5	3.0–48.0	.086	.30	25.0	11.0–51.0	23.0	15.0–61.0	.955	.01
IR	2.0	0.0–4.0	2.0	0.0–6.0	.068	.32	2.0	0.0–7.0	2.0	1.0–7.0	.399	.15
LTM	5.5	3.0–8.0	5.0	2.0–7.0	.109	.28	6.0	2.0–8.0	7.0	3.0–8.0	.021	.42
COGTEL	26.2	8.5–45.4	25.8	6.0–41.6	.660	.08	29.7	13.8–44.5	31.9	21.0–46.0	.088	.31

Note. STM = short-term memory; WM = working memory; VF = verbal fluency; IR = inductive reasoning; LTM = long-term memory; COGTEL = cognitive telephone screening instrument total score; r = effect size (by dividing the z value by the square root of n).

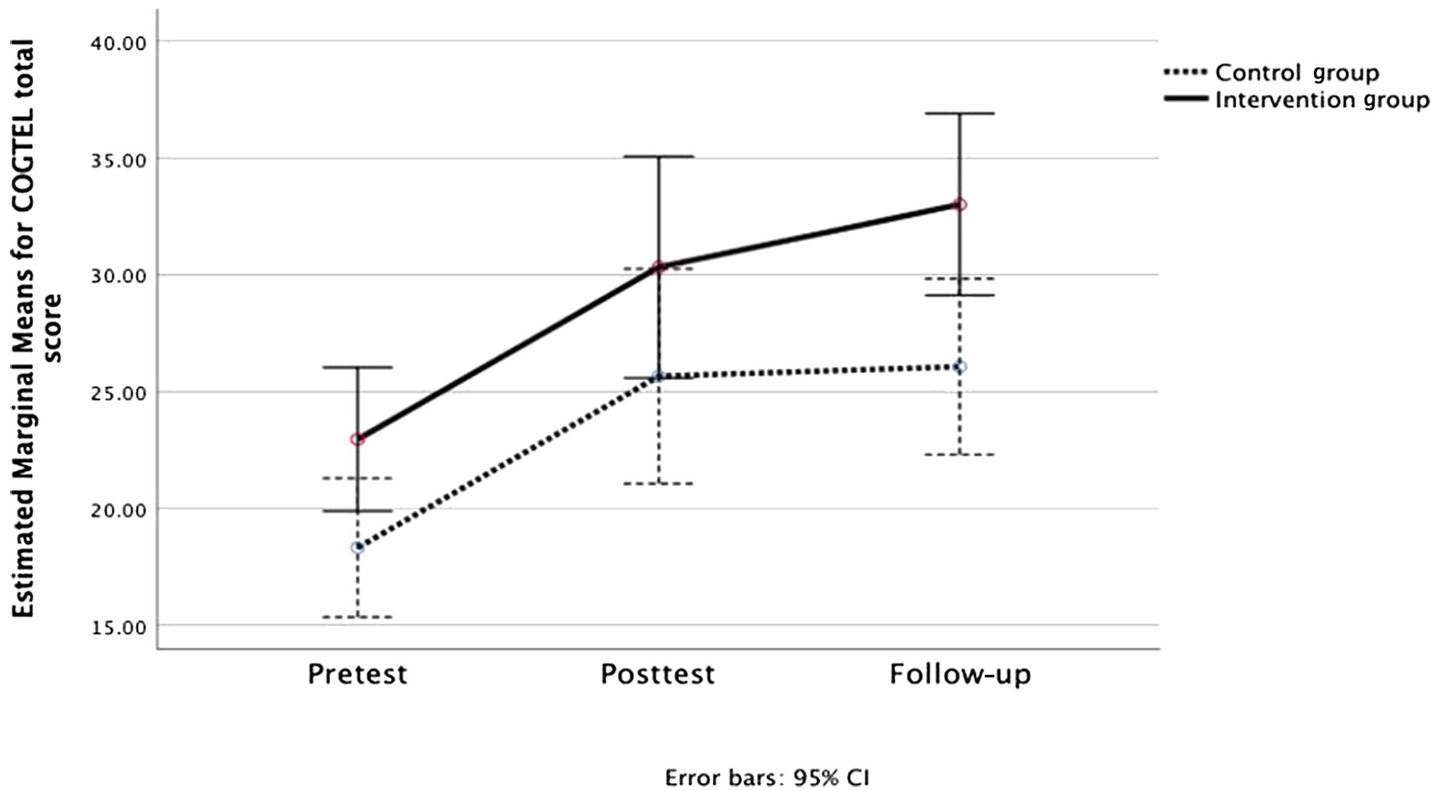

Figure 2 — Graphic representation of the results from the mixed between-within subjects' analysis of variance, showing the change in COGTEL mean total scores over time for the IG and the CG (error bars: 95% CI). CI = confidence interval; IG = intervention group; CG = control group; COGTEL = cognitive telephone screening instrument total score.

function, an increase in the default mode network has been found following physical exercise, which is associated with better memory performance (Hampson, Driesen, Skudlarski, Gore, & Constable, 2006). Finally, it has been speculated that exercise-induced neurogenesis and angiogenesis is potentiated by an increase in some molecules such as brain-derived neurotrophic factor, insulin-like growth factor, and vascular endothelial growth factor (Bherer et al., 2013). However, more evidence is needed to better understand this complex phenomenon.

This study has several contributions. First, the physical exercise multicomponent training intervention including exergames and the group traditional training exercise sessions was based on an equivalent fitness training routine following specific exercise prescription guidelines for older adults. Second, the exergaming-related tasks were based on local cultural traditions that contribute to a meaningful environment. This is an important predictor of the adherence and motivation to engage in the program. Third, this study contributes further evidence for the positive effects of the introduction of exergaming targeting a group of healthy community-dwelling older adults. From a practical perspective, this study supports that a set of customized exergames developed from a multicomponent functional fitness perspective is a useful method to be introduced to maintain or to improve overall CF, particularly STM and LTM. Finally, another important strength of this study is that we use an active CG. This methodological design in general allows us to better demonstrate the detailed benefits of introducing an individual exergame session on CF.

We acknowledge that our findings may also be limited by factors related to sample size/characteristics and instruments. First, this sample of active older adults is very homogeneous in terms of functional fitness. It is an open question whether the same effect would emerge on less-active older adults. Second, lack of experience with exergaming could influence the outcomes; however, when analyzing the attrition rate, only involuntary reasons were given by dropouts, suggesting high acceptability and interest of the participants. Finally, the assessment of cognitive domains was supported on field-based tests. However, the COGTEL allows an excellent feasibility in applied environments such as a research context and has been shown to be a brief, reliable, and valid instrument for capturing interindividual differences in CF in healthy older adults also in field research (Ihle et al., 2017; Kliegel et al., 2007).

In summary, the results of this study suggest that the integration of customized exergaming based on a multicomponent functional fitness exercise program might have the potential to maintain and improve CF, particularly verbal STM and LTM, in healthy community-dwelling older adults. Additional research should be developed to further assess the mechanisms underlying the effect of this intervention and its effectiveness in large-scale pragmatic trials.

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References

Anderson-Hanley, C., Arciero, P.J., Brickman, A.M., Nimon, J.P., Okuma, N., Westen, S.C., . . . Zimmerman, E.A. (2012). Exergaming and older adult cognition: A cluster randomized clinical trial. *American Journal of Preventive Medicine, 42*(2), 109–119. PubMed ID: 22261206 doi:10.1016/j.amepre.2011.10.016

Baecke, J.A., Burema, J., & Frijters, J.E. (1982). A short questionnaire for the measurement of habitual physical activity in epidemiological studies. *The American Journal of Clinical Nutrition, 36*(5), 936–942. PubMed ID: 7137077 doi:10.1093/ajcn/36.5.936

Ballesteros, S., Kraft, E., Santana, S., & Tziraki, C. (2015). Maintaining older brain functionality: A targeted review. *Neuroscience and Biobehavioral Reviews, 55,* 453–477. PubMed ID: 26054789 doi:10.1016/j.neubiorev.2015.06.008

Barcelos, N., Shah, N., Cohen, K., Hogan, M.J., Mulkerrin, E., Arciero, P.J., . . . Anderson-Hanley, C. (2015). Aerobic and cognitive exercise (ace) pilot study for older adults: Executive function improves with cognitive challenge while exergaming. *Journal of the International Neuropsychological Society, 21*(10), 768–779. PubMed ID: 26581789 doi:10.1017/S1355617715001083

Belleville, S., & Bherer, L. (2012). Biomarkers of cognitive training effects in aging. *Current Translational Geriatrics and Experimental Gerontology Reports, 1*(2), 104–110. PubMed ID: 23864998 doi:10.1007/s13670-012-0014-5

Bherer, L., Erickson, K.I., & Liu-Ambrose, T. (2013). Physical exercise and brain functions in older adults. *Journal of Aging Research, 2013,* 197326. PubMed ID: 24163767 doi:10.1155/2013/197326

Borg, G. (1982). Psychophysical bases of perceived exertion. *Medicine and Science in Sports and Exercise, 14,* 377–381. PubMed ID: 7154893

Bruderer-Hofstetter, M., Rausch-Osthoff, A.K., Meichtry, A., Münzer, T., & Niedermann, K. (2018). Effective multicomponent interventions in comparison to active control and no interventions on physical capacity, cognitive function and instrumental activities of daily living in elderly people with and without mild impaired cognition—A systematic review and network meta-analysis. *Ageing Research Reviews, 45,*1–14. doi:10.1016/j.arr.2018.04.002. PubMed ID: 29679658

Bushman, B., & American College of Sports Medicine. (2017). *ACSM's Complete Guide to Fitness & Health-2nd Edition*. Champaign, IL: Human Kinetics.

Colcombe, S.J., Erickson, K.I., Raz, N., Webb, A.G., Cohen, N.J., McAuley, E., & Kramer, A.F. (2003). Aerobic fitness reduces brain tissue loss in aging humans. *The Journals of Gerontology, Series A: Biological Sciences and Medical Sciences, 58*(2),M176–M180. doi:10.1093/gerona/58.2.M176

Eggenberger, P., Schumacher, V., Angst, M., Theill, N., & de Bruin, E.D. (2015). Does multicomponent physical exercise with simultaneous cognitive training boost cognitive performance in older adults? A 6-month randomized controlled trial with a 1-year follow-up. *Clinical Interventions in Aging, 10,* 1335. PubMed ID: 26316729

Erickson, K.I., Prakash, R.S., Voss, M.W., Chaddock, L., Hu, L., Morris, K.S., . . . Kramer, A.F. (2009). Aerobic fitness is associated with hippocampal volume in elderly humans. *Hippocampus, 19*(10), 1030–1039. doi:10.1002/hipo.20547

Faul, F., Erdfelder, E., Lang, A., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*(2), 175–191. PubMed ID: 17695343 doi:10.3758/BF03193146

Folstein, M.F., Folstein, S.E., & McHugh, P.R. (1975). Mini-mental state: a practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research, 12*(3), 189–198. PubMed ID: 1202204 doi:10.1016/0022-3956(75)90026-6

Gonçalves, A., Muñoz, J., Gouveia, E., Cameirão, M.S., & Badia, S.B. (2017). Portuguese tradition inspired exergames for older people - strategic tools to promote functional fitness. *Proceedings of the International Congress on Sports Sciences Research and Technology Support,* 6–7. Retrieved from https://www.scitepress.org/Papers/2017/66018/66018.pdf

Gouveia, B.R., Jardim, H.G., Martins, M.M., Gouveia, E.R., Freitas, D.L., Maia, J.A., & Rose, D.J. (2016). An evaluation of a nurse-led rehabilitation programme (the ProBalance Programme) to improve balance and reduce fall risk of community-dwelling older people: A randomised controlled trial. *International Journal of Nursing Studies, 56,* 1–8. PubMed ID: 26742607 doi:10.1016/j.ijnurstu.2015.12.004

Guerreiro, M., Silva, A.P., Botelho, A., Leitão, O., Castro-Caldas, A., & Garcia, C. (1994). Adaptação à população portuguesa da tradução do mini mental state examination (MMSE). *Revista Portuguesa De Neurologia, 1,* 9–10.

Hampson, M., Driesen, N.R., Skudlarski, P., Gore, J.C., & Constable, R.T. (2006) Brain connectivity related to working memory performance. *The Journal of Neuroscience, 26*(51), 13338–13343. PubMed ID: 17182784 doi:10.1523/JNEUROSCI.3408-06.2006

Hedayati, M., Sum, S., Hosseini, S.R., Faramarzi, M., & Pourhadi, S. (2019). Investigating the effect of physical games on the memory and attention of the elderly in adult day-care centers in Babol and Amol. *Clinical Interventions in Aging, 14,* 859–869. PubMed ID: 31190772 doi:10.2147/CIA.S196148

Heyward, V.H., & Gibson, A. (2014). *Advanced fitness assessment and exercise prescription* (7th ed.). Champaign, IL: Human Kinetics.

Ihle, A., Albiński, R., Gurynowicz, K., & Kliegel, M. (2018). Four-week strategy-based training to enhance prospective memory in older adults: Targeting intention retention is more beneficial than targeting intention formation. *Gerontology, 64*(3), 257–265. PubMed ID: 29402862 doi:10.1159/000485796

Ihle, A., Gouveia, É.R., Gouveia, B.R., & Kliegel, M. (2017). The cognitive telephone screening instrument (COGTEL): A brief, reliable, and valid tool for capturing interindividual differences in cognitive functioning in epidemiological and aging studies. *Dementia and Geriatric Cognitive Disorders Extra, 7*(3), 339–345. PubMed ID: 29118786 doi:10.1159/000479680

Karssemeijer, E.G.A., Aaronson, J.A., Bossers, W.J., Smits, T., Olde Rikkert, M.G.M., & Kessels, R.P.C. (2017). Positive effects of combined cognitive and physical exercise training on cognitive function in older adults with mild cognitive impairment or dementia: A meta-analysis. *Ageing Research Reviews, 40,* 75–83. PubMed ID: 28912076 doi:10.1016/j.arr.2017.09.003

Kayama, H., Okamoto, K., Nishiguchi, S., Yamada, M., Kuroda, T., & Aoyama, T. (2014). Effect of a kinect-based exercise game on improving executive cognitive performance in community-dwelling elderly: Case control study. *Journal of Medical Internet Research, 16*(2), e61. PubMed ID: 24565806 doi:10.2196/jmir.3108

Kliegel, M., Martin, M., & Jäger, T. (2007). Development and validation of the cognitive telephone screening instrument (COGTEL) for the assessment of cognitive function across adulthood. *The Journal of Psychology, 141*(2), 147–170. doi:10.3200/JRLP.141.2.147-172

Muñoz, J.E. (2018). *Supporting physical training in healthy older adults through biocybernetic adaptation and exergaming* (Doctoral Dissertation). University of Madeira. Funchal.

Muñoz, J.E., Gonçalves, A., Gouveia, E.R., Cameirão, M.S., & Badia, S.B. (2019). Lessons learned from gamifying functional fitness training through human-centered design methods in Portuguese older adults. *Games for Health Journal, 8*(6):387–406. PubMed ID: 31368834 doi:10.1089/g4h.2018.0028

Northey, J.M., Cherbuin, N., Pumpa, K.L., Smee, D.J., & Rattray, B. (2018). Exercise interventions for cognitive function in adults older than 50: A systematic review with meta-analysis. *British Journal of Sports Medicine, 52*(3),154–160. PubMed ID: 28438770 doi:10.1136/bjsports-2016-096587

Nouchi, R., Taki, Y., Takeuchi, H., Sekiguchi, A., Hashizume, H., Nozawa, T., . . . Kawashima, R. (2014). Four weeks of combination exercise training improved executive functions, episodic memory, and processing speed in healthy elderly people. *Age, 36*(2), 787–799. PubMed ID: 24065294 doi:10.1007/s11357-013-9588-x

Rikli, R.E., & Jones, J. (2001). *Senior fitness test manual. Development and validation of a functional fitness test for community-Residing older adults*. Champaign, IL: Human Kinetics.

Rose, D.J., Lucchese, N., & Wiersma, L.D., (2006). Development of a multidimensional balance scale for use with functionally independent older adults. *Archives of Physical Medicine and Rehabilitation, 87*(11), 1478–1485. PubMed ID: 17084123 doi:10.1016/j.apmr.2006.07.263

Stanmore, E., Stubbs, B., Vancampfort, D., de Bruin, E.D., & Firth, J. (2017). The effect of active video games on cognitive functioning in clinical and non-clinical populations: A meta-analysis of randomized controlled trials. *Neuroscience and Biobehavioral Reviews, 78,* 34–43. PubMed ID: 28442405 doi:10.1016/j.neubiorev.2017.04.011

Stojan, R., & Voelcker-Rehage, C. (2019). A systematic review on the cognitive benefits and neurophysiological correlates of exergaming in healthy older adults. *Journal of Clinical Medicine, 8*(5), 734. doi:10.3390/jcm8050734

Vaughan, S., Wallis, M., Polit, D., Steele, M., Shum, D., & Morris, N. (2014). The effects of multimodal exercise on cognitive and physical functioning and brain-derived neurotrophic factor in older women: a randomised controlled trial. *Age Ageing, 43*(5), 623–629. PubMed ID: 24554791 doi:10.1093/ageing/afu010