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Original Article

Active videogame-based physical activity vs. aerobic exercise and cognitive performance in older adults: a randomized controlled trial

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Abstract:
Objective: To compare the effects of active video game-based (AVG) physical activity program with aerobic exercise on cognitive performance among healthy older adults. **Methods:** Individuals of both sexes, aged 55 years or older, were randomly assigned to either AVG group and aerobic exercise group (active control group). For AVG program, we used games that simulated sports activities (Xbox 360 Kinect[tm]). The aerobic exercise program (moderate intensity) was conducted on treadmills and cycle ergometers. We used the CogState Battery (six tests) for cognitive performance, and the Mini-Mental State Examination (MMSE) for global cognitive assessment. **Results:** Participants of the AVG group showed significant differences in executive function and delayed recall. For executive function, the number of errors decreased and increased by the number of movements per second, while the number of movements per second increased in the delayed recall test. After 12 weeks, the participants of the aerobic group showed an increase in the following characteristics: the number of movements per second in the executive function test; execution speed increased in the visual attention and short-term memory test; the number of movements per second increased in a delayed recall test. We also observed an increase in the score of MMSE. There were no significant differences between the groups, except for short-term memory in pre-intervention. **Conclusion:** Our results and the adherence to the program suggest that sports AVG may be used as exercise alternative for older adults because it produces effects on the cognitive performance similar to the aerobic exercise.
Key words: cognition, elderly, video games, exercise, virtual reality exposure therapy.

Introduction

Human aging is associated with structural and functional changes in the brain, such as decreased in volume and neural plasticity, which may cause a decline in cognitive performances (Harada, Love, & Triebel, 2013). In this context, changes in cognitive functions can compromise people's independence and autonomy (Watson et al., 2010). Among the possible techniques to preserve and improve cognitive performance, the practice of physical exercises (Smith et al., 2010) and the use of electronic games (Latham, Patston, & Tippett, 2013) have stood out and received scientific interest. The meta-analytic and systematic review showed that aerobic exercise improved the cognitive performance of healthy older adults (Guimarães, Rocha, & Barbosa, 2014; Smith et al., 2010) and reduces their risk of impaired cognitive function (Sofi et al., 2011). Furthermore, it can contribute to the preservation of mental functions, even in people with neurodegenerative diseases (Etgen et al., 2010). Recently, in parallel with technological advancements, active video games (AVG), also called exergames, have been used as the alternatives to increasing physical and cognitive demands (Eggenberger et al. 2015; Maillot, Perrot, & Hartley, 2012). The AVG requires a body movement for their execution, having different options of commercial consoles (PlayStation, Wii and Xbox), besides games created exclusively for use in the research (Kayama et al., 2014).

Some studies on AVG and conducted with healthy older adults identified positive effects on balance tasks (Maixnerová et al. 2017), mobility (Maillot et al., 2012), physical and cognitive parameters (Eggenberger et al. 2015; Mullins, Tessmer, McCarroll, & Peppel, 2012). However, few studies have investigated the effects of AVG on cognition (Eggenberger et al. 2015; Kayama et al., 2014; Maillot et al., 2012), and no study has compared the effects of this type of intervention with aerobic exercise. In the previous studies, an AVG group was compared with an inactive control group (Maillot et al., 2012), or with standardized training (aerobic exercise, progressive strength training, flexibility and balance exercises (Eggenberger et al. 2015; Kayama et al., 2014).

Thus, there is a need to ascertain whether the use of AVG can lead to cognitive changes and be considered as an alternative to regular physical exercise. In addition, there is a need to expand information about the effects of sports AVG and physical exercise on cognitive performance. Thus, the aim of this study was to

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compare the effects of active video game-based (AVG) physical activity with aerobic exercise on cognitive performance in healthy older adults.

Material & Methods

This is a randomized clinical trial with a two-arm parallel design (active control trial), approved by the local university's ethics committee and registered in the Brazilian Clinical Trials Registry (http://www.ensaiosclinicos.gov.br/rg/RBR-9crpzc/). All participants signed the free and informed consent form.

Participants, Setting and Recruitment

The participants, setting, recruitment, design and flow of participants was previously published (Queiroz, Borgatto, Barbosa, & Guimarães, 2017). This study included men and women (≥ 55 years); non-participants in a regular physical exercise; without previous experience of AVG, and without visual or hearing impairment in identifying images, colors, and sounds. The exclusion criteria were: diagnosis of Alzheimer's or Parkinson's disease; disabling neurological diseases, psychiatric disorders, neurodegenerative diseases, cardiovascular disease; use of antihypertensive medications containing beta-blockers or depression and anxiety medications.

The randomization was performed via computer-generated random numbers to select AVG group and aerobic group (active control group). The interventions were conducted in 36 sessions, three times a week (alternate days) for 12 weeks. Before starting the program, three sessions were conducted over the course of a week. The temperature of the interventions rooms was kept stable (~ 21º - 24º Celsius).

Interventions

AVG group: This program was conducted by using the Microsoft Xbox 360 Kinect^{tm} console, using sports games from the *Kinect Sports Ultimate Collection* (Bowling, Boxing, Skiing, Soccer, Table Tennis, Tennis, and Track and Field). Some games are shorter (about one minute), called "mini games" where the goal is to score as many points as possible (e.g., Pin Rush, Target Kick, Super Saver, Body Ball, and Paddle Panic). All the games produce visual and auditory information. To stimulate performances, songs and comments are used to assist in controlling and playing the games. The games were selected based on the report and preferences of participants in the pilot study.

The sessions were performed in pairs, and held in a room equipped with a 240- × 180-cm projection screen (Epson Powerlite 96W), and a set of speakers to carry out the activities. An EVA carpet/mat was placed in the playing area, and each session lasted 60 minutes (5 to 10 minutes for the initial warm-up, 40–45 minutes for playing the sports games, and 5–10 minutes for stretching at the end). The intensity of the activity was monitored by the heart rate monitor (Polar® S810i model).

Aerobic group: The aerobic exercise program was conducted in a laboratory using treadmills and cycle ergometers (Moviment® - Biocycle 2600), and the sessions were done in a group. Training intensity was calculated for each participant. To maintain the intensity of the sessions, each participant used a Polar® heart rate monitor (model FS1) with values of 40% to 59% of heart rate reserve, which was considered as an aerobic activity of moderate intensity (Garber et al., 2011).

Volume and training intensity was gradually increased. Each session began with a warm-up of approximately 10 minutes, followed by 40 minutes of aerobic exercise and stretching to finish (5 to 10 minutes).

Outcomes

Cognitive performance

Cognitive performance was assessed using a battery of computerized cognitive assessments: "*CogState Battery*" (www.cogstate.com). This instrument evaluates cognitive tasks by means of cards, with nonverbal acts or linguistic operations. The instrument has been validated for older adults (Fredrickson et al., 2009) and used by different authors in Brazil (Oliveira, Trezza, Busse, & Filho, 2014).

To reduce learning effects and improve assessment reliability (Fredrickson et al., 2009), each participant performed the battery twice. The first step was to familiar with the test and understand the procedures, and the second was for analysis. All the computerized battery tests had auditory signals, and when the person evaluated made a mistake or answers too early or late, a noise was emitted. Assessment results were generated and presented using the CogState Battery software. The tests selected for this battery covered the following cognitive domains:

1) Executive function (Groton Maze Learning Test), scored according to the performance speed and number of errors.
2) Psychomotor function (Detection Test), the score reflected accuracy and reaction time for correct answers.
3) Visual attention (Identification Test), the score reflected the accuracy and reaction time for correct answers.
4) Short-term memory and visual learning (One Card Learning Test), the score reflected the accuracy and reaction time for correct answers.
5) Working memory (One Back Memory Test), the score reflected the accuracy and performance speed.
6) Delayed recall (Groton Maze Learning Test and the Groton Maze Recall), the score reflected the performance speed and number of errors made to remember the hidden path.

Overall cognitive ability was also assessed using the Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975) based on the version proposed for use in Brazil (Brucki, Nitrini, Caramelli, Bertolucci, & Okamoto, 2003). This instrument consists of questions grouped into seven categories with scores ranging from 0 to 30.

Characterization of the Sample

The following variables were used based on their significance to the study sample: sex, marital status, age, education, self-perception of health status, body mass index, reading habits, use/handling of computers, and resting systolic and diastolic blood pressures (Omron HEM-7200 digital device).

Sample Size

To calculate the sample size (mixed design ANOVA), a confidence interval of 95% was considered, with a bilateral hypothesis test, a significance level of 0.05 (error type I) and 80% test power (error type II). In the executive function test, the effect on size for partial analysis of variance was calculated for all participants. Thus, for a moderate effect on size (Cohen, 1992) of 0.5, the verification of minimal clinically significant difference, and a minimum sample size of at least 11 people were necessary for each group.

Statistical Analysis

The normality of the data in each group was tested using the Shapiro-Wilk test, a histogram analysis, and the coefficient variation. When the data were negative, the corresponding nonparametric tests were performed. In the initial period (pre-intervention), the groups were compared in terms of the *variables* related to the categorization of the sample by using the Fisher exact test (categorical variables) and the Student *t* test for independent samples.

Cognitive performance was verified using the ANOVA with a mixed model by considering the time (pre and post-intervention), the group (aerobic and AVG) and the interaction (time x group). Sidak post hoc was performed to provide a comparison between group and time, as well as considering the interaction. We analysed the training's effect size using the proposal suggested by Cohen (1992): < 0.2 = small effect, 0.2 to 0.8 = medium and > 0.8 = large. All analyses were carried out using the Statistical Package for the Social Sciences (SPSS version 16.0 software), with a statistical significance level of 5% ($p < 0.05$). The tabulation and data analysis were performed 'blind' to control unintended bias on the part of investigators/statistics.

Results

Thirty-six people (14 men and 22 women) were randomly divided into the intervention groups, and 27 individuals completed the 12 weeks training. During the intervention period, those who participated in any other exercise program; used drugs for depression, anxiety, cardiovascular disease or drugs containing beta-blockers,; or attended less than 75% of all sessions, were excluded from the analyses (n = 9).

The adherence of the participants' AVG group was 90.6%, with 424 sessions completed from a possible 468 sessions (13 participants x 36 sessions). In the aerobic group, adherence was 86.9%, with 438 sessions of a possible 504 sessions (14 participants x 36 sessions). There were no significant differences. Table 1 presents the characteristics of the study participants; no significant difference was observed between the groups.

Table 1. Characteristics of participants

	Groups				*p*-value
	AVG (n=13)		Aerobic(n = 14)		
	Mean	SD	Mean	SD	
Age (years)	60,0	4.0	60.7	3.6	.556
Education (years)	16,3	3.4	15.3	6.2	.606
BMI (kg/m^2)	28,0	4.4	27.4	5.5	.795
Systolic blood pressure	130,0	9.2	126.0	8.3	.246
Diastolic blood pressure	80,2	5.5	76.6	2.1	.180
	n	%	n	%	
Sex					.24
Male	03	23.1	8	57.1	
Female	10	76.9	6	42.9	
Marital status	2	15.4	0	0.0	.17
Married	07	53.8	11	78.6	
Single	03	23.1	-	-	
Divorced	03	23.1	02	14.3	
Widowed	-		01	7.1	
Reading habits					.40
Daily	09	69.2	08	57.1	
≤ 3x/week	04	30.8	06	42.9	
Use of computers					.53
Yes	12	92.3	12	85.7	
No	01	7.7	02	14.3	

Notes: AVG = active videogame; SD, = Standard Deviation; BMI = Body Mass Index; * Fisher exact test.

The means and standard deviations of the group cognitive performance, as well as comparisons between the groups and pre/post-intervention period are presented in Table 2.

Table 2. Mean values and standard deviation of the cognitive performance for the AVG (active videogame) and aerobic groups (n = 14), pre and post-intervention.

	Groups			
	AVG (n = 13)		Aerobic (n = 14)	
	Pre	Post	Pre	Post
Executive function				
Errors	78.62 ± 19.32Aa	63.31 ± 20.39Ab	74.36 ± 23.78Aa	64.93 ± 24.00Aa
MPS	0.59 ± 0.15Aa	0.71 ± 0.18Ab	0.54 ± 0.14Aa	0.65 ± 0.20Ab
Psychomotor function				
Speed perf. (ms)	2.57 ± 0.05Aa	2.56 ± 0.08Aa	2.61 ± 0.09Aa	2.60 ± 0.10Aa
Accuracy	1.52 ± 0.08 Aa	1.51 ± 0.10 Aa	1.51 ± 0.16 Aa	1.51 ± 0.10 Aa
Visual attention				
Speed perf. (ms)	2.75 ± 0.06Aa	2.73 ± 0.05Aa	2.77 ± 0.04Aa	2.73 ± 0.07Ab
Accuracy	1.41 ± 0.14Aa	1.49 ± 0.11Aa	1.43 ± 0.18Aa	1.51 ± 0.10Aa
Short-term memory				
Speed perf. (ms)	3.01 ± 0.04Aa	3.00 ± 0.05Aa	3.09 ± 0.08Ba	3.04 ± 0.10Ab
Accuracy	1.00 ± 0.10Aa	1.02 ± 0.09Aa	0.93 ± 0.11Aa	0.94 ± 0.11Aa
Working memory				
Speed perf.(ms)	2.93 ± 0.07Aa	2.93 ± 0.06Aa	2.97 ± 0.05Aa	2.94 ± 0.05Aa
Accuracy	1.34 ± 0.15Aa	1.36 ± 0.17Aa	1.39 ± 0.20Aa	1.36 ± 0.12Aa
Delayed recall				
Errors	13.31 ± 4.27Aa	11.62 ± 3.62Aa	13.07 ± 5.90Aa	10.86 ± 4.04Aa
MPS	0.68 ± 0.18Aa	0.83 ± 0.29Ab	0.58 ± 0.19Aa	0.75 ± 0.23Ab
MMSE score	28.92 ± 0.28Aa	29.15 ± 0.80Aa	28.36 ± 0.84Aa	29.07 ± 0.62Ab

Notes: MPS: moves per second; Speed perf., speed performance; ms: milliseconds; MMSE: Mini Mental State Examination.

Equal majuscule letters represents no statistic difference (5%) between the groups. Equal minuscule letters represents no statistic difference (5%) between the times.

According table 2, the AVG group showed a significant difference in executive function and delayed recall. In executive function, the number of errors decreased ($p \leq .05$) and increased the number of movements per second ($p \leq .05$). In the delayed recall, the number of movements per second increased ($p \leq .05$). The aerobic group showed significant differences in executive function, visual attention, short-term memory, delayed recall, and cognitive evaluation. In executive function, an increase was observed only in the number of movements per second ($p \leq .05$). In visual attention and short-term memory, execution speed increased ($p \leq .05$). In the delayed recall, the number of movements per second increased ($p \leq .05$). We also observed an increase in the overall cognitive assessment score ($p \leq .05$). In the group comparison, there were significant differences in values between the initial evaluation (pre-intervention) and short-term memory. The speed performance was higher in the aerobic group ($p \leq .05$).

Table 3 shows the analysis of the training's size effect. The results show small effects when compared to group and interaction. The executive function (errors and MPS), visual attention (speed performance and accuracy), delayed recall (MPS) and the MMSE score had medium effects in comparison with pre-and post-intervention. It should be noted that the effect of size is related to the importance of group and time comparisons for the cognitive performance variables. The F test indicated a significant difference for the short-term memory variable (speed performance) between the groups. The executive function (MPS), visual attention (velocity of performance), delayed recall (MPS), and MMSE's scores are differences when compared to intervention time.

Table 3. Values of the F test and effect size (d) for the cognitive performance

	Group		Time		Group*Time	
	F	*d*	F	*d*	F	*d*
Executive function (GML)						
Errors	0.031	0.001	9.824**	0.282	0.555	0.022
MPS	0.627	0.024	26.949*	0.519	0.116	0.005
Psychomotor function						
Speed perf. (ms)	2.137	0.079	0.452	0.018	0.007	0.001
Accuracy	0.035	≤0.001	0.010	0.001	0.009	0.001
Visual attention						
Speed perf. (ms)	0.210	0.008	7.493***	0.231	0.788	0.031
Accuracy	0.321	0.013	5.734***	0.187	0.016	0.001
Short-term memory						
Speed perf. (ms)	5.484**	0.180	5.534***	0.181	4.050	0.139
Accuracy	4.481**	0.151	1.260	0.048	0.100	0.004
Working memory						
Speed perf. (ms)	1.085	0.042	1.813	0.068	1.610	0.061
Accuracy	0.368	0.015	0.014	0.001	0.486	0.019
Delayed recall						
Errors	0.113	0.004	4.278***	0.146	0.076	0.003
MPS	1.311	0.050	18.993*	0.432	0.042	0.002
MMSE score	2.909	0.104	7.111***	0.221	1.861	0.069

Note. Group = AVG x Aerobic; Time = Initial x 12 weeks; Group x time = interaction time; Speed perf., speed performance; ms: milliseconds;
* significant at the $p <. 001$ level. **Significant at the $p < .005$ level. *** Significant at the $p < .05$ level.

Discussion

In this randomized clinical trial, both training groups were composed of participants with similar characteristics, that is, with no differences in factors that could affect cognitive performance, such as age (Harada et al., 2013), education, health status (Salthouse, 2010), computer use (Xavier et al., 2014), and resting blood pressure (Knecht et al., 2008). The results showed that 12 weeks of training had positive effects on cognitive performance, as evaluated with computerized tests. The participants in the AVG group demonstrated an improvement in executive function and delayed recall. The aerobic group showed improvements in executive function, short-term memory, delayed recall, and overall cognition.

The improvement in the cognitive function of the participants who performed aerobic exercises was consistent with the literature (Evers, Klusmann, Schwarzer, & Heuser, 2011; Ruscheweyh et al., 2011). The main mechanisms to explain the relationship between aerobic exercise and cognitive performance is an increase in neural plasticity and functions, the volume of white and grey matter in the prefrontal cortex (Erickson et al., 2010), and cerebral oxygenation (Kirk-Sanchez & McGough, 2014). Aerobic exercise can also reduce the cardiovascular risk factors, which are related to changes in cognitive functions (Rovio et al., 2017).

The cognitive benefits associated with the use of AVG, as observed in this study, may be related to visual stimuli and the characteristics of the games, which require speed and ability to play. These benefits were in line with the results of studies on conventional video games, which also showed improvements in an executive function, reaction time, and memory recall (Kueider, Parisi, Gross, & Rebok, 2012; Latham et al., 2013). The video games require constant monitoring of the screen, planning and quick strategic decision, and adapting to changes in the challenges proposed by the game (Zelinski & Reyes, 2009).

The effects of AVG on cognitive performance may also be related to increased cardiovascular demands, increased oxygen supply and transport through regular physical activity (Maillot et al., 2012; Mullins et al., 2012). However, studies investigating the effects of AVG on cognition provide controversial results (Anderson-Hanley et al., 2012; Kayama et al., 2014; Maillot et al., 2012). Controversies may be associated with the instruments used to assess cognition, intervention time and type of intervention with AVG. Maillot et al. (2012) identified improvement in executive function and speed of processing tasks, after 12 weeks of training (Nintendo Wii[tm]). Contrary to this study, the subjects were only compared with a control group with no physical activities in the Maillot et al.'s (2012) study.

In another study (Anderson-Hanley et al., 2012), the exergames consisted of stationary bicycles and monitor to simulate virtual circuits and cognitive performance using the trail-making test (TMT) and verbal fluency test. The participants of exergaming group demonstrated better results in executive function than those trained with a traditional stationary bicycle. The results could be explained by the additional stimulus (virtual) of exergames, as the intensity was continuous and moderate in both groups.

In the study carried out by Kayama et al. (2014), exergames were used as a complement to a physical exercise program (aerobic, strength, flexibility, and balance), and cognitive performance was assessed using the trail-making test and verbal fluency test. The participants who played five minutes of exergames with combined exercises had better executive function than the group who only performed physical exercises.

In the present study, the difference in performance in the cognitive tests after 12 weeks of intervention proved to be significantly similar between the groups, except for the short-term memory (speed performance) in the pre-intervention measure. This result is consistent with the observation of Maillot et al. (2012) that the cognitive benefits observed in a training with sports exergames may be similar to conventional physical activity programs. The AVG is an interval physical activity, since the games varied in interval time and intensity. Depending on the performance and motivation of each participant, the aerobic energy system responds to the demands of physical activity, irrespective of the intensity (Gastin, 2001).

The study has strengths and limitations. Its strengths include the use of a randomized intervention study; the type of innovative intervention used, the use of sports video games; and the comparison with conventional aerobic physical exercise. Also noteworthy is the use of a computerized battery to evaluate cognitive performance, which has been validated for use in older adults. The instrument facilitated the evaluation and generation of test scores. Based on our literature search, this is the first study conducted in Brazil to investigate the effect of sports AVG on cognitive performance in healthy older adults. Despite the inclusion criteria, this study did not examine motivational aspects and nutritional issues (Smith & Blumenthal, 2010), such as nutrient intake prior to the application of the cognitive tests, which could influence the performance of the cognitive tests and training activities.

Conclusion

In conclusion, of the seven cognitive domains evaluated, five (executive function, visual attention, delayed memory, short-term memory and overall cognition) improved in the aerobic group and only two (executive function and delayed memory) improved in the AVG group. However, we found no significant difference in the performance in the cognitive tests between the groups. This indicates that sports AVG may have cognitive benefits similar to those using the conventional aerobic exercises.

The results show that sports AVG are an alternative to inactive leisure time, and can increase physical and cognitive stimuli. AVG can be played at home, individually or in groups, at different rates and times, which can contribute and increase adherence to healthy habits. The use of sports AVG as a physical exercise may be an alternative activity that can provide cognitive benefits and prevent cognitive changes associated with the aging.

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Conflicts of interest - The authors declare that they have no competing interest.

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