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Original Article

The Benefits of Custom Exergames for Fitness, Balance, and Health-Related Quality of Life: A Randomized Controlled Trial with Community-Dwelling Older Adults

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Abstract

Objective: This research aimed to measure the benefits in older adults' motor performance and quality of life during a 12-week-long multidimensional training combining custom-made exergames and traditional exercise in a complementary manner, compared with traditional training alone.
Materials and Methods: Community-dwelling older adults participated in a randomized controlled trial ($N = 31$) consisting of two weekly exercise sessions of 60 minutes for 12 weeks. Participants allocated to the exergames group ($n = 15$) had one individual session of exergames and one traditional exercise group session per week. Control group participants ($n = 16$) had two weekly traditional exercise group sessions. Outcome measures on fitness, balance, and health-related quality of life were measured at the start of the intervention, 6th, 12th, and 16th week (1-month follow-up).
Results: The exergames group showed a significant increase in lower-body and upper-body strength from pre- to postintervention. When compared with control, participants had significantly higher developments of upper-body strength from pre- to postassessments. There was a significant decrease in shoulder range of motion between the end of the intervention and follow-up for participants in both conditions. Balance increased significantly during the intervention but decreased at follow-up in both conditions. The mental component of health-related quality of life was significantly higher at the end compared with the start of the intervention in the exergames group, and this difference was significantly higher when compared with control.
Conclusion: Integrating personalized exergames designed for multidimensional fitness training in traditional settings can be an effective strategy to enhance older adults' motor performance and mental well-being.

Keywords: Exergames, Fitness, Elderly, Balance

Introduction

Developed countries are undergoing a demographic shift toward a more aged population due to low birth rates and rising life expectancy.[1] In 2018, 28.2% of the Portuguese population was >60 years,[2] and nearly one-third of Europeans will be $\geq$65 years by 2060.[3] Concurrently, physical inactivity is an identified health risk. Sedentary behaviors are the fourth main risk factor in worldwide mortality, associated with 6% of deaths.[4] These behaviors are more prevalent in older adults, with 65%–80% of their awake time spent sitting.[5]

Evidence shows that regular physical activity produces extensive health benefits, particularly in older adults who experience more frequently the outcomes related to inactivity.[4] The American College of Sports and Medicine made

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recommendations and guidelines for physical activity in old age.[6] They recommended 150 minutes per week of multidimensional moderate-intensity exercise, targeting aerobic fitness, musculoskeletal function, flexibility, and balance.

Exergames, videogames that require physical exercise to be played, offer an affordable option to prevent sedentarism. Previous studies on the effects of exergames show positive impact on physical fitness and overall health.[7–23] Exergaming facilitates moderate-intensity physical activity levels[7,8] and is as effective or sometimes more than conventional exercise.[9] Regarding clinical effects, outcomes have shown to be small but significant,[10] with improvements in gait, balance, and cognitive function.[11–14] Exergames have also been found to reduce depressive symptoms while improving quality of life[11] and positively affecting healthy lifestyles.[10] Exergames for elderly had positive impacts on physical and mental health,[15] balance and postural control,[16–18] mobility,[13,14,19]overall fitness,[20] and motivation aspects.[21] In addition, players have reported forgetting time, place, and pain, which can be an added benefit of the immersive nature of games.[22]

The most effective serious games are customized to both the target population and behavior that they want to change.[10] In terms of motivation and preferences, mastery over the game is an essential factor,[24] and a clear preference for gesture-based controllers was identified in the elderly.[25] The match between skill and challenge, fitness and intensity, is a motivating factor.[26,27] Other factors that improve engagement in games are music, lack of consequences for underperformance, adaptive difficulty,[28] and clear goals and progression levels.[9] Besides these, exergames should not be seen as an extraordinary activity but instead offered as an accessible, complementary, and enjoyable activity akin to traditional exercise.[9]

Although there is an extensive body of research in this field, further efforts need to be made if exergames are to become a scientifically proven modality for exercise.[14] According to a review of 149 publications, 40% of the research focuses on the 10–20 age gap.[29] It was observed that almost three-quarters of the studies were conducted in laboratory environments, reducing the generalizability of results and feasibility in field settings. Concerning exergames for older adults, a review of thirty articles showed that two-thirds of the studies targeted balance or fall prevention as primary outcomes,[12] lacking studies that cover other motor performance domains. A review of 60 studies targeting older adults found that more than two-thirds of them used commercial exergames,[9] which tend to be designed with other populations in mind and overlook older adults' specific needs. Other reviews into this subject also report that there is a lack of studies that explore the longitudinal effect of exergames.[9,19]

In previous study, we presented four exergames for the elderly, intended to train several key functional fitness dimensions.[30] The game design was steered by what was learned from the literature on serious games for health and made to the target population through a user-centered design approach.[31] Although we have shown that these games can achieve the recommended levels of physical activity in the elderly,[32,33] in this article, we want to address some of the aforementioned limitations and answer the following question:

- What are the older adults' motor performance and quality of life benefits obtained by complementing custom-made (multidimensional) exergames with traditional exercise during longitudinal training compared with traditional training alone?

Materials and Methods

Experimental design and protocol

We designed a 12-week-long randomized controlled trial, where participants were randomly allocated to an experimental or control group. Both groups underwent two sessions per week consisting of warmup (10 minutes, stretching and muscular preparation), multidimensional physical training (40 minutes, intense exercise), and cooldown (10 minutes, muscle relaxation). Two sports professionals alternately led the sessions that were designed to be equivalent in Frequency, Intensity, Time, and Type.[34] The training was structured following American College of Sports Medicine recommendations for multidimensional training for older adults[6]: 50% of aerobic training, 30% upper and lower limb strength, and 20% motor ability training. The difference between the groups lay in the exercise modality that was practiced at the sessions.

- *Exergames group*—Combined exergames and conventional training: Engaged once a week in individual exergames sessions. The other weekly session was conventional group exercise.
- *Control group*—Conventional training: Engaged in conventional exercise group sessions two times per week.

Conventional training sessions were based on the exercise patterns of a local elderly gym, covering marching in place, step touches, stepping on pads, squats, and others.

Participants were assessed for functional fitness and health-related quality of life at four different moments: preintervention (0th week), mid-intervention (6th week), postintervention (12th week), and 1-month follow-up (16th week).

Setup

The system consisted of a low-end gaming computer, a projector that projected the games on the floor, and a Microsoft Kinect V2 to track the players (Fig. 1). The 2.5 m × 3.0 m floor projection acted as a digital playground, large enough to demand measurable amounts of exertion.[32,33]

Exergames

Five custom-made exergames were used in the intervention (Fig. 2).[30,31] These were developed by a multidisciplinary team in a human-centered design process based on playtests with the target population.[31] Each game was designed with a functional fitness area in mind, and four of the games follow a national tour of Portugal theme, focusing on traditional regional activities. The games are as follows:

- Grape Stomping: Recreates the traditional method of grape treading in wine production. Focusses on aerobic training, elicited through the need to step in place to stomp the grapes, with a minor component of upper-body strength and cognitive training.
- Rabelos: Players must navigate a boat downriver, using arm rotation to row and side-stepping to avoid obstacles. Its focus is upper-body strength training due to

FIG. 1. Diagram showing the system setup used in this study.

both the rowing gesture and the motion needed to pick cargo from the docks. Minor lower-body strength training is performed due to the side-steps.

- Exermusic: A large floor projected piano keyboard where players must step over the correct key at the right time. Focus is lower-limb strength and flexibility. There is a minor training component of upper-body strength due to the need for arm movement to trigger bonus notes.
- Toboggan Ride: Replicates an old transportation method used in Madeira, Portugal. The players control a toboggan downhill through trunk flexion-hyperextension movements and side-stepping, thus training balance, postural stability, and trunk muscular strength.
- Exerpong: A mix of the classic Pong and Breakout games adapted to exergaming. The player's side-step motion controls a paddle, provides a fast-paced game to train aerobic endurance, agility, and dynamic balance.

Measurements

To assess fitness, we used six tests of the Senior Fitness Test battery[35]:

- 30-s Chair Stand Test—Lower-body strength, number of complete sit to stand repetitions in 30 seconds.
- 30-s Arm Curl Test—Upper-body strength, number of bicep curl repetitions with a weight in 30 seconds.
- Chair Sit-&-Reach—Lower-body flexibility, centimeters that the fingertips go past the toes when reaching the toes from a legs extended sitting position.
- Back Scratch Test—Shoulder range of motion, hand overlap (or distance) in centimeters when meeting them behind the back.
- 8-Feet Up-&-Go—Agility and dynamic balance, time to stand, walk 2.4 m, return, and sit. Higher score means lower performance.
- 6-Minute Walk Test—Aerobic endurance, distance, in meters, walked in 6 minutes.

To quantify the risk of fall we used the Short Form Fullerton Advanced Balance Scale (FAB), which consists of four tasks that test static and dynamic balance.[36] Each item is scored on a 5-point ordinal scale (0–4); the sum of all item scores is the total FAB, rated 0–16. Finally, the 12-Item Short-Form Health Survey (SF-12) was used to evaluate the quality of life outcomes from the participants' perspective.[37] The score of this test is made of two components, mental and physical.

Participants

The study took place in a local (Madeira, Portugal) senior gymnasium where active community-dwelling older adults were recruited. The inclusion criteria were 50–75 years old,

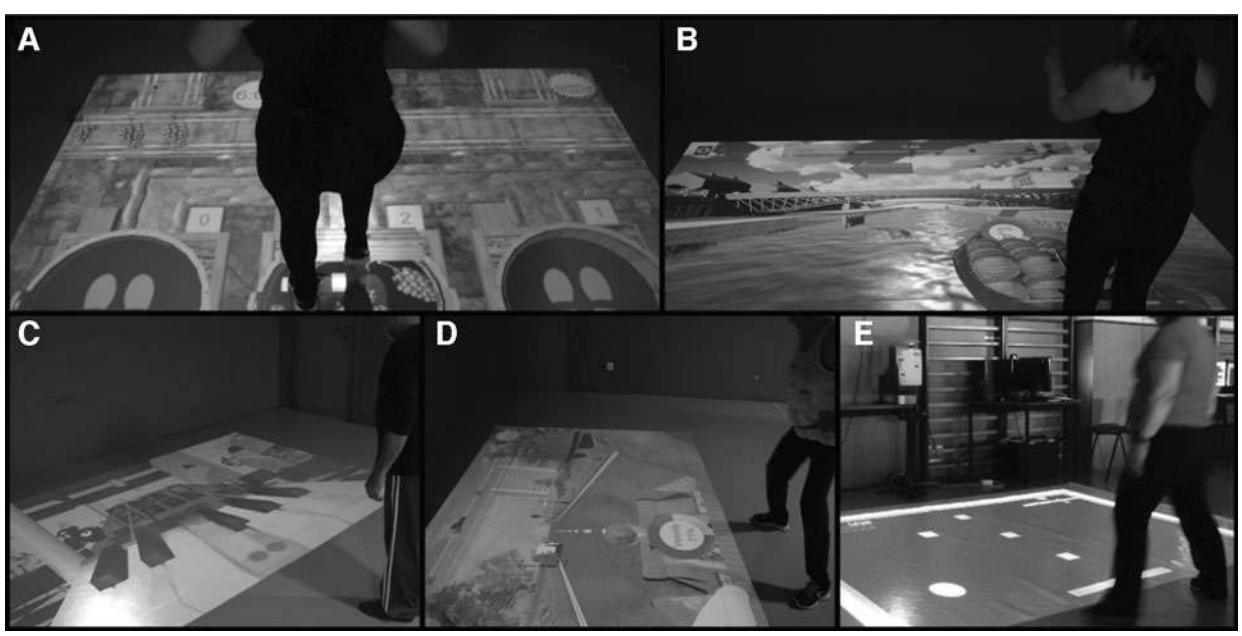

FIG. 2. The set of Exergames used in the Exergames group. Grape stomping **(A)** and Exerpong **(E)** train aerobic fitness. Rabelos **(B)** trains upper and lower limb strength, whereas the Exermusic **(C)** and Toboggan Ride **(D)** train motor ability.

able to read and write, members of the gymnasium for 3 or more months, able to understand the procedure, game rules and goals, no severe visual impairments, no impediment to exercise practice, no severe or unstable heart diseases, a FAB score higher than 9, and no falls for the past 6 months. A total of 37 volunteers were gathered, two volunteers did not receive the intervention, and four failed to show at follow-up. The remaining 31 completed the study (Fig. 3). Sixteen participants were assigned to the *control* group (12 females, age average 69.1, standard deviation [SD] 4.4), and 15 to the *exergames* group (10 females, age average 67.6, SD 5).

Data analysis

Nonparametric tests were used due to either non-normal distributions or the ordinal nature of the data. The normality of distributions was assessed using the Kolmogorov–Smirnov test. The Friedman test was used to detect significant within-group differences over time. The analysis focused on finding which variables had significantly improved during the intervention and which decreased from end to follow-up. For pairwise comparisons, the unidirectional Wilcoxon test was used to find if the increase from start to end (0th–12th week) and decrease from end to follow-up (12th–16th week) were significant. Next, a between-groups analysis was done to understand if the *exergames* condition had significantly larger performance gains in each measurement compared with *control* from start to end and lower losses from end to follow-up. The difference in differences[38] method was used, first calculating the differences between the 0th and 12th weeks, and 12th and 16th week, for both conditions. Then, using the unidirectional Mann–Whitney test to check for higher *exergames* gains from the 0th to 12th week and higher *control* losses from the 12th to 16th week. The significance level used was $\alpha = 0.05$ and Bonferroni's correction was used to correct for multiple comparisons. All analysis was done using IBM SPSS Statistics 22 (IBM, New York).

Ethical Approval

The study was reviewed by the Faculty of Human Motricity's ethical council, University of Lisbon (Review 14/2017), who confirmed it complied with the national and international guidelines for scientific research with humans. All the participants gave their informed written consent.

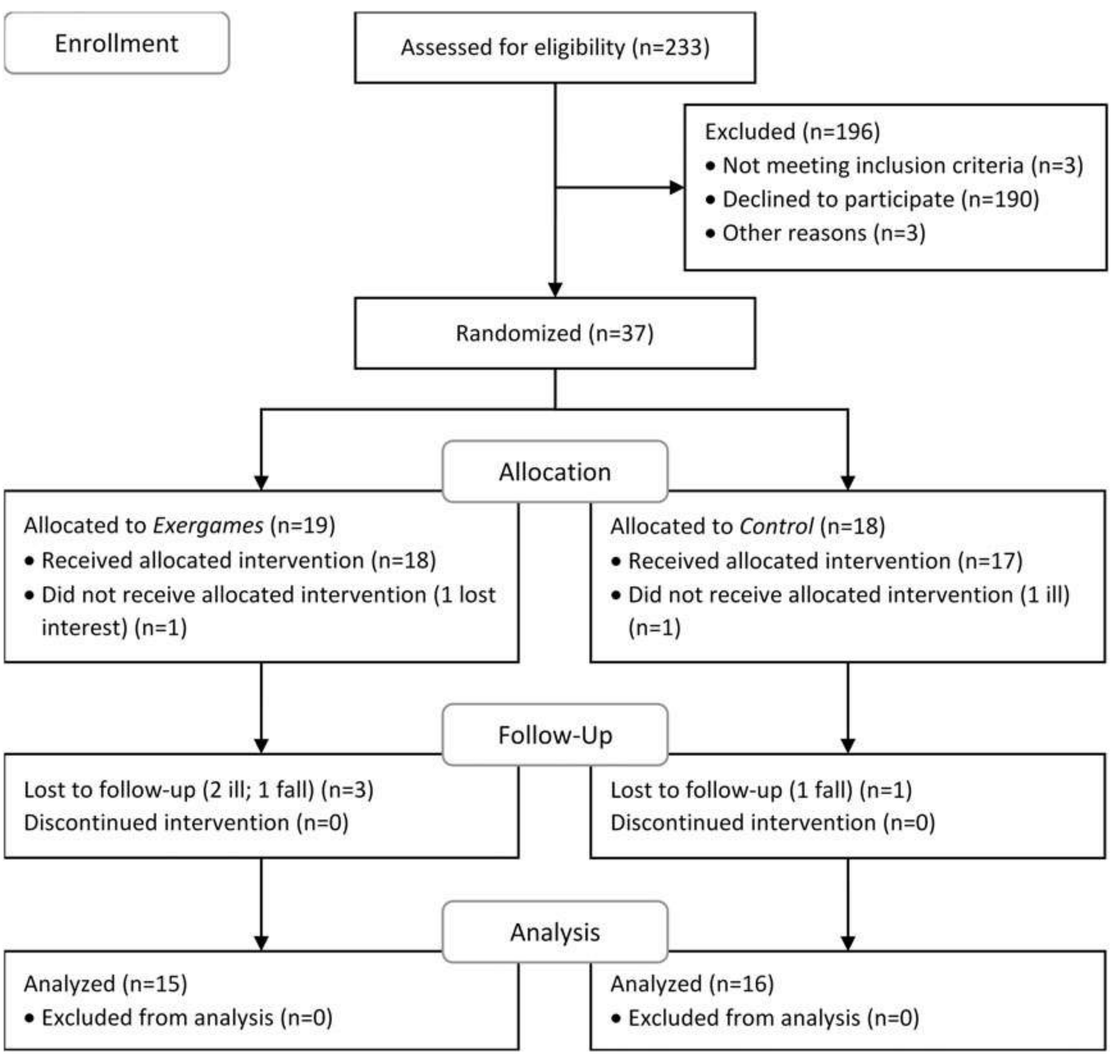

FIG. 3. Participants flow through the phases of the randomized controlled trial.

Results

Senior fitness test

Differences over time

Exergames. There were significant differences over time, $P<0.05$, in lower-body strength, $\chi^2(3)=8.127$, upper-body strength, $\chi^2(3)=11.553$, shoulder range of motion, $\chi^2(3)=18.103$, and agility and dynamic balance, $\chi^2(3)=14.534$. *Post hoc* analysis testing after Bonferroni correction showed a significant increase, $P<0.05/2$, of lower-body, $T=6$, $r=-0.44$, and upper-body strength, $T=14.5$, $r=-0.474$, from 0th to 12th week, and a significant decrease of shoulder range of motion, $T=14$, $r=-0.441$, from 12th to 16th week (Fig. 4). The agility and dynamic balance results were significant but did not validate our hypothesis due to the directionality of the differences.

Control. Only the shoulder range of motion, $\chi^2(3)=25.591$, and agility and dynamic balance, $\chi^2(3)=32.758$, were found to be significantly different over time. *Post hoc* analysis showed a significant decrease in shoulder range of motion between the end of the intervention and follow-up, $T=11$, $r=-0.508$ (Fig. 4).

Difference between conditions. When checking the difference in differences of the evolution of fitness from 0th to 12th and 12th to 16th between conditions, we found that upper-body strength and shoulder range of motion had significantly higher developments in the *exergames* group as compared with *control*, $U=76$, $r=-0.315$, and $U=67.5$, $r=-0.373$, from 0th to 12th week (Table 1).

Short form Fullerton advanced balance scale

Differences over time

Exergames. As measured by the FAB scale score, balance and risk of fall were found to have significant differences over time during the exergames intervention, $\chi^2(3)=14.026$. The *post hoc* analysis showed that the FAB score increased significantly during the intervention, $T=2.5$, $r=-0.499$, but decreased in the following month, $T=3.5$, $r=-0.488$ (Fig. 5).

Control. The FAB score was significantly different for *control* as well, $\chi^2(3)=17.837$, revealing the effect of time in balance. The *post hoc* analysis showed that the FAB score increased significantly during the intervention, $T=0$, $r=-0.497$, and had significantly decreased 1 month after the intervention, $T=5.5$, $r=-0.562$ (Fig. 5).

Difference between conditions. There were no significant differences between conditions in their differences over time.

12-Item Short-Form Health Survey

Differences over time

Exergames. When considering the health-related quality of life in the *exergames* participants, the mental component measured by the SF-12 questionnaire was found to have been

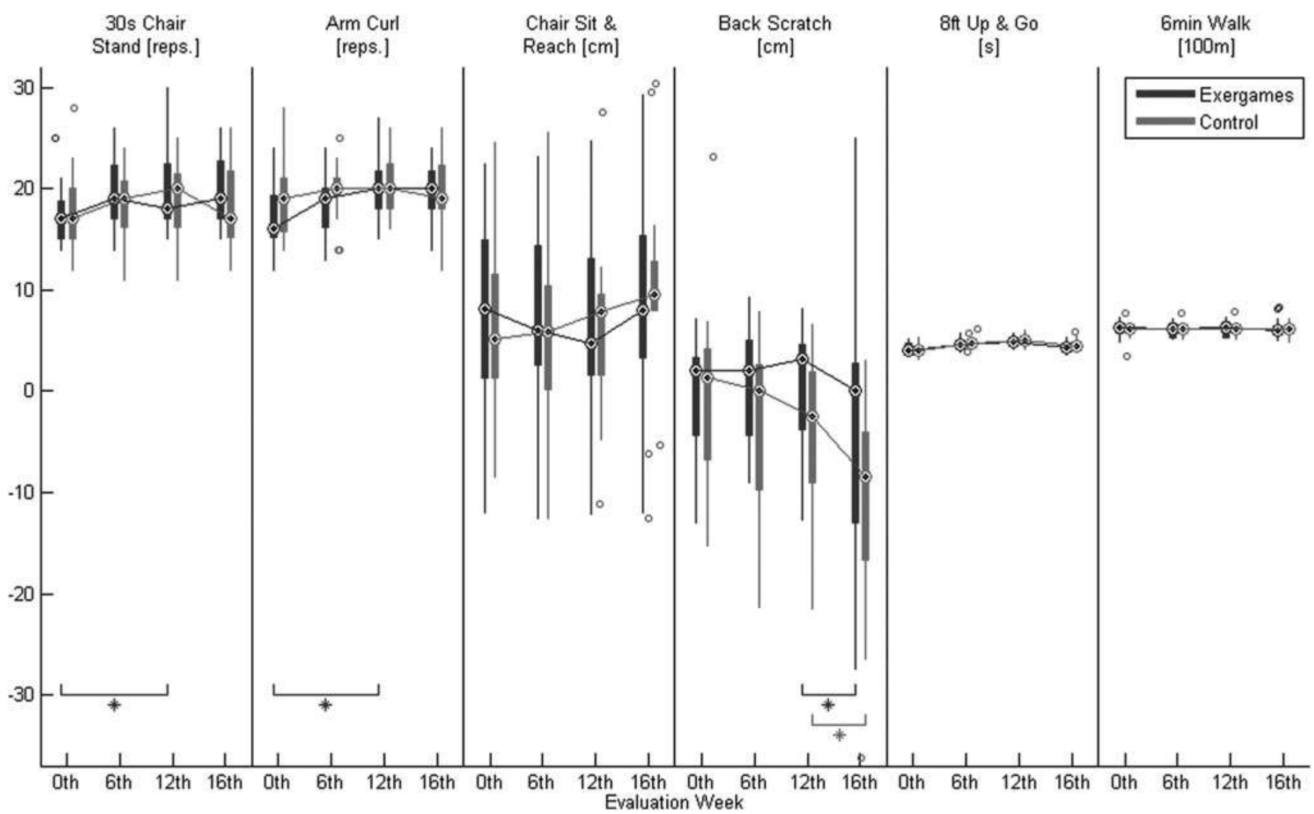

FIG. 4. Results of the 6 SFTs over time for both conditions, significant differences highlighted with asterisk. SFT, Senior Fitness Test.

Table 1. Descriptive Statistics of the Differences Over Time from Pre- to Postintervention and Postintervention to Follow-Up of Both Conditions for the Senior Fitness Tests and 12-Item Short-Form Health Survey Results, and Mann–Whitney Sig. Differences of Differences between Conditions

		Exergames		*Control*		
Measurement	*Evaluation week*	*Dif. median*	*Dif. interquartile range*	*Dif. median*	*Dif. interquartile range*	*Mann–Whitney sig. dif. in dif.*
30-s Chair Stand (reps)	0th–12th	1	5	1	3	No (P=0.235)
	12th–16th	−1	5	−1	4	No (P=0.256)
Arm Curl (reps)	0th–12th	3	4	1	5	Yes (P=0.043)
	12th–16th	−1	4	0	3	No (P=0.357)
Chair Sit-&-Reach (cm)	0th–12th	0.90	7.0	−0.4	8.6	No (P=0.286)
	12th–16th	1.35	9.7	2.8	9.2	No (P=0.357)
Back Scratch (cm)	0th–12th	1.00	2.5	−1.3	7.7	Yes (P=0.019)
	12th–16th	−4.15	8.6	−8.6	10.6	No (P=0.153)
8-Feet Up-&-Go (seconds)	0th–12th	0.73	1.36	0.89	0.56	No (P=0.150)
	12th–16th	−0.50	0.32	−0.41	0.42	No (P=0.372)
6-Minute Walk (m)	0th–12th	2.5	55	−5	45	No (P=0.097)
	12th–16th	−2.5	59	−5	60	No (P=0.326)
SF-12 mental	0th–12th	11.91	28.57	2.38	22.63	Yes (P=0.021)
	12th–16th	0.00	15.47	−2.38	17.86	No (P=0.157)
SF-12 physical	0th–12th	4.67	41.67	6.66	13.33	No (P=0.327)
	12th–16th	0.00	25.33	0.00	14.67	No (P=0.066)

SF-12, 12-Item Short-Form Health Survey.

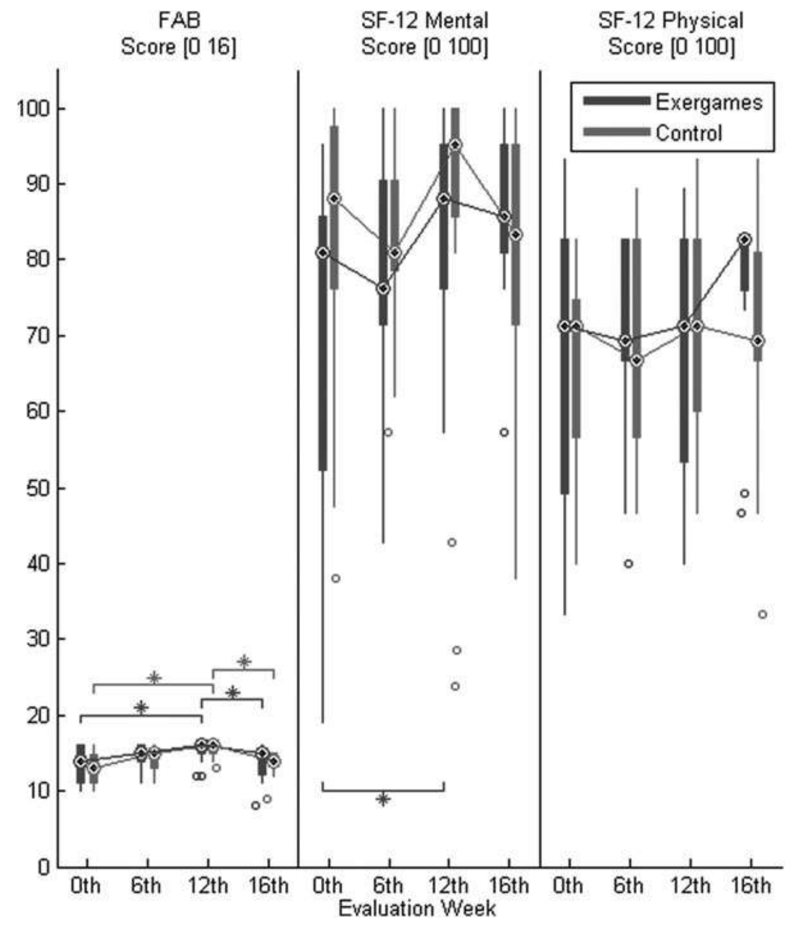

FIG. 5. Results of the FAB and SF-12 evaluations over time for both conditions, significant differences highlighted with asterisk. FAB, Short Form Fullerton Advanced Balance Scale; SF-12, 12-Item Short-Form Health Survey.

significantly affected by time, $\chi^2(3) = 8.366$. *Post hoc* analysis testing showed a significant increase between the start of the intervention and the end, $T = 10.5$, $r = -0.515$ (Fig. 5). No effect was detected on the physical component.

Control. Neither the mental nor the physical components showed an effect during the intervention in the *control* group.

Difference between conditions. When comparing conditions, only the mental component showed significant differences, with the *exergames* having a significantly higher improvement (Median 11.91) than control (Median 2.38), $U = 68.5$, $r = -0.367$ (Table 1).

Discussion

Benefits on strength

The results obtained from our multidimensional training program with exergames revealed significant increases over time in lower-body and upper-body strength. No significant improvements were detected in the *control* group. Improvements of specific functional fitness domains such as strength in the upper and lower limbs can have a significant impact in elders' daily life activities,[39] as well as an association with decreased physical impairments and functional limitations.[40] Only the upper body flexibility domain did not reveal sustained effects after follow-up for the *exergames* condition. The same was observed in the *control* condition. The reason for these results may be that the exergames used in this research involve lower limbs in a more consistent and transversal manner than upper limbs. Thus, more features that encourage upper-limb movements, and training of other aspects besides strength, such as flexibility, should be incorporated in the next generation of these exergames. Research using similar methods with different training program duration and frequency showed analogous results in the overall strength component.[20]

Benefits on balance

Both the *exergames* and *control* groups showed significant improvements in balance, revealing the importance of physical activity in supporting balance skills.[6] These findings are essential since improvements in balance can significantly reduce long-term functional impairments due to falls. Also, reducing the risk of falls has been associated with decreased mortality[41] and independence to perform daily life activities.[42] However, the positive effects were not maintained 1 month after the intervention. This can be due to the training program length, which limits a sustained impact.[19] These results support the idea that there is a continuous need for exercises that target this domain for maintaining a low risk of falls in older age.

Exergames and conventional versus conventional

Our *exergames* condition offered a complementary training of exergames and conventional exercise, in line with what is recommended,[43] which was compared with an equivalent training of conventional exercise alone. The combined approach contrasts with the supplemental, adding extra exergames' sessions to conventional training, and the alternative approach, training with exergames only, predominantly studied in the literature. The results revealed that upper-body strength improvements in the *exergames* condition were significantly higher than those obtained for the *control*. This allows us to extract an important finding of this research: combining exergames with conventional exercises was more effective in impacting functional fitness compared with conventional exercises alone. Integrating exergames to the already existing conventional exercise programs seems to be a feasible and effective strategy to extend the use of these technologies beyond research trials, in senior care facilities[44] and at home. Besides, one of the strengths of this study is the carefully selected *control* condition, which allowed us to carry out a fair comparison between conditions. Since past literature reviews of randomized controlled trials including exergames have pointed out the limitations of using nonequivalent control conditions, our decision to include conventional multidimensional training with a sports science coach allowed a more reliable scientific evidence toward defining specific and quantifiable effects of longitudinal exergaming.[45]

Benefits on health-related quality of life

We observed improvements in perceived quality of life, particularly in the *exergames* group who showed a significant improvement in the quality of life mental component. These results are aligned with what was reported in exergames reviews: improvements in balance, cognitive function, quality of life, and health.[11,12,19,46] So far, the relationship between exergaming training programs and perceived quality of life in older adults has not been well established, and the existing literature does not provide conclusive insights.[45] This finding is key for improving our understanding of the specific domains in which exergaming programs are better than conventional exercises.[45]

Strengths

Our research adds to the body of literature in exergaming for older adults by (1) showing results of a longitudinal intervention where custom-made Exergames, instead of commercial, are used (2) providing data collected in a real-world setting through a randomized controlled 3-month longitudinal intervention, (3) using a quantifiable and multidimensional evaluation methodology to validate the use of exergames in real-life scenarios, using widely validated and accessible physical fitness tools and questionnaires, and (4) demonstrating the benefits of using exergames as complement to conventional exercise instead of as a supplement, as recommended by previous review articles.[43]

Limitations

It is impossible to identify the multidimensional fitness training program-specific benefits' origin when combining several exergames with conventional exercise. Some of the combined training program gains declined 1 month after the intervention, showing the need for lasting exercise programs to provide durable benefits in older adults. We adopted a wide range of ages (50–75 years) in our sample; related literature typically reports studies with participants >65 years of age, making it somewhat difficult to compare results. In addition, our inclusion criteria guaranteed a healthy sample of participants, not representative of the general older adult population. We suggest following up this research with validation on frailer population, usually institutionalized under senior care, given our positive results. Finally, a technical limitation is the setup used, making this intervention hard to adopt in senior care facilities. For this reason, we have developed ''PEPE: Portable Exergames Platform for the Elderly'' to deploy our custom-made Exergames.[47]

Conclusions

In both conditions, we observed a global and positive impact. From the significant improvements observed in several of the dimensions measured in the *exergames* condition participants, we conclude that the benefits from physical training in older adults can be enhanced when the training includes exergames. Integrating carefully designed and highly personalized exergames in multidimensional fitness training can be attractive (e.g., more engaging and fun) for older adults and more effective in eliciting the desired physical improvements.

Author Disclosure Statement

No competing financial interests exist.

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References

1. World Health Organization. *World Report on Ageing and Health*. Geneva: World Health Organization; 2015.
2. Instituto Nacional de Estatística. Distribution of resident population (%) by Age group. Statistics Portugal. Published June 14, 2019. https://www.ine.pt/xportal/xmain?xpid=INE&xpgid=ine_indicadores&indOcorrCod=0001276&xlang=en&contexto=bd&selTab=tab2 (accessed February 10, 2020).
3. European Commission: DG Economic and Financial Affairs. *The 2012 Ageing Report: Economic and Budgetary Projections for the 27 EU Member States (2010-2060)*. European Commission; 2012. https://ec.europa.eu/economy_finance/publications/european_economy/2012/2012-ageing-report_en.htm.
4. World Health Organization. *Global Recommendations on Physical Activity for Health*. Geneva: World Health Organization; 2010. https://www.ncbi.nlm.nih.gov/books/NBK305057 (accessed February 10, 2020).
5. Wullems JA, Verschueren SMP, Degens H, Morse CI, Onambélé GL. A review of the assessment and prevalence of sedentarism in older adults, its physiology/health impact and non-exercise mobility counter-measures. Biogerontology 2016; 17:547–565.
6. American College of Sports Medicine, Bushman BA. *ACSM's Complete Guide to Fitness & Health*. Champaign, IL: Human Kinetics; 2017.
7. Peng W, Lin J-H, Crouse J. Is playing exergames really exercising? A meta-analysis of energy expenditure in active video games. Cyberpsychol Behav Soc Netw 2011; 14:681–688.
8. Sween J, Wallington SF, Sheppard V, Taylor T, Llanos AA, Adams-Campbell LL. The role of exergaming in improving physical activity: A review. J Phys Act Health 2014; 11:864–870.
9. Skjæret N, Nawaz A, Morat T, Schoene D, Helbostad JL, Vereijken B. Exercise and rehabilitation delivered through exergames in older adults: An integrative review of technologies, safety and efficacy. Int J Med Inf 2016; 85:1–16.
10. DeSmet A, Van Ryckeghem D, Compernolle S, et al. A meta-analysis of serious digital games for healthy lifestyle promotion. Prev Med 2014; 69:95–107.
11. Klompstra LV, Jaarsma T, Strömberg A. Exergaming in older adults: A scoping review and implementation potential for patients with heart failure. Eur J Cardiovasc Nurs 2014; 13:388–398.
12. Ravenek KE, Wolfe DL, Hitzig SL. A scoping review of video gaming in rehabilitation. Disabil Rehabil Assist Technol 2015; 0:1–9.
13. Fang Q, Ghanouni P, Anderson SE, et al. Effects of exergaming on balance of healthy older adults: A systematic review and meta-analysis of randomized controlled trials. Games Health J 2019; 9:11–23.
14. Pacheco TBF, de Medeiros CSP, de Oliveira VHB, Vieira ER, de Cavalcanti FAC. Effectiveness of exergames for improving mobility and balance in older adults: A systematic review and meta-analysis. Syst Rev 2020; 9:163.
15. Hall AK, Chavarria E, Maneeratana V, Chaney BH, Bernhardt JM. Health benefits of digital videogames for older adults: A systematic review of the literature. Games Health J 2012; 1:402–410.
16. Bleakley CM, Charles D, Porter-Armstrong A, McNeill MDJ, McDonough SM, McCormack B. Gaming for health: A systematic review of the physical and cognitive effects of interactive computer games in older adults. J Appl Gerontol 2015; 34:NP166–NP189.
17. Nawaz A, Skjæret N, Helbostad JL, Vereijken B, Boulton E, Svanaes D. Usability and acceptability of balance exergames in older adults: A scoping review. Health Informat J 2016; 22:911–931.
18. van Diest M, Lamoth CJ, Stegenga J, Verkerke GJ, Postema K. Exergaming for balance training of elderly: State of the art and future developments. J NeuroEng Rehabil 2013; 10:101.
19. Larsen LH, Schou L, Lund HH, Langberg H. The physical effect of exergames in healthy elderly—A systematic review. Games Health J 2013; 2:205–212.
20. Konstantinidis EI, Billis AS, Mouzakidis CA, Zilidou VI, Antoniou PE, Bamidis PD. Design, implementation, and wide pilot deployment of FitForAll: An easy to use exergaming platform improving physical fitness and life quality of senior citizens. IEEE J Biomed Health Inform 2016; 20:189–200.
21. Molina KI, Ricci NA, de Moraes SA, Perracini MR. Virtual reality using games for improving physical functioning in older adults: A systematic review. J NeuroEng Rehabil 2014; 11:156.
22. Keefe FJ, Huling DA, Coggins MJ, et al. Virtual reality for persistent pain: A new direction for behavioral pain management. PAIN® 2012; 153:2163–2166.
23. Kappen DL, Mirza-Babaei P, Nacke LE. Older adults' physical activity and exergames: A systematic review. Int J Hum Comput Interact 2019; 35:140–167.
24. Maillot P, Perrot A, Hartley A. Effects of interactive physical-activity video-game training on physical and

cognitive function in older adults. Psychol Aging 2012; 27: 589–600.

25. Pham TP, Theng Y-L. Game Controllers for Older Adults: Experimental Study on Gameplay Experiences and Preferences. In: *Proceedings of the International Conference on the Foundations of Digital Games*. FDG'12. ACM; 2012:284–285.
26. Csikszentmihalyi M. *Flow: The Psychology of Optimal Experience.* Harper & Row, New York, NY; 1990.
27. Sinclair J, Hingston P, Masek M. Exergame development using the dual flow model. In: *Proceedings of the Sixth Australasian Conference on Interactive Entertainment*. IE'09. ACM; 2009:11:1–11:7.
28. Laamarti F, Eid M, Saddik AE. An overview of serious games. Int J Comput Games Technol 2014; 2014:11:11.
29. Kharrazi H, Lu AS, Gharghabi F, Coleman W. A scoping review of health game research: Past, present, and future. Games Health J 2012; 1:153–164.
30. Gonçalves A, Muñoz J, Gouveia É, Cameirão M, Bermúdez i Badia S. Portuguese Tradition Inspired Exergames for Older People. In: *IcSPORTS 2017—Extended Abstracts—AHA*; 2017. https://www.researchgate.net/profile/Sergi_Bermudez_i_Badia/publication/320852961_Portuguese_Tradition_Inspired_Exergames_for_Older_People_Strategic_Tools_to_Promote_Functional_Fitness/links/59fdff68458515d0706ac05a/Portuguese-Tradition-Inspired-Exergames-for-Older-People-Strategic-Tools-to-Promote-Functional-Fitness.pdf (accessed March 26, 2018).
31. Muñoz JE, Gonçalves A, Rúbio Gouveia É, Cameirão MS, Bermúdez i Badia S. Lessons learned from gamifying functional fitness training through human-centered design methods in older adults. Games Health J 2019; 8:387–406.
32. Gonçalves AR, Muñoz JE, Gouveia ÉR, Cameirão M da S, Bermúdez i Badia S. Effects of prolonged multidimensional fitness training with exergames on the physical exertion levels of older adults. Vis Comput 2021; 37:19–30.
33. Muñoz J, Gonçalves A, Gouveia E, Cameirão M, Bermúdez i Badia S. Measured and Perceived Physical Responses in Multidimensional Fitness Training through Exergames in Older adults. In: *2018 10th International Conference on Virtual Worlds and Games for Serious Applications (VS-Games)*, September 5–7, Germany, IEEE; 2018.
34. Heyward VH, Gibson A. *Advanced Fitness Assessment and Exercise Prescription 7th Edition*. Champaign, IL: Human Kinetics; 2014.
35. Rikli RE, Jones CJ. *Senior Fitness Test Manual*. Champaign, IL: Human Kinetics; 2013.
36. Rose DJ, Lucchese N, Wiersma LD. Development of a multidimensional balance scale for use with functionally independent older adults. Arch Phys Med Rehabil 2006; 87: 1478–1485.
37. Ware JE, Kosinski M, Keller SD. A 12-Item Short-Form Health Survey: Construction of scales and preliminary tests of reliability and validity. Med Care 1996; 34:220–233.
38. Gertler PJ, Martinez S, Premand P, Rawlings LB, Vermeersch CMJ. *Impact Evaluation in Practice, Second Edition*. Washington, DC: World Bank Publications; 2016.
39. Gouveia ÉR, Maia JA, Beunen GP, Blimkie CJ, Fena EM, Freitas DL. Functional fitness and physical activity of portuguese community-residing older adults. J Aging Phys Act 2013; 21:1–19.
40. Binder EF, Schechtman KB, Ehsani AA, et al. Effects of exercise training on frailty in community-dwelling older adults: Results of a randomized, controlled trial. J Am Geriatr Soc 2002; 50:1921–1928.
41. Bell AJ, Talbot-Stern JK, Hennessy A. Characteristics and outcomes of older patients presenting to the emergency department after a fall: A retrospective analysis. Med J Aust 2000; 173:179–182.
42. Tromp AM, Pluijm SMF, Smit JH, Deeg DJH, Bouter LM, Lips P. Fall-risk screening test: A prospective study on predictors for falls in community-dwelling elderly. J Clin Epidemiol 2001; 54:837–844.
43. Reis E, Postolache G, Teixeira L, Arriaga P, Lima ML, Postolache O. Exergames for motor rehabilitation in older adults: An umbrella review. Phys Ther Rev 2019; 24: 84–99.
44. Pichierri G, Coppe A, Lorenzetti S, Murer K, de Bruin ED. The effect of a cognitive-motor intervention on voluntary step execution under single and dual task conditions in older adults: A randomized controlled pilot study. Clin Interv Aging 2012; 7:175.
45. Cacciata M, Stromberg A, Lee J-A, et al. Effect of exergaming on health-related quality of life in older adults: A systematic review. Int J Nurs Stud 2019; 93: 30–40.
46. Stanmore E, Stubbs B, Vancampfort D, de Bruin ED, Firth J. The effect of active video games on cognitive functioning in clinical and non-clinical populations: a meta-analysis of randomized controlled trials. Neurosci Biobehav Rev 2017; 78:34–43.
47. Simão H, Bernardino A. User centered design of an augmented reality gaming platform for active aging in elderly institutions. In: *Proceedings of the 5th International Congress on Sport Sciences Research and Technology Support*. AHA; 2017:1:151–162.

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