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ORIGINAL ARTICLE

Effects of prolonged multidimensional fitness training with exergames on the physical exertion levels of older adults

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Abstract

While exergames have been used with older adults in an attempt to promote higher physical activity (PA) levels, and its subsequent health benefits, there is a lack of research that objectively quantifies the PA levels that custom-made exergames can produce throughout an extended training program. In this paper, we describe a 3-month intervention study that aimed to measure the participants PA levels during exergames' sessions and their effectiveness in eliciting the recommended activity levels. Over the course of the study, two groups of older adults participated in either a conventional multidimensional fitness training program of two sessions of exercise per week ($n = 16$) or in an equivalent combined program ($n = 15$), of one conventional and one exergame session per week. Both the objective PA levels (through accelerometry) and subjective effort (perceived exertion) were collected in each session. Results revealed that while participants spent more time in moderate-to-vigorous PA during exergaming than during conventional sessions, they also spent less energy, thus working out at lower intensities but for a more sustained amount of time. The self-reported exertion was consistently higher for the sessions of the combined exercise program. We showed that a set of custom-made exergames can be successfully used by trainers to set up personalized training sessions and can be used in combination with regular exercise for sustained long-term training, exposing differences between the two training regimes in terms of efficiency, elicited PA, and perceived effort.

Keywords Exergames · Activity trackers · Perceived exertion · Multidimensional training · Older adults

1 Introduction

Exercise video games (exergames) aim to encourage players to actively move in order to achieve in-game success, providing a genuinely fun strategy to promote physical activity (PA) in older adults [1]. Exergames can be as effective or more than conventional exercise [2] with small but significant clinical effects outcomes [3], several studies reporting particular improvements in gait, balance, and cognitive function [4, 5]. Advantages which are not present in conventional exercise. The added benefit of the exergames might reside in their immersive nature, which enables participants to forget time, place, and pain to a certain degree [6]. Despite increasing efforts in assessing the effectiveness of using exergames as a complementary (and sometimes alternative) way to

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deliver exercise training programs to the older population [7], many approaches fail in the quantification of the PA through accurate metrics [8]. To guarantee effectiveness in PA promotion through exergames, movement quantification, via activity trackers and specialized tools, helps to accurately characterize the exercise and define their suitability to be used in the older population. However, the use of these technologies has been limited, and the investigation of the body responses during long-term interventions with exergames is still a work in progress [9].

One of the most widely accepted frameworks that establishes the recommendations regarding PA levels in older adults comes from the American College of Sports and Medicine (ACSM) [10]. Essentially, the guidelines contemplate a multidimensional training that embraces aerobic, muscular, flexibility, and neuromotor (balance, motor ability) components to deliver a satisfactory PA. Specifically, regarding exercise intensity for active older adults, the ACSM states that exercises at moderate-to-vigorous PA (MVPA) intensities can produce greater benefits than less intense training [10, 11].

Results from reviews on the quantification of PA during exergaming have exposed the potential of using active playing strategies to elicit physiological responses, as measured by heart rate (HR), oxygen consumption (VO2), and energy expenditure (EE) [8, 12–14]. Most of the studies with healthy older adults have used commercially available exergames (e.g., Nintendo Wii, PlayStation Move, Xbox 360 with Kinect) [7, 15]. For instance, energy expenditure in a group of 19 older adults was measured during boxing and bowling exergaming sessions (Nintendo Wii and Xbox 360 with Kinect) [16] and compared against rest. Three different measurements were used to quantify the energy expenditure: indirect calorimetry (respiratory gas exchange), two dual-axial accelerometers worn on the right hip and dominant wrist, and rating of perceived exertion using a 6–20 scale. Results revealed that those off-the-shelf exergames provided light-intensity exercises and elicited significantly higher energy expenditure compared to rest. Reported physical exertion (RPE) values were not significantly different between equivalent exergames played during 5-min intervals. Cardiac and electrodermal activities were also measured during an exergaming session that exhibited greater HR modulation (as measured through heart rate variability) and arousal responses when compared to the non-active version of the same game [17].

Other studies compared exergaming training with closely matching exercises, showing, for instance, lower EE and HR responses in exergames when compared to aerobic exercise on a treadmill [18] and lower perceived exertion levels for exergaming conditions against non-gamified exercises [19]. No studies were found to report the effects of multidimensional training in the quality and quantity of movement measured during exergaming interventions. This is, however, necessary to enable a more comprehensive interpretation of the benefits of training multiple physical functions [15]. One study concluded that exergames are a feasible alternative to traditional aerobic exercises for older adults, however, without comparing to other exercise modalities or resting state [20].

In longitudinal interventions, pre- and posttest methodologies have been used to investigate the physical effects of exergame-based training programs in older adults, quantifying the longitudinal physical effects of such exercises. In a 24-session intervention (1 h per session, 14 weeks), Maillot and colleagues measured the fitness responses in a group of older adults while playing with the Wii Fit game. Cardiovascular responses measured through the mean HR, maximum HR, and HR reserve did not show significant differences in either the second, twelfth, or twentieth sessions [21]. The HR levels measured fell within moderate (and below) intensity ranges for older adults [10]. Using a more immersive, adaptive, and interactive setup, older adults that had survived a coronary artery bypass grafting intervention were evaluated in a submaximal endurance training program with a controlled exergame played on a treadmill. Participants were subject to twenty training sessions (30 min per session, 10 weeks) and were evaluated for maximum load, target oxygen consumption, and target HR during the intervention. Results revealed that by the end of the twentieth training session, 9 of 10 subjects that played the exergame had reached the recommended target HR. Moreover, all players also achieved their targeted metabolic costs after two training sessions [22]. In another study, wearable activity trackers were used in investigating the long-term use of a custom-made exergame targeting the improvement of balance skills in older adults. The average walking speed was used as the kinematic marker to measure the effectiveness of an exergaming training program that lasted 12 weeks. On average, there was an improvement in the walking speed (5%) in the older adults that used the exergame compared against a reduction in the same variable with those who did not [23]. Similarly, functional fitness tests have been used to quantify the effects of PA by means of exergames in senior players, demonstrating significant differences in fitness domains such as balance, muscle strength, flexibility, and other important mobility factors [24–26]. Other longitudinal and qualitative studies have been carried out with older adults revealing important usability patterns such as engagement, flow, adherence, enjoyment, and motivation, demonstrating the effectiveness of exergames to persuade players in keeping exercising for long periods of time [27, 28].

We are particularly interested in investigating the PA patterns associated with multidimensional training programs with custom-made exergames. There is a need for comparative and descriptive studies that report the differences in physical and perceived responses of older adults to custom-made exergames and conventional exercises as these data might reveal critical elements for the design of genuinely effective exergames [29]. The related work, presented above, points to lower values of EE and RPE in exergames sessions comparatively to conventional exercise sessions. Different studies measuring HR during exergaming have shown conflicting results, either failing or meeting the target HR. This leads us to expect that exergames' training sessions might be used in elderly training programs as a way to achieve the efficient MVPA level while having a lower EE and RPE. Therefore, the goal of this paper is twofold, to demonstrate the effectiveness of such training sessions in eliciting recommended levels of PA in older adults, measured by gold-standard activity trackers and RPE, and to assert whether such sessions have an impact on the behavior of participants in long-term multidimensional training. To do that, we compared information collected during a three-month training program with customized exergames against equivalent conventional exercise sessions.

This paper is an extended version of the conference paper "Measured and Perceived Physical Responses in Multidimensional Fitness Training through Exergames in Older Adults" [30], presented at the 10th International Conference on Virtual Worlds and Games for Serious Applications (VS-Games) 2018.

2 Methods

To evaluate the effectiveness of a set of custom-made exergames designed for multidimensional training in active older adults, we performed a three-month long study. It comprised a combined exercise program (exergames and conventional training) and an equivalent conventional exercise training program, acting as control condition. We aimed at addressing two research questions:

1. Can custom-made exergames be as effective as conventional exercise in achieving MVPA levels during elderly multidimensional training sessions? And if so,
   (a) Will EE be lower?
   (b) Will RPE be lower?
2. Does exergaming, used as a complement to exercise in long-term multidimensional training affect, the way elderly perform when exercising?

2.1 Participants

We recruited 31 active community-dwelling older adults (22 females, ages 67.5 ± 4.6 years) from a local senior gymnasium. After obtaining written consent to participate in the experiment, the Mini-Mental State Examination (MMSE) [31] was used as a cognitive screening tool to ensure that participants could understand the exergames, and their average MMSE score was 27.8 ± 1.3. The participants' balance and functional fitness were evaluated using, respectively, the Short-Form Fullerton Advanced Balance (FAB) scale and the Senior Fitness Test (SFT) [32]. With the SFT battery we evaluated a multitude of fitness domains, the tests were the following:

- 30-s Chair Stand (*lower-body strength*)—the number of stands performed from a sitting position in 30 s;
- 30-s Arm Curl (*upper-body strength*)—the number of biceps curls performed in 30 s holding a 2.3 kg weight for women and 3.6 kg for men;
- Chair Sit and Reach (*lower-body flexibility*)—when reaching the toes with a hand from a sitting position with the leg extended, the number of centimeters between the tip of the fingers and toes;
- Back Scratch (*shoulder range of motion*)—while standing, measure how much the hands overlap, or are far apart, when meeting them behind the back, one hand going from the top behind the head as far as possible, and the other from below;
- 8-ft Up-and-Go (*agility and dynamic balance*)—from a seated position, time to get up, walk 2.4 meters, turn, and return to the seated position;
- 6-min' Walk (*aerobic endurance*)—distance, in meters, walked in 6 min;
- Hand Grip (*static grip strength*)—hand grip strength measured with a hand dynamometer.

This assessment served to characterize the sample and to make sure both experimental groups were equivalent. No significant differences were found between both groups in any of the tests; see Fig. 1 for more details.

2.2 System setup and exergames

2.2.1 System setup

The hardware system used in this work consisted of a PC, connected to a floor facing Optoma GT760 projector (Optoma, New Taipei, Taiwan), and a Kinect V2 sensor (Microsoft, Washington, USA). The floor projection was 3 meters wide by 2.5 meters tall (see Fig. 2), and the Kinect was placed at the top of the projection, facing the players so that it could always track them. This configuration acted as a simplified and static version of the PEPE [33] system, which was developed together with a set of exergames [34] described in the next section, to be compact and highly mobile. Floor projection allows the creation of a

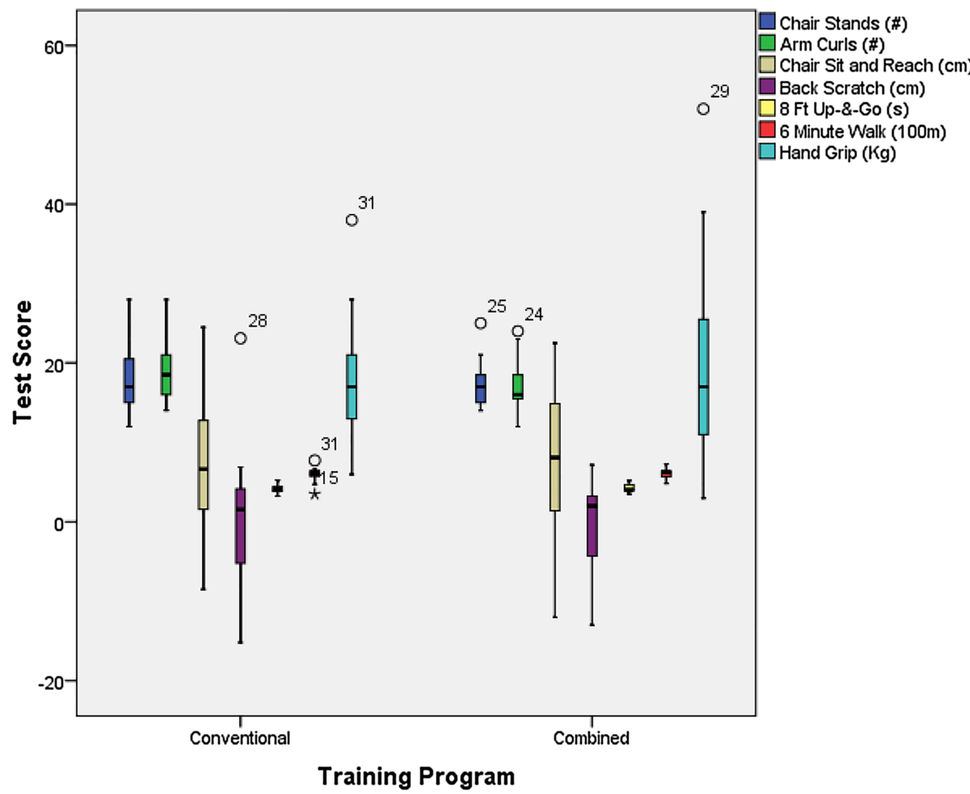

Fig. 1 Tests' scores of the participants, from both groups, in the SFTs' battery of seven tests

large interactive play area, affording a one-to-one mapping between players and games. This avoids the limitations of using a screen, which would make the platform not only cumbersome but also highly restrictive in terms of image size and interaction modalities. In fact, the large size of the projection was meant to be able to demand moderate levels of PA in older players when being used as a play area, as opposed to players being static in front of a TV or projection screen on a wall. Also, by using floor projection with a one-to-one mapping, we can guarantee that the attention of players is focused on the same space with which they are interacting. This attention focus is important as it lowers the need for physical awareness that other means, such as wall projection or TV, create, where the split attention between the display and the play area increases the risk of fall or collision with obstacles. Other, more immersive systems, such as CAVEs or virtual reality (VR) head-mounted displays (HMD), were also considered undesirable. CAVEs, equipped with full body tracking, could offer an equivalent or superior experience than this system, but the cost of building a CAVE is several orders of magnitude higher than the PEPE, besides not being mobile and requiring dedicated infrastructure. VR HMD, on the other hand, while being cheap would create several safety issues, by disconnecting players from reality, and their sense of balance could be severely affected, and the risk of fall greatly increased; it would also raise hygiene issues. The system was installed in a multi-purpose exercise room at the facilities of a local senior gymnasium; lighting conditions and privacy were controlled.

2.2.2 Exergames

A set of custom exergames was used to deliver multidimensional fitness training (see Fig. 3 and supplementary video) [17, 34]. Each exergame was designed with a predominant training domain in mind but with adjustable game variables allowing for training other domains. The exergames are described as follows:

- Exerpong (aerobic, Fig. 3a): Inspired by the classic games Pong and Breakout. In this game, the player controls the lateral position of a paddle located at the bottom of the screen. The player, who stands along the bottom of the projection, has his or her waist tracked, and the game matches the paddle location on the screen with it so that both player and paddle are always aligned. A ball bounces around the other three edges of the screen, which are covered by walls; the player must then use the paddle, by moving laterally along the bottom of the projection, to prevent the ball from going through the lowest edge. A pattern of colorful bricks represented at the center of the screen; these bricks get destroyed whenever the ball passes over them twice, and the goal of the game is to clear these bricks without letting balls pass

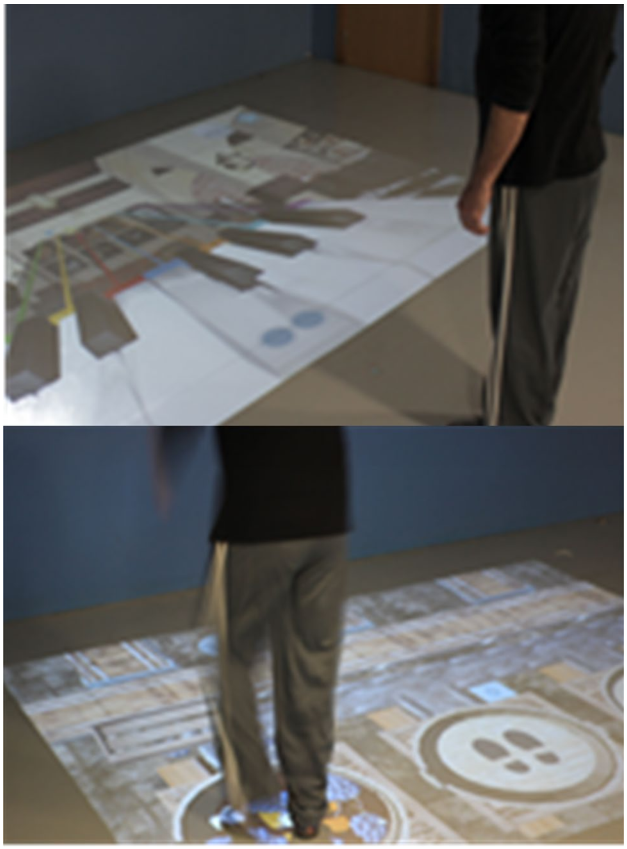

Fig. 2 A player exercising with the floor projection installed in a local senior gymnasium

Fig. 3 Exergames used for the intervention. The Exerpong (**a**) and Grape Stomping (**b**) games train aerobic fitness. The Rabelos (**c**) experience trains upper and lower limbs strength while the Exermusic (**d**) and Toboggan (**e**) propose a motor ability training. Images **b** to **e** were adapted from [34]

through the bottom of the screen. The game difficulty can be adjusted by varying the width of the paddle, and the size and velocity of the ball. Alternatively, the game can be set to adjust its own difficulty according to the player's performance, by increasing the paddle width by a small amount every time a ball is lost, making it easier, and increasing the ball velocity when the player successfully hits it, making it harder;

- Grape Stomping (aerobic, Fig. 3b): It replicates the ancient traditional methods of grape pressing used in wine production, where people repeatedly tread the grapes with their bare feet to extract the juice that will be fermented to produce wine. This game presents three half barrels and a conveyor belt that continuously brings new grape bunches into the play area. The player must physically step into the projection and chose a barrel where to stand; then, by flexion–extension of the arms, they pull the grapes from the conveyor into their barrel. Once there are grapes in the barrels, the player can step on them to tread the grapes, which are converted into a rising level of juice contained on the barrel. Each grape bunch has a limit of steps it takes to be successfully processed; once that limit has been reached, more grape bunches are needed to be pulled from the conveyor belt into the barrel to raise the juice level higher. As soon as the grape juice hits the top, that barrel starts emptying its contents through a channel and becomes unavailable to play for the duration, forcing players to move laterally into another barrel. The grape bunches can come in three kinds, green, red, and rotten (distractors). The game can be configured to have an extra cognitive difficulty layer by having each barrel require specific amounts of red and green grape bunches, if these limits are broken that barrel becomes unplayable for some seconds. Pulling rotten grapes into any barrel has the same consequence. The goal of the game is to produce as much grape juice as possible, which elicits a stepping in place exercise, typically used in aerobic training, this is combined with the arm pulling motion for extra variety. The height that the feet must be raised from the ground to stomp a grape successfully can be configured at startup; together with percentage of rotten grapes (distractors), the grape type requirements per barrel and the time between new grape bunches on the belt, this allows an adjustment of the exercise difficulty;
- Rabelos (upper/lower limbs strength, Fig. 3c): The Rabelos boats are a traditional transportation method of wine barrels in the Douro River, Portugal, and this game replicates those voyages. The player is in charge of navigating a Rabelo boat downriver, avoiding obstacles and docking on the margins to collect barrels. The game takes a third-person perspective from behind the boat where the banks of the river are aligned with the lateral edges

of the projection. The lateral boat position on the river is controlled through the player waist position, which is directly mapped to the projection, just like in Exerpong. To move the boat forward an arm rotation gesture that replicates the rowing activity is required, in this manner, this exergame aims at exercising the upper limbs. As the players row the boat downriver, they encounter rocks that they have to avoid, through lateral movement, and barrel filled docks at the river's margins. These docks must be approached, and their barrels collected via an elbow extension–flexion motion. The goal of the game is to collect as many barrels as possible while avoiding the river rocks. The difficulty set by adjusting the distance between docks and the number of rocks on the river;

- Exermusic (motor ability, Fig. 3d): This game reproduces the environment of a typical Fado house from Lisbon, Portugal, where people go at night to eat, drink, and listen to live music. The projection renders a keyboard on the floor with the different keys aligned with the bottom of the projection. The player stands at the bottom of the projection and both feet control which key they want to activate. Vertically aligned with each key is a colored track over which musical notes travel downwards. The goal is to have the correct key activated at the moment a musical note hits it. Therefore, the player has to play the piano with their feet in synchrony with the visual cues. Over which of the tracks, each note appears depends on the pitch, at that moment, of the music being played, with low pitch making notes spawn at the left keys of the keyboard and high pitch at the right. Additional to this, there are special notes that can be activated by an arm "swiping" movement. This activity is intended to train agility in both upper and lower limbs. Missed musical notes lead to distortion on the song being played, producing negative audio feedback. The music to be played can be chosen from an extensive list of midi files, each with a different duration. By setting, at startup, the speed of the falling notes and the time between consecutive notes, the difficulty is controlled;
- Toboggan (motor ability, Fig. 3e): On the island of Madeira, Portugal, a unique way of transportation was used in the past. Wicker toboggans, driven by two people, would carry passengers downhill, from the hills to the city center. This tradition is now kept alive as a touristic activity. In the game, this activity is recreated virtually. The toboggan and player are presented in the center of the screen from a third-person perspective. Lateral movement is controlled just like Exerpong and Rabelos, by moving sideways along the bottom edge of the projection. The speed is adjusted though trunk inclination, leaning the trunk forward accelerates the toboggan, while leaning backward deaccelerates it. Over the path, there are pedestrian crossings and car intersections to force the player should slow down. While the goal of the game is to drive as far as possible in the allotted time, there are also obstacles to avoid, bonuses to collect, and speed limits to keep under.

All the exergames, except Grape Stomping, are played along the bottom edge of the projection, but with players far enough from it so they are not forced to look directly down to the floor, in what could be an unnatural pose. By contrast, in Grape Stomping, where the player needs to stand over the projection to interact with it, the immersivity that it brings is an advantage to players' perception and engagement. Because these games are played through full-bodied interactions, enabled by a natural user interface that relies on simplified motions and gestures, the need for acquisition of competencies before interaction and engagement is very small.

The exergames' sessions were defined according to their training dimensions, ACSM guidelines (times and intensities) and characteristics from each game, as follows: (1) Exerpong (aerobic) 10 min, (2) Rabelos (strength) 7 min, (3) Grape Stomping (aerobic) 10 min, (4) Exermusic or Toboggan (motor ability) 7 min. Breaks of 2 min were used for the transition between each exergame.

2.3 Experimental design

To quantify the PA intensities, we designed a two-way mixed experiment with a duration of 12 weeks where participants were randomly allocated to two experimental groups. Participants in the *conventional* condition ($n=16$) performed exercise two times per week in a group of conventional fitness training routine for the older population, in sessions lasting 40 min. The training routine followed ACSM recommendations for active older adults concerning multidimensional training components [10], meaning that 50% of the session time was used for aerobic training while 30% was used for both upper and lower limb strength training and the remaining 20% was used for motor ability (also called neuromotor) training. Exercises aimed at encouraging users to perform specific functional tasks such as marching in place, squats, lateral movements, step touches, and stepping on pads. The second group of older adults participated in a *combined* training program ($n=15$) also consisted of two exercise sessions per week. One session was identical to the *conventional* group, and the other was performed with the previously described set of custom-made exergames. Four exergames were used per session to provide a multidimensional training session of 40 min, with similar training components as in the conventional sessions. Both conditions aimed at training seniors with moderate-to-vigorous physical intensity as recommended by ACSM [10].

2.4 Measurements

To quantify PA levels, we rely on both objective (measured) and subjective (RPE) data.

Accelerometers quantified PA: The research-grade three-axial accelerometer ActiGraph WGT3X-BT (Actigraph, Florida, USA) was used to monitor player's PA. The waist-worn sensor was set to register the complete routines of 40 min at 30 Hz sampling frequency and using epochs of 30 s. By using the standalone software of the manufacturers (Actilife 6.10), we computed the time people spent in MVPA (in minutes). Besides, the software provides the EE (metabolic equivalent—METs). This sensor has been widely used and is considered a gold-standard tool to quantify PA in different populations [35] due to its accuracy to effectively characterize the human movement.

To collect subjective data of the levels of reported physical exertion after each exercise routine, we used a pictorial version of the 0–10 rating of RPE scale OMNI [11]. The final OMNI score for the exergaming sessions was the average of the reported values for each game in that session.

2.5 Study protocol

The exercise sessions, of the two conditions, were carried out in a suitable room of the local senior gymnasium and always guided by professional trainers. One trainer was responsible for the odd-numbered sessions (1–23) of both groups, which were always conventional exercise, while the second trainer was responsible for the even sessions (2–24) which were conventional for the *conventional* group and exergames for the *combined* group. Accelerometers were configured taking into account the age, gender, and weight from users. A first session was performed one week before the study to familiarize users with the exercise routines (conventional or exergames), sensor connectivity, and interpretation of the OMNI scale.

2.6 Data analysis

We divided the data into two, the odd sessions, consisting of the conventional sessions of both conditions, and the even sessions, both conventional and exergames. This allowed us to run the same analysis to explore different effects, one to compare the differences in session between conventional exercise and exergames, research question one, the other to see if the type training program affected the users' response to exercise, research question two. For data analysis, a two-way mixed MANOVA was used. The between-subjects factor was the training program each participant was allocated to (2 levels), and the within-subjects factor was program progression (session number). The dependent variables were RPE on the OMNI scale, METs spent, and minutes of MVPA. Separate ANOVAs were run for each dependent variable to ascertain which were being genuinely affected by the training program.

On the 1st, 2nd, 6th, 7th, 9th, and 11th weeks of the study, there was incomplete data from accelerometry. Thus, as the two-way mixed MANOVA requires complete data, we removed those weeks from the analysis. Additionally, data from the 5th and 8th weeks were also excluded because the data failed the Levene's test of equal variance. The remaining weeks, 3rd, 4th, 10th, and 12th, were analyzed, using the MANOVA with four levels of within-subjects factor.

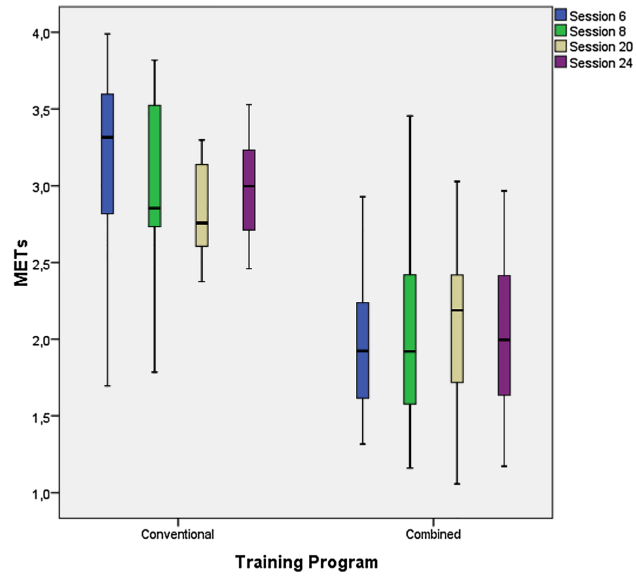

Fig. 4 METs spent during conventional sessions by participants in the conventional program and exergame sessions by the subjects in the combined exercise program, at weeks 3, 4, 10, and 12

3 Results

3.1 Comparison between different program sessions

When the conventional exercise sessions of the *conventional* group were compared with the corresponding weekly exergame sessions of the *combined* program group, a statistically significant effect of the type of training program was identified, $F(3, 27) = 27.958$, $p < .05$; Wilks' $\Lambda = .244$. The univariate ANOVAs revealed significant differences on all three outcomes, with more METs spent on *conventional* sessions ($M = 2.976$, SD = .106) than *combined* ($M = 2.046$, SD = .110), $F(1) = 37.138$, $p < .05$ (Fig. 4); but, on the other hand, MVPA, $F(1) = 11.044$, $p < .05$, and OMNI, $F(1) = 7.977$, $p < .05$, had higher marginal means for the *combined* program ($M = 36.183$, SF = .545; $M = 3.767$,

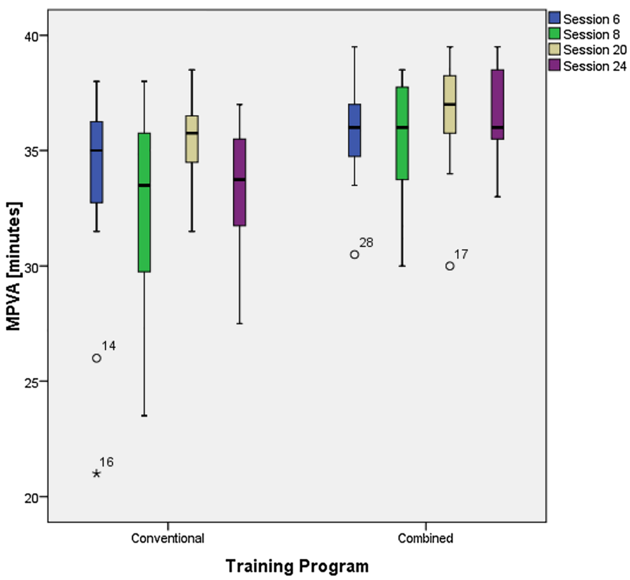

Fig. 5 Minutes spent doing MVPA in conventional sessions by participants in the conventional program and exergame sessions by the subjects in the combined exercise program, at weeks 3, 4, 10, and 12

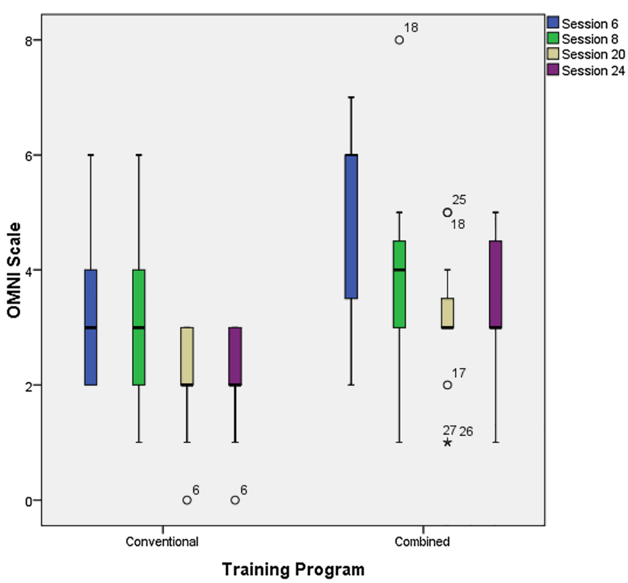

Fig. 6 Self-reported exertion, on the OMNI scale, at the end of the conventional exercise sessions by subjects in the conventional program and the end of the exergames sessions by the subjects in the combined program, at weeks 3, 4, 10, and 12

SD = .271) than *conventional* (M = 33.664, SD = .527; M = 2.703, SD = .262) (Figs. 5, 6).

There was not a statistically significant interaction effect between the type of training program and time, $F(9, 21) = 2.106$, $p = .077$; Wilks' $\Lambda = .526$. The univariate ANOVAs of the outcome variables presented no significant differences for OMNI, $F(2.517) = 1.253$, $p = .296$, METs,

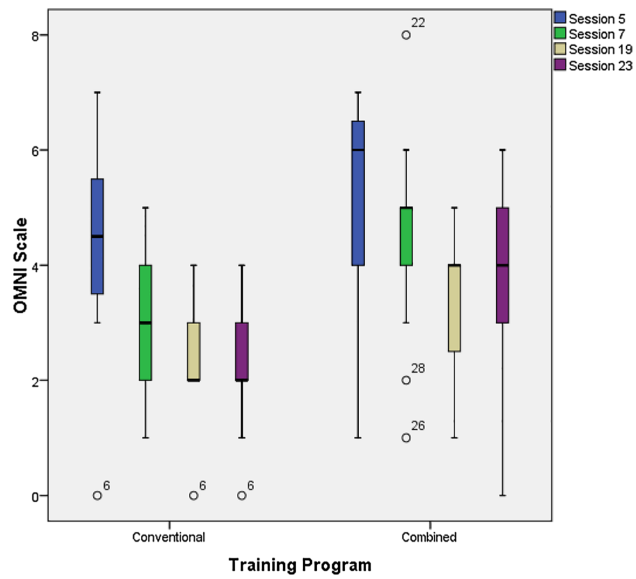

Fig. 7 Self-reported exertion, on the OMNI scale, at the end of the conventional exercise sessions by participants of both the conventional and combined exercise program, at weeks 3, 4, 10, and 12

$F(3.000) = 1.733$, $p = .166$, and MVPA, $F(2.911) = 1.198$, $p = .315$.

3.2 Comparison between conventional sessions' of the training programs

The comparison between conventional exercise sessions of participants in the *combined* exercise program with the equivalent (conventional) session by the *conventional* group revealed a statistically significant effect of the type of training program on the dependent variables, $F(3, 27) = 3.444$, $p < .05$; Wilks' $\Lambda = .723$. Separate univariate ANOVAs on the outcomes did not show significant differences in both spent METs, $F(1) = 2.280$, $p = .142$, and MVPA, $F(1) = .041$, $p = .841$. However significant differences were observed in the OMNI scale, $F(1) = 6.119$, $p < 0.05$, with higher score of RPE (M = 4.117, SD = .302) for the *combined* exercise program than *conventional* group (M = 3.078 SD = .292) (Fig. 7).

There was not a statistically significant interaction effect between the type of training program and time, $F(9, 21) = 1.810$, $p = .126$; Wilks' $\Lambda = .563$. Univariate analysis of the outcomes also failed to find significant difference in METs, $F(2.220) = 2.905$, $p = .057$, MVPA, $F(2.260) = .805$, $p = .465$, and OMNI, $F(2.596) = .830$, $p = .467$.

4 Discussion and conclusion

The results show that exergames can be used by older adults to perform exercise sessions that meet the international recommendations of MVPA without altering their behavior, relative to conventional exercise, during a 3 months training program.

As was hypothesized, the exergames' sessions were able to meet the MVPA goals, which even marginally surpassed the minutes of MVPA spent during conventional exercise. Differences between MVPA and METs reflect the need to interpret data of the activity trackers carefully. For example, more energy expenditure does not necessarily mean greater health benefits in the older population [36]. Having more time spent in MVPA and lower METs during the Exergaming might be interpreted as participants in the *conventional* workout exercised with higher intensities but spent less time within the recommended levels when compared with Exergaming. Therefore, participants during the Exergaming were able to exercise with lower intensity levels but, at the same time exercising within the recommended levels for longer, being more efficient in their training, which answered our first research question. One possible explanation of why the participants spent more time in MVPA during exergames sessions than traditional exercise is that the games can keep players engaged with the activity, as the participants get absorbed by the individual stimulation of a game that reacts to them, which in conventional training would equate to personal training. In this sense, it could have also been the higher individualization of exercise through gaming that motivated people to engage for longer periods. This might have meaningful impacts on the long-term adoption of Exergaming technology in the older population, producing a firm notion of a safe environment for exercising [15]. Nevertheless, having very similar MVPA in both multidimensional exergaming and conventional exercise illustrates how combined strategies can create enjoyable routines without losing efficiency in the PA. This study used research-grade activity trackers and perceived exertion scales in quantifying the PA levels of older adults with training that use custom-made exergames. Subjective data from the OMNI goes against what was expected, showing higher levels of perceived exertion in the *combined* condition once compared with the *conventional*. However, it never exceeded the intensity of hard (score = 8), which successfully meets the ACSM guidelines [37].

The fact that, over three months, there were no differences in the objective measurements of PA between conventional sessions of both training programs answers our second research question. Exposure to exergames had the same effect on PA as conventional exercise. Mainly, we were focused on researching the long-term effects of engaging with custom-made exergames and its effects on the measured and perceived levels of PA. Although some studies have reported the impact of Exergaming in the time players spent exercising at MVPA levels in young adults [38] and children [39], to our knowledge, this is the first study reporting MVPA exertion in the older population.

We highlight the importance of using custom-made exergames rather than commercially grade consoles to promote exercise in older adults. This has been mentioned as one of the most renowned limitations of exergames since the older population is diverse and complex [1, 15]. Our approach included a set of highly personalized exergames especially designed to cover multidimensional training in older adults. Results emphasize the importance of accurately quantifying the PA and characterizing human movement during interventions with exergames to exploit them not only as an attractive option to promote exercise, but also an effective training modality for older adults [29]. While in our study the difficulty of the games was set by a trainer, given the player capabilities and needs, we envision that they can have specific difficulty levels for each fitness domain that would be set automatically according to fitness evaluations and live physiological monitoring of the player. Further studies comparing exergames with standardized training routines in older adults should reveal the quantitative differences of both regarding PA, leading to a more objective, consistent and in-depth discussion about the real impact of playing while exercising, beyond motivation and enjoyment.

From this work, we conclude that exergames were shown to be an effective complement to training programs for the elderly. That exergames' sessions can promote a higher percentage of time spent in MVPA than conventional exercise, which is a benefit for growth and preservation of functional aptitude. The higher RPE by the participants while playing exergames shows that greater care to workload monitorization is required, this strengthens the need for better sensor integration with the games.

Possible limitations of this study are: Although the activity tracker used in this study is considered a very accurate and trustable device for PA quantification, studies have suggested that the cut points which define the light, moderate and vigorous thresholds are dependent on the units of analysis (30 epochs and tri-axial in our case) and subjects variability [40]. However, there is still not a consensus on the values for these cut points for the older population [41, 42]. Because our training was multidimensional, through the use of multiple games, each focusing on a fitness dimension, we are not able to study the effects of individual games on specific physical parameters of the participants. Finally, while we measured data from every session to analyze the players' behavior, in terms of PA levels produced, other types of data are needed to conclude about the long-term impact of exergames on functional fitness and in the activities of daily living.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical standards This work was confirmed to comply with the national and international guidelines for scientific research with humans by the ethical council of the Faculty of Human Motricity, University of Lisbon (Review 14/2017).

Informed consent All the participants gave informed written consent.

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