Measured and Perceived Physical Responses in Multidimensional Fitness Training through Exergames in Older adults

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***Abstract*— Exergames have been used to increase physical activity levels to produce health benefits in older adults. However, only a small number of studies have quantified the physical activity levels produced by custom-made Exergames and their capacity to elicit recommended levels of exercise. This study investigates the effectiveness of custom-made Exergames, designed for multidimensional fitness training, in eliciting recommended levels of exercise. We rely on both objective (accelerometry) and subjective (perceived exertion) information collected in two different modalities of exercise, consisting of 40-minutes sessions: Exergaming and conventional training (Control). A between-subjects analysis was done involving two groups of active older adults (n=33). Participants in the *Control-Between* condition performed physical activity in conventional group fitness training, while the intervention group used individualized *Exergaming* as training modality. In addition, a sub-group of the *Exergaming* participants also performed a conventional training session (*Control-Within*), which enabled a within-subjects comparison. Results show that participants spent significantly more time in moderate-to-vigorous intensities during *Exergaming*, interestingly, perceiving significantly lower exertion levels. The between-subjects analysis only presented statistically significant differences for the perceived exertion scale. This study helps to unveil the impact of custom-made Exergames in physical activity levels during training when compared to conventional training for the older adult population.**

Keywords—component; Exergames, Activity Trackers, Perceived Exertion, Multidimensional Training, Older Adults.

I. Introduction

Exercise videogames (Exergames) aim to encourage active movement of players to achieve in-game success, providing a genuinely fun strategy to promote physical activity (PA) in older adults [1]. Despite recent efforts in trying to demonstrate the effectiveness of using Exergames as a complementary way to deliver exercise training programs to the older population [2], several approaches fail in the quantification and validation of the PA by means of accurate metrics [3]. One of the most widely accepted frameworks that establish recommendations regarding PA levels in older adults comes from the American College of Sports and Medicine (ACSM) [4]. The guidelines theorize a multidimensional training that embraces aerobic, resistance, flexibility and neuromotor exercises to deliver satisfactory PA. For active older adults, the ACSM suggests that exercise at moderate-to-vigorous intensities produces greater benefits [4]. Subjective and objective methods can be used to measure exercise intensities. Ratings of perceived exertion (RPE) scales are used to subjectively measure the exercises intensities. In seniors, it is recommended exercising at intensities between 5 and 8 in a 0 to 10 scale of RPE. Activity trackers that use accelerometers are conventionally used as objective measures to accurately characterize the exercise and define the suitability of using specific exercises in the older population [4]. In Exergaming research, both approaches have been mostly studied separately, hiding the relations between measured and perceived exercise intensities [1]. As older adults have specific requirements in terms of training personalization and fall prevention [1], without proper subjective and objective PA measurements Exergames might produce undesirable effects. Knowing this relation can help researchers to better define exercise intensities when using Exergames with older adults, thus reducing risks associated with over exercising while maximizing the benefits of PA.

II. Physical activity and energy expenditure in Exergaming

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 (VO_2) and energy expenditure (EE) [3], [6], [7]. Most of the studies with healthy older adults have used commercially-available Exergames [2], [8]. For instance, EE in a group of 19 older adults was measured during boxing and bowling Exergaming sessions [9] and compared against resting states. Results revealed that Exergames provided light-intensity exercises and elicited significantly greater EE when compared with resting. RPE values were not significantly different between equivalent Exergames played during 5-minutes intervals. Cardiac and electrodermal activities were also measured during an Exergaming session that exhibited greater HR modulation (as measured through HR variability) and arousal responses in comparison with the non-active version of the same game [10]. Other studies compared Exergaming training to similar exercises, showing, for instance, lower EE and HR responses in Exergames when compared with aerobic exercise on a

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treadmill [11] and lower RPE levels for Exergaming conditions against non-gamified exercises [12]. Despite the clear benefits of training multiple physical functions, no studies were found that that reported on the quality and quantity of movement during Exergaming interventions [8]. Only one non-controlled multidimensional study concluded that Exergames are a feasible alternative to traditional aerobic exercises for older adults [13].

To conclude, 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 to reveal key elements in the design of truly effective Exergames [14]. Therefore, the goal of this paper is to demonstrate the effectiveness of multidimensional training using customized Exergames to elicit recommended levels of PA in older adults, measured by gold-standard activity trackers and RPE.

III. Methods

To evaluate the effectiveness of a set of custom-made Exergames designed for multimodal training in active older adults, we performed a pilot study using an equivalent conventional multidimensional exercise session as a control condition. We aim at addressing two research questions:

a. Are custom-made Exergames more effective than conventional exercise in producing the recommended PA intensity in older adults (moderate-to-vigorous)?

b. Are the RPE levels consistent with the PA intensity measured from activity trackers in older adults?

A. Participants

We recruited 33 active community-dwelling older adults (23 females, ages 67.1 ± 4.2 years, weight 71.4 ± 10.3 Kg) from a local senior gymnasium. After obtaining a written consent to participate in the experiment the Mini-Mental State Examination (MMSE) was used as cognitive screening tool and to ensure that participants could understand the Exergames. Functional fitness was evaluated using the Senior Fitness Test (SFT) [15].

B. Exergames and system setup

1) System Setup: to create a digital playground able to demand moderate levels of PA in older players, we used a 2.5m x 3.0 m floor projection setup (see fig. 1). The KinectV2 sensor (Microsoft, Washington, USA) was used for motion tracking. The system was installed at the facilities of a local senior gymnasium, where lights and privacy were controlled.

Fig. 1. A player exercising with the floor projection installed in a local senior gymnasium.

2) Exergames: a set of custom Exergames was used to deliver multidimensional fitness training (see fig. 2) [10], [16]. Each Exergame was designed with a predominant training domain in mind but with adjustable game variables allowing to train other domains. The Exergames are described as follows:

- Exerpong (aerobic, fig. 2A): inspired by the classic pong and break-out games, players control a paddle to hit a bouncing ball. A pattern of bricks is placed in the center of the screen. These are destroyed when they are passed over twice by the ball and the goal is to destroy them. The game is controlled by tracking the waist of the player and matching it to the lateral movement of the paddle.
- Grape stomping (aerobic, fig. 2B): based on the stepping exercise for aerobic training, this Exergame uses a virtual activity of stomping on grapes placed in tanks projected on the floor. Players must also pull the grapes from a conveyor belt via flexion-extension arm gestures.
- Rabelos (upper/lower limbs strength, fig. 2C): via a rowing motion, this Exergame aims at exercising the upper limbs in a river navigation activity. Players control the lateral boat position on a river through their waist position, forcing them to do lateral movements. Barrels are located on docks at the river's margins. The player must dock and perform an elbow extension-flexion to collect barrels. The goal is to collect as many barrels as possible.
- Exermusic (motor ability, fig. 2D): by projecting a keyboard on the floor, this Exergame uses the mechanic of playing a piano with the feet for training agility in both upper and lower limbs. It uses music to encourage players to match their physical feet position with notes that scroll down the screen. If a musical note is missed, the

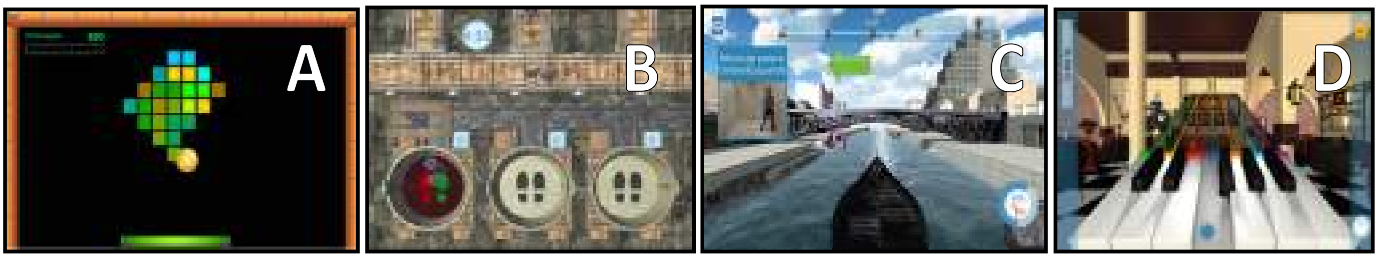

Fig. 2. Exergames used for the intervention. The Exerpong (A) and Grape Stomping (B) games train aerobic fitness. The Rabelos (C) experience trains upper and lower limbs strength while the Exermusic (D) proposes a motor ability training. Images adapted from [16].

soundtrack will be distorted producing negative audio feedback. Bonus notes appear randomly, requiring the player to perform a hand swipe gesture to get them.

Following the training dimensions, ACSM guidelines (times and intensities) and characteristics from each Exergames, the exercise session was distributed as follows: i) Exerpong (aerobic) 10 minutes, ii) Rabelos (strength) 7 minutes, iii) Grape Stomping (aerobic) 10 minutes, iv) Exermusic (motor ability) 7 minutes. Breaks of 2 minutes length were used for the transition between each Exergame.

C. *Experimental design*

1) Between subjects design: to quantify the PA intensities, we designed a between-subjects experiment using two experimental groups randomly allocated. Participants in the *Control-Between* condition (n=16) voluntarily made exercise using a conventional group fitness-training routine for the older population lasting 40 minutes. The training routine followed ACSM recommendations for active older adults in terms of multidimensional training components [4], meaning that the 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 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 training session using the set of custom-made Exergames previously described. In the *Exergaming* condition (n=17), four Exergames were used to provide a multidimensional training of 40 minutes length, similarly distributed as in the *Control-Between* condition. Both the *Control-Between* and *Exergaming* conditions aimed at training seniors with moderate-to-vigorous physical intensity as recommended by ACSM [4].

2) Within-subjects design: a subgroup (n=11) of participants involved in the *Exergaming* condition participated in a conventional training session (*Control-Within*) that was carried out on a different day of the same week. This was done to compare the effects of the Exergames in the same senior participants minimizing the effect of subjects variability. Here, conventional training was identical to the *Control-Between* condition.

D. *Measurements*

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

1) PA quantified by accelerometers: the research-grade three-axial accelerometer ActiGraph WGT3X-BT (Actigraph, Florida, USA) was used to monitor player's physical activity. The waist-worn sensor was set to register the complete routines of 40 minutes at 30 Hz sampling frequency and using epochs of 30 seconds. By using the standalone software of the manufacturers (Actilife 6.10), we computed the time people spent in moderate-to-vigorous PA (MVPA in minutes). Besides, the software provides the EE (metabolic equivalent - METs) and the number of steps. This sensor has been widely used and is considered a gold-standard tool to quantify PA in different populations [17] due to its accuracy to effectively characterize human movement.

2) RPE: to collect subjective data of the levels of physical exertion after each exercise routine, we used a pictorial version of the 0-10 rating of RPE scale OMNI [18]. The final OMNI score for the Exergaming condition was the average between the reported values.

E. *Study Protocol & Data Analysis*

Exercises for the two conditions were carried out in a suitable room of the local senior gymnasium and were always guided by professional trainers. Accelerometers were previously configured taking in to account the age, gender, and weight from users. To familiarize users with the exercise routines (conventional or Exergames), sensor connectivity, and OMNI scale, a first session was performed one week before the study. Additionally, both cognitive and functional fitness assessments were carried out one week before. To increase the personalization in the exercise sessions, users in the *Control-Between* condition were divided into two smaller subgroups (n=8) that completed the exercise routine on different days. For data analysis, the Mann-Whitey test was used for between-group analysis. The paired-samples T-test was used to compare within-group differences in normally distributed data and the Wilcoxon signed rank test for non-normal data.

IV. Results

PA effectiveness was quantified as the total amount of MVPA in minutes that users spent in the 40 minutes session of training. The between-subjects results show that players spent more minutes of MVPA during the *Exergaming* (Mdn=34.5) when compared with the *Control-Between* condition (Mdn=32.2), although the difference was non-significant. The within-subjects analysis revealed significant differences, $t(10)=3.91$, $p<0.05$, showing that players spent more time in MVPA during the *Exergaming* (M=34.4, SD=3.1) when compared to the *Control-Within* condition (M=32.0, SD=2.2).

Additionally, we compared the EE and the total number of steps for both the between and within experiments. Results revealed higher number METs burned for the *Control-Between* (Mdn=2.5) when compared to the *Exergaming* condition (Mdn=1.8). The Mann-Whitney test showed that the differences were statistically significant $U=62.0$, $z=-2.6$, $p<0.05$. Similarly, the differences in the within experiment were significantly higher $T=0$, $p<0.05$, for the *Control-Within* (Mdn=2.4), compared to the *Exergaming* condition (Mdn=1.9). Total steps were also higher in the *Control-Between* (Mdn=1864) compared with the *Exergaming* (Mdn=1481). Contrarily in the within-subjects experiment, steps were higher for the *Exergaming* (M=1656, SD=399) when compared to the *Control-Within* (M=1497, SD=351) condition, but the difference was not significantly in both cases.

RPE data from one user in the *Control-Between* condition was excluded due to human error. Statistically significant differences, U=63.0, z=-2.5, p<0.05 demonstrated that players perceived higher exertion during Exergaming (Mdn=4) when compared to the *Control-Between* (Mdn=5) condition. Interestingly, results from the within analysis revealed that players perceived significantly lower levels of exertion, T=7, p<0.05, in the *Exergaming* (Mdn=5), when compared to the *Control-Within* condition (Mdn=6).

V. DISCUSSION & CONCLUSION

The between and within comparison data of this study support that a multidimensional training that uses custom-made Exergames can efficiently elicit the recommended levels of PA in older adults. Accelerometer data revealed statistically greater levels of MVPA in the Exergaming routine compared to conventional exercise in the same group of older adults. Some previous studies have reported the impact of Exergaming in the time players spent exercising at MVPA levels in young adults [19] and children [20]. However, to our knowledge, this is the first study reporting MVPA exertion in the older population. Differences between MVPA, METs, and steps in the within and between experiments reflect the need to carefully interpret data of the activity trackers. For example, more EE does not necessarily mean greater health benefits in the older population [21]. Having more time spent in MVPA and lower METs during the Exergaming might be interpreted as participants in the conventional workout having exercised at higher intensities while spending less time within the recommended levels. Therefore, participants during Exergaming were able to exercise with lower intensity levels but at the recommended levels during more time.

Data from the OMNI scale supports the equivalence between the two training methods compared, which were both multidimensional and guided by professional trainers. RPE never exceeded the intensity of hard (score = 8), in accordance with ACSM guidelines [4]. The within comparison demonstrated that the *Exergaming* condition produced a more effective training compared to the control condition, without over-exercising older adults. Finally, we highlight the importance of using custom-made Exergames rather than commercially-grade consoles to promote exercise in older adults. This has been identified as one of the most important limitations of Exergames since the older population is diverse and complex [1], [8]. Our approach included a set of highly personalized Exergames especially designed to cover a multidimensional training in older adults. The comparison of Exergames with standardized training routines in older adults reveals the quantitative differences of both in terms of PA, leading to a more objective, consistent and constructive discussion about the impact of playing while exercising. We emphasize the need to carry out studies with older adults that allow a proper quantification of the PA intensity and EE spent in Exergaming interventions as well as the advantages of including equivalent conventional exercise approaches to compare such responses. This study contributed to unveil the differences of measurements through research-grade activity trackers and RPE scales in quantifying the PA levels of older adults using custom-made Exergames. Additionally, it will help to disseminate that the use of Exergames can efficiently boost the health benefits of exercising while enhancing the motivation and engagement of doing it.

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