Efficacy of Augmented Reality-based Virtual Hiking in Cardiorespiratory Endurance: A Pilot Study

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Keywords: Hiking Simulator, VR Environments, User Experience, Heart Rate, Exertion Level, Virtual Reality, Exergames.

Abstract: Exergames can be used to overcome a sedentary lifestyle. Virtual Reality (VR) has made exergames successful, and they can be used to increase heart rate, but some limitations are found, such as the adaptation of the heart rate in exergames to the player's fitness profile. VR technology has been used to simulate virtual cycling and walking experiences. We designed and developed an exergame' Virtual Levadas' in a cave-based VR environment to simulate the Levadas hiking tracks. They are the main attraction for tourists in Madeira Island, Portugal. This study's main objective was to assess player exertion, usability, participation, and realism of the simulation of the Levadas tracks. We performed this study with 13 participants who played Virtual Levadas for 6 minutes and found a significant increase in player's average physical activity and heart rate. Overall, our results demonstrate that Virtual Levada's exergame provides a higher exertion level, immersion, and realism of the virtual environment than the literature.

1 INTRODUCTION

Exergames (video games with physical activity) are becoming more popular because of their reported benefits (Ketcheson et al., 2015). The main goal in the design of exergames is to keep players motivated during gameplay and physical activity (Yue Gao and Regan L. Mandryk, 2011) (Knights et al., 2014). An exercise session of ten minutes can increase concentration and provides cognitive incentives (Klein and Simmers, 2009). The combination of physical activity and video games increases player interest and motivation (Yoo and Kay, 2016). Exergames can help to overcome a sedentary lifestyle (Klein and Simmers, 2009). According to the US National Heart, Lung Blood Institute, the limitations of inadequate physical activity levels include lifestyle, fewer recreational facilities, age, and health conditions (NIH, 2012).

In recent progress, virtual reality (VR) technology has made exergames successful (Yoo and Kay, 2016). The most common VR setups are large screen displays (Cave systems) and head-mounted displays (HMDs). Nintendo Wii (Park et al., 2014) and the Microsoft Kinect (Chan et al., 2011) introduced exergames and confirmed high interest and physical activity. Wii Fit (wiifit.com) has been commercially recognized and promoting Mircosoft Kinect (microsoft.com) as an input device. However, the exergames' immersion and motivation were observed low with less involvement (Bolton et al., 2014). Some exergames may elevate high physical activity levels (PA) and adherence (Staiano et al., 2018). However, traditional physical exercises induce higher PA than in exergames (Schneekloth and Brown, 2018). More

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Ahmad, M., Sousa, H., Quintal, É. and Bermúdez i Badia, S.
Efficacy of Augmented Reality-based Virtual Hiking in Cardiorespiratory Endurance: A Pilot Study.
DOI: 10.5220/0010312405750582
In *Proceedings of the 14th International Joint Conference on Biomedical Engineering Systems and Technologies (BIOSTEC 2021) - Volume 5: HEALTHINF*, pages 575-582
ISBN: 978-989-758-490-9

research is required that the regular use of the exergames can make players physical active (Soltani et al., 2020).

In this study, we developed an application using VR to simulate hiking on Levadas and Veredas tracks and promote physical activity while enjoying Madeira's unique hiking trails. Madeira (Portugal) is one of Europe's leading island destinations (World Travel Awards [WTA], 2019) and has 2/3 of the area cataloged as a Natural Park. There are more than 28 hiking-tracks recommended by the local government and municipalities to visit the park. Hiking is very popular in Levadas and Veredas (Madeira's Hiking trails) because of increased tourism (Roque et al., 2018).

In this work, we modified the 2-minute step test (TMST), introduced by Rikli and Jones, as part of the Senior Fitness Test in 1999 (Rikli and Jones, 1999). TMST may be used as an alternative to a six-minute walk test to measure of aerobic endurance. We hypothesized that a six-minute stepping exercise would induce physical activity by elevating the player's heart rate. An augmented reality-based setup may simulate Levadas tracks with a higher sense of presence, realism, and usability. In our virtual Levada simulation, participants need to march-in-place as fast as possible for 2 minutes while lifting knees at a criterion height. A six-minute stepping exercise was performed by the participants with three variations of the knee height to walk in a VR environment, and exertion of the physical activity was assessed through heart rate to address the following research questions:

RQ1. Does a cave-based VR system provide a high presence and usability to simulate virtual Levadas?

RQ2. Can a stepping exercise in Virtual Levada's exergame be used to induce adequate physical activity?

2 RELATED WORK

The physical activity component of video games defines exergames. Christos Ioannou and co-authors proposed virtual performance augmentation of in-place running and jumping and assessed a VR exergame effect. They found that in-place running and jumping in a VR can be used to create a natural experience and induce moderate to high physical activity (Ioannou et al., 2019). Another developed a VR table tennis exergame and compared the participants' heart rate generated through traditional and VR-based table tennis (Varela Aldás et al., 2020). They reported a decrease in the participants' heart rate in the VR version, which indicated that VR-based table tennis was not suitable to induce physical activity (PA). A recent study built a bike 'Greedy Rabbit' adopting a design-based exergame approach to assess young adults' physical activity and situational interest. They found that a design-based exergame approach is an excellent method to elevate the player's physical activity and situational interest (Cédric Roure et al., 2020). Another study created an exergame VRun in which players physically run on the spot to interact with the virtual environment. They compared laptop display and large screen display setups and reported large-screen display had high immersion (Yoo and Kay, 2016).

Similarly, Mallory Ketcheson and co-authors introduced and assessed heart rate power-ups' novel game concept to induce higher physical activity during gameplay. The heart rate power-ups endorse players to elevate their heart rate to the target level by providing those rewards in the game. They developed three exergames and found a significant increase in the players' exertion level and enjoyment level (Ketcheson et al., 2015). Gao et al. (2017) reported that a school-based exergaming program induced children's moderate-to-vigorous PA (7–10 years old) over two years in overweight and obese adolescents. Staiano et al. (2017) found an increase in PA during a 12 weeks dance exergaming intervention program in overweight and obese adolescent girls. Grab apple exergame elevated 72% of the maximum heart in ten minutes, making players play at different intervals of the day (Yue Gao and Regan L. Mandryk, 2011). This exergame was considered useful for those people who were not able to perform a long exercise.

Moreover, Shaw et al. used an HMD environment to simulate an exercycle game in which players have to pedal to move in a virtual environment. The authors reported a statistically significant increase in exertion and motivation when playing the game. However, a small increase in motivation and no difference in exertion level were found in the HMD environment (Shaw et al., 2015).

Sinclair stated that one limitation of designing physical activity exergames is that gameplay and exercise may not be synchronized to acquire a desired target heart rate (Sinclair, 2011). Finkelstein and Suma developed the immersive VR exergame "Astrojumper" and reported a significantly increased heart rate of users after gameplay. The participants' exertion level was correlated with their motivation level (Finkelstein and Suma, 2011).

3 METHOD

Our study's main objective was to recreate Levadas hiking-tracks' experience to develop a virtual simulation scenario. For that, we designed and created the "Virtual Levadas" exergame in a mixed reality-based setup. We assessed users' physical responses and usability, fidelity, and perceived level of presence during the experience. The participants were provided an informed consent that is compiled with Helsinki and Portugues laws. The study was conducted at the facilities of the Madeira Interactive Technologies Institute in Funchal, Portugal.

3.1 Experiment Setup

3.1.1 Hardware

The KAVE is a unity plugin for CAVE systems previously developed at our research lab. It comprises scripts, objects, and prefabs that use a 140$ Kinect V2 tracking sensor (Microsoft, Redmond, USA) to add parallax effect and full-body tracking for interaction with virtual objects. The latest Azure Kinect DK can be used with the Kave plugin because Kinect V2 is out of production. The height and width of the CAVE walls were 2.2 and 2.8 meters, respectively. A Kinect V2 sensor was installed at the front wall to detect full-body gestures. External speakers and four HD projectors were positioned in a way as to project on walls and floors (Figure 2). The price of the CAVE (structure, projectors, and Kinect) was just under 3,800€ (projectors costing 3,200€). However, it requires a computer capable of displaying in 4 screens. For more details on the KAVE, refer to (Gonçalves and Bermúdez I Badia, Sergi, 2018). Physical activity was assessed by ActiGraph WGT3X-BT (Actigraph Corporation, Pensacola, FL, USA), a tri-axial accelerometer (size: 3.5 × 3.5 × 1 cm, weight: ~14 g). ActiGraph's WGT3X-BT activity tracker is a validated small, lightweight, portable device that measures body acceleration and energy expenditure associated with movement ("ActiLife 6 User's Manual", 2020). Also, the WGT3X-BT was paired with a heart rate chest band Polar H10 (Polar Electro Oy, Kempele, Finland), and hence heart rate data were collected synchronously with the ActiGraph system. ActiLife6 software (version 6.13.4, ActiGraph, Cary, NC, USA) was used to process data and calculate the vector magnitude.

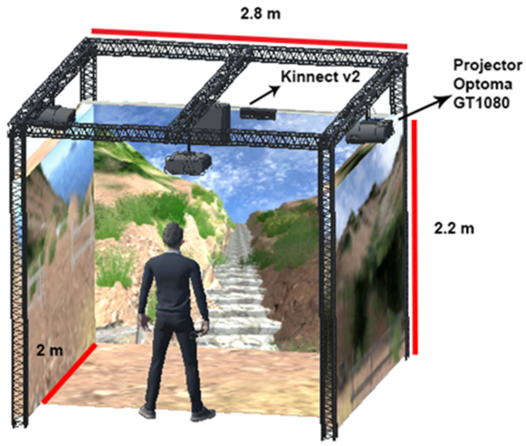

Figure 1: Schematic diagram of our KAVE Setup.

3.1.2 Software

Three types of Levada tracks were created in Unity 3D to simulate a six-minute hiking experience. The VR environment contains computer-generated 3D objects such as mountains, trees, grass, birds, irrigation canals, etc., created in Unity3D and the Blender creation suite (Blender Foundation, Amsterdam, Netherlands) (Figure 2). The user moves through the hiking trail by stepping-in-place. The Kinect V2 is used to detect the knee height and trigger the virtual movement. Three different difficulty levels were created by modulating the required stepping height of the knee.

Figure 2: Design of Virtual Levada and Six-minute hiking simulation in Augmented Reality.

3.2 Instruments

3.2.1 User Experience

Witmer and Singer's Presence Questionnaire (WSPQ) was used. It includes 24 items addressing Involvement, Immersion, Visual Fidelity, Interface Quality, and Sound (Witmer et al., 2005). Items 1-22 are rated on a 7-point scale. Sound items (20-22) were not considered for the overall WSPQ score's computation, consistent with other studies (Witmer et al., 2005). Items 23 and 24 are not applicable, as the application does not have haptic feedback.

Our study also used the System Usability Scale (SUS), created by (John Brooke, 1996), to assess the application's usability. SUS comprises ten items with five response options from strongly disagree to strongly agree. It allows a quick evaluation of the usability of a wide variety of products and services, including hardware and software.

3.2.2 Fitness

Senior fitness tests (SFT) were introduced to assess lower-body strength, agility and dynamic balance, and aerobic endurance among the elderly (Rikli & Jones, 1999). The SFTs have been used in many clinical trials as a tool to assess the physical function of older adults (Yang et al., 2019). The SFTs are easy to use and do not require any special technical skills, infrastructure, or setup (Birgitta Langhammer and Johan K. Stanghelle, 2019). We used the two-minute step test (TMST) to assess aerobic endurance. The TMST was modified to use as a six-minute stepping exercise to simulate virtual Levadas. The number of steps was recorded through the exergame.

3.3 Protocol

Before starting, the study's protocol was provided, and participants provided informed consent, and all were randomly assigned to one group. Repeated measures experimental design was used, and a two-minute demo session was provided to familiarize them with the application and task. After the demo session, participants were asked to wear the Actigraph accelerometer and the heart rate chest band. Participants executed three consecutive 2-minute marching at the same place trials of the Virtual Levada, each with a different and increasing difficulty level (easy, medium, and hard), based on the knee's high. One minute rest was provided to participants after each trial. After the Virtual Levada experience, participants answered the WSPQ and SUS questionnaires.

3.4 Participants

The participants were a convenience sample recruited at the Madeira Interactive Technologies Institute and the University campus. It consisted of 13 participants (females =8, ages: M=30.29 SD =6.4). Sample was composed by graduate students and research assistants, that had no physical disabilities, were able to understand and speak English, and received no compensation for their participation. Three participants were removed because of technical problems with the accelerometer.

3.5 Statistical Analysis

The number of steps, magnitude vector, and heart rate was computed as median and standard deviation, Mdn (IQR). For the WSPQ and SUS, we calculated the total mean score and standard deviation M (SD) to compare with related work. The normality of the distributions was assessed using the Kolmogorov-Smirnov test. Data were considered not normal for all three parameters, and nonparametric tests were used. The Friedman test was used to evaluate the impact of different experimental conditions. The threshold for significance was set at 5% (α=0.5). The post hoc 2-tailed Wilcoxon signed-rank test was used for pairwise comparisons. Because of multiple comparisons, Bonferroni correction was applied. Analysis of data was performed using SPSS version 26.

4 RESULTS

4.1 User Experience

The virtual environment was created in a virtual Levada exergame using VR technology to simulate real Levadas. The hiking tracks with irrigation canals, trees, birds, grass, and plants, audio, and visual effects were added in the virtual environment to achieve high visual fidelity, immersion, and presence. The total mean score of the user perception of presence in WSPQ was M=99.6 (20.3), which indicates a higher sense of presence. The high average score for the subdomains of the WSPQ, such as involvement, immersion, visual fidelity, interface quality, and sound, indicates that the user-perceived high presence, realistic environment, reliable, and user-friendly (Table 2). The high mean score reported in the SUS (M=79.2(16.3)) suggests that virtual Levada exergame can simulate real Levadas and assess the user's exercise exertion level.

Table 1: Mean (SD) scores.

WSPQ	Items	Scores
Total score	All execpt 20,21,22	99.6 (20.3)
Involvement	1,2,3,4,5,6,7,10,13	5.1 (0.98)
Immersion	8,9,14[a],15,16,19	5.0 (0.98)
Visual Fidelity	11,12	4.2 (1.5)
Interface Quality	17[a],18[a]	5.8 (1.5)
Sound	20,21,22	4.6 (1.7)

[a] Reversed items

4.2 Fitness

We implemented and modified a 2-minute step test of SFTs in virtual Levada exergame to induce adequate physical activity level. Three levels (conditions) of difficulty in exergame were added to elevate the user heart rate and analyze the number of the steps and vector magnitude. There was a statistical difference in all parameters over three conditions of Levada $FR(2)=0.20$, $p<0.001$. Post hoc analysis with the Wilcoxon signed-rank test was used with a Bonferroni correction applied, resulting in a significance level set at $p < 0.017$, which indicates that we found variation in physical activity. Mdns (IQR) number of steps for the easy, medium, and hard were 113.0 (27), 96.0 (19), and 83.5 (24), respectively. There were significant differences in all three conditions for the number of steps, which were easy and medium ($Z = -3.29$, $p = 0.0005$), easy and hard ($Z = -3.29$, $p < 0.001$), and medium and hard ($Z = -2.22$, $p = 0.013$). The number of steps decreased at each difficulty level, which suggests that our exergame impacts the participant's exertion level. Similarly, Mdns (IQR) average magnitude vectors for the easy, medium, and hard were 371.1 (253.15), 394.4 (327.52), and 789.6 (360.18), respectively. There were no significant differences in the average magnitude vector between easy and medium ($Z = -1.97$, $p = 0.024$). However, statistical significant differences were found between the easy and hard ($Z = -2.73$, $p = 0.003$), and medium and hard ($Z = -2.85$, $p = 0.002$). Mdns (IQR) heart rates for the easy, medium, and hard were 125.0 (54), 126.5 (53) and 138.0 (40), respectively. The significant differences were found in all three conditions for the heart rate, which were easy and medium ($Z = -3.11$, $p = 0.001$), medium and hard ($Z = -2.27$, $p = 0.011$), and easy and hard ($Z =-2.41$, $p = 0.008$) (Figure3). The participant's heart rate suggests that the adaptation of the participant heart rate to the exergame can induce different physical activity levels.

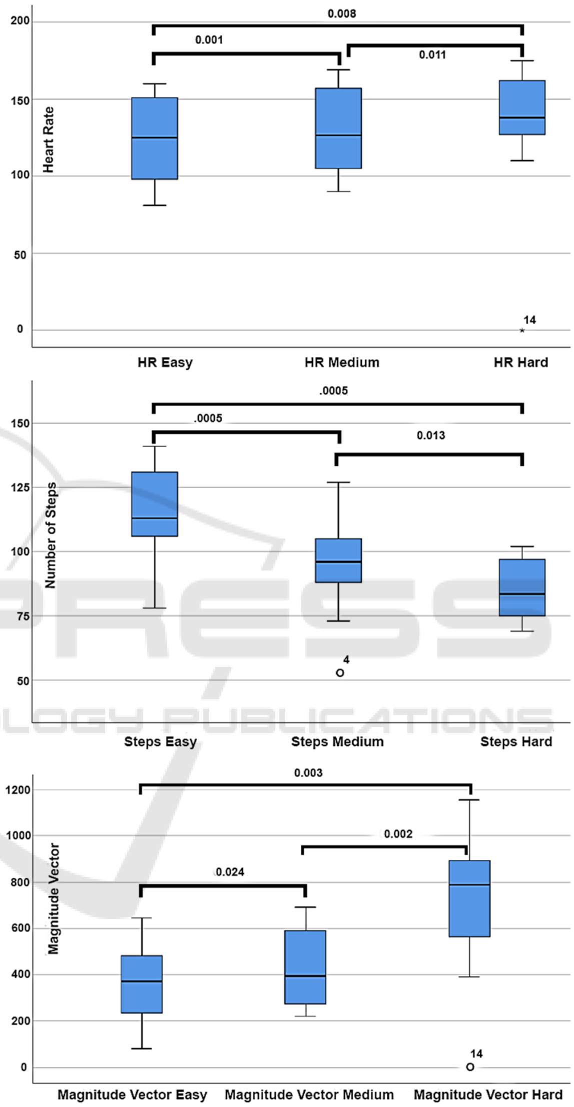

Figure 3: Boxplot from post hoc results of Heart Rate, Magnitude Vector, and number of steps.

5 DISCUSSION AND CONCLUSIONS

5.1 Fitness

We assessed the efficacy of the application by measuring heart rate variability at different difficulty levels. We observed a significant increase in heart rate in each difficulty level of application from the results, which may acquire the target heart by modulating the application's duration and difficulty levels. The difficulty level of the application was associated with the participant's knee height during the stepping exercise. The stepping activity was the modification of a two-minute step test.

A recent study compared the two-minute step test with a six-minute walk test, and they reported higher fatigue and leg fatigue after the two-minute step test than the six-minute walk test (Węgrzynowska-Teodorczyk K et al., 2016). We expected that our exergame would increase the exertion level of the participants. They performed a six-minute stepping exercise with three levels of difficulty and one-minute rest after each difficulty level. Another recent study assessed the average exertion level of multiple exergames through the participant's heart rate and found an elevation in the heart rate (Ketcheson et al., 2015). They measured the exertion level of the exergame through heart rate. The virtual Levada exergame significantly increased the player's heart rate and exertion level. Our results suggest that virtual Levada exergame can induce adequate physical activity level to answer our second research question.

5.2 User Experience

The usability and user perception of the application's presence was also assessed using SUS and WSPQ instruments. The average SUS score is 68, and our study reported a SUS score (M=79.2(16.3)), which indicates high usability of the application. Some other studies also reported SUS scores; for example, Yoo and Kay reported SUS to score 75 and 65 for HMD and large-screen display, respectively (Yoo and Kay, 2016). Another study reported the highest SUS score (M=87.0(11.1)) of the Mole exergame developed by SilverFit (Nawaz et al., 2014). The subjective measures such as high usability score answer our second research question that virtual Levada can induce physical activity. The total score (M=99.6 (20.3)) over the 19-item presence questionnaire WSPQ (Witmer et al., 2005) was considered significantly higher when compared to literature, which indicates that our application had higher immersion and involvement. For example, a recent study reported a mean score of 109.35 (13.65) using an HMD (Deb et a, 2017). In another study, Feldstein et al. reported 93 (1.23) presence scores in an HMD setup (Feldstein et al., 2016). The high score for subdomains of involvement and immersion indicates that participants perceived high presence and realistic environment, whereas fidelity suggests the application's reliability. The mean score of interface quality informs that the interface of the application was user-friendly. The average score for sound was measured separately (M= 4.6(1.7)) indicated a realistic ambient sound of Levadas. The high score of fidelity and immersion answers our first research question and suggests that our exergame can simulate virtual Levadas using immersive VR technology.

In this study, we designed and developed an exergame in a cave-based VR environment to provide a virtual simulation of Levadas. They are the main attraction for tourists in Madeira, and our exergame would bring more awareness and promote tourism. We also assessed the exergame's average exertion level through a player's average heart rate and found a significant heart rate increase. However, there are still limitations such as portability of the application, small sample size, space constraints, and consistent heart rate data acquisition in real-time. In future work, we will assess the target heart rate according to ACSM recommendations (Mitchell et al., 2006) by adapting the user heart rate to the exergame's difficulty level in real-time. We would include more challenging tasks and rewards in this application to increase the player's motivation and interest. Hiking could be a more challenging task for the elderly because of their physical balance and fitness. We will conduct further studies with a large sample size of the elderly.

ACKNOWLEDGEMENTS

This work is supported by NOVA LINCS (UIDB/04516/2020) with the financial support of FCT- Fundação para a Ciência e a Tecnologia, through national funds

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