Adaptive Control of Cardio-respiratory Training in a Virtual Reality Hiking Simulation: A Feasibility Study

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Abstract: Adaptive Virtual Reality applications are a novel way to enhance and promote higher levels of physical activity and cardiorespiratory fitness, leading to a healthier lifestyle and avoid cardiovascular diseases. In this study, we developed a system using a virtual hiking simulator, the Levadas from Madeira Island, that aims to increase the compliance of recommendations levels of exertion by implementing a closed-loop adaptation according to the heart rate. The system was tested with a sample of twenty healthy young adults on a repeated measures design, comparing the adaptive VR, a non-adaptive VR version of the software, and a non-VR version. Perceived exertion, presence, usability and intrinsic motivation were assessed. The results from the study reveal that the adaptive control according to the heart rate promoted approximately 20% more time of exertion in the recommended target heart rate zone, while perceiving lower levels of exertion by the participants, compared to the non-adaptive condition.

1 INTRODUCTION

Physical inactivity has been recognized as the fourth leading cause of death worldwide (Lee et al., 2012). A sedentary lifestyle is considered a sole risk factor for cardiovascular diseases, which account for approximately 30% of global mortality. Thus promoting an increase in physical activity in people of all ages will help in reducing the risk of cardiovascular diseases (Hoffmann et al., 2015). A novel way to increase physical activity is to use exergames to exercise and promote health and well-being (Muñoz et al., 2018). Exergames are digital games that require the usage of the whole-body to control a game, increasing the physical activity level, potentially improving the physical fitness components, such as endurance, strength, balance and flexibility (Oh and Yang, 2010). According to the American College of Sports and Medicine (ACSM), exergaming can be described as a healthy and beneficial form of exercising by engaging and challenging the participants to play (Dean et al., 1998). Several studies have shown that exergames can enhance enjoyment and intrinsic motivation compared to traditional exercises and are efficient to promote physical and mental health (Pluchino et al., 2012; Rosenberg et al., 2010).

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Although not strictly a computer game, the system used in this paper is a Virtual Reality (VR) simulation of a pleasant real-life experience (Ahmad, 2021). In recent years, VR technologies have made much progress and many VR systems have been introduced. The usage of VR technology is trending because it provides a high level of immersion - the extent to which the VR system delivers sensations from the real world to the virtual world (Bailenson et al., 2008; Stasieñko and Sarzyńska-Długosz, 2016). In particular, systems such as CAVE (Cave Automatic Virtual Environment) have been reported to be effective to immerse and engage participants during VR experiences (Gonçalves et al., 2021).

VR-based applications are being used for athletic training, fitness training, and high-intensity interval training, as the full-body interaction and high immersive experience are the main advantages of using VR technology for cardiorespiratory training (Shepherd et al., 2018). Recent studies have established that VR applications can increase enjoyment, motivation and engagement, contrary to traditional exercises, such as cycling and running. Garcia et al. (Garcia et al., 2016) investigated the feasibility and efficacy of Kinect-based stepping exergame, and reported improvements of participants in stepping, standing balance, gait speed, and mobility. Christos Ioannou et al. (Ioannou et al., 2019), introduced the concept of Virtual Performance Augmentation (VPA) of running and jumping in-place. They reported that VPA can induce moderate to high physical activity levels, increasing intrinsic motivation and general physical activity motivation, and perceived competence and flow. Huang et al. assessed the effect of immersion on the perceived exertion by using a stationary bicycle-based training system (Huang et al., 2008). They compared perceived exertion in PC-Desktop screen, a projector, Head Mounted Displays (HMD), and a non-VR system. A significantly lower perceived exertion was found in the HMD and projector conditions when compared to non-VR. No significant difference was found between HMD and projector conditions. The outcomes of this study were consistent with (Mestre et al., 2011), who compared immersive VR with virtual feedback and no 3D computer generated feedback setups. They reported lower perceived exertion and higher excitement in the immersive VR environment.

Although these VR applications have shown the potential to improve the cardiorespiratory training, training intensity is often lower than what is expected to be the fitness recommendations (Dean et al., 1998). Thus, to maintain the player's training intensity, one possibility is to monitor the user and adapt the VR applicationin response. This adaptation allows changing the training load required to achieve the desired levels of exertion (Hoffmann et al., 2015). Here, a closed-loop control approach was implemented using the biocybernetic-loop-engine (BLEngine) (Muñoz et al., 2017) to monitor the heart rate (HR) and adapt a virtual hike experience to control the intensity of the exercise performed by the participants. We aimed to address the following research questions:

- RQ1: Can an adaptive system successfully manipulate training intensity?
- RQ2: Can an adaptive system effectively keep participants in the desired target HR zone?
- RQ3: How does an adaptive system compare to its non-adaptive counterpart?
- RQ4: What is the impact of VR feedback on perceived exertion levels and motivation?

2 METHODOLOGY AND MATERIALS

2.1 Participants

The participants were recruited from a convenience sample of volunteer subjects, all university students and workers. Twenty-two healthy adults (12 females, 10 males) volunteered to participate in this study. Two participants were excluded from the study: a male participant due to a technical error and a female participant decided to withdraw due to virtual reality sickness. The sample considered for the analysis was composed of the remaining 20 participants, with an average age of 29 years old. The demographical information of the participants is described in Table 1.

Table 1: Sample statistics.

(n=20)	Mean	STD	Min	Max
Age	29,25	5,03	23,00	44,00
Height (cm)	168,95	9,06	159,00	191,00
Weight (kg)	64,35	14,16	47,00	102,00
BMI (kg/m^2)	22,26	2,60	17,91	27,96

2.2 Experimental Setup

2.2.1 Hardware

The virtual environment was designed to work in a CAVE with walls of 2.2 meters width and 2.8 meters of height, using the KAVE software developed by (Gonçalves and Badia, 2018). The display consists of the front and lateral projections, as well as a floor projection, thus it requires a computer with a graphic card capable of displaying 4 screens simultaneously. A Kinect V2 (Microsoft, Redmond, USA) body tracking sensor was used to track the full-body of the participants (3D position of the 25 joints' skeleton) (Gonçalves et al., 2021). A schematic version of our CAVE setup is shown in Figure

A photoplethysmography (PPG) sensor was used to measure the heart rate (HR) at rest during the pre-assessment procedure (section 2.3.2) with a wearable device, the Biosignalsplux (PLUX - Wireless Biosignals, Lisboa). Finally the HR at rest was computed with the Opensignals software (PLUX-Wireless Biosignals, Lisboa) (https://biosignalsplux.com/products/software/opensignals.html).

To measure the HR of the participants during the experiment, the HR chest band Polar H10 (Polar Electro Oy, Kempele, Finland) was placed on the participants. The Polar H10 was paired with the Acti-

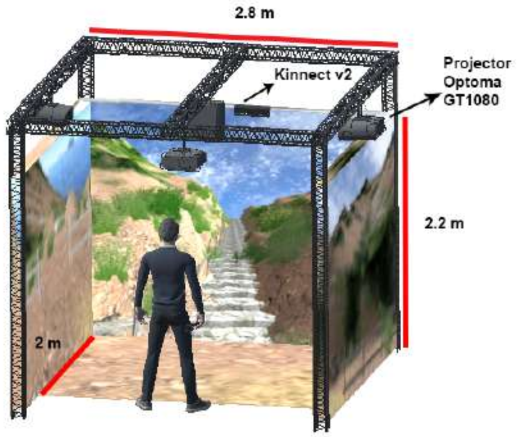


Figure 1: Schematic of our CAVE setup.

Graph's WGT3X-BT accelerometer (Actigraph Corporation, Pensacola, FL, USA) to measure physical activity during the experiment. The metrics for physical activity were computed using the ActiLife6 software (version 6.13.4, ActiGraph, Cary, NC, USA) to process the accelerometer data.

2.2.2 Software

The environment simulated a Levada hiking track and was developed by Ahmad et al (Ahmad, 2021). The Levada track included computer-generated 3D objects, such as trees, mountains, tunnels and irrigation canals, created with Unity3D Engine and Blender software (Blender Foundation, Amsterdam, Netherlands) (Ahmad, 2021).

Then, an adaptation of the procedure in (Gonçalves et al., 2016) was implemented in the VR Levada environment, to determine a target height at which the knee of the participant had to be raised during stepping-in-place to progress in the VR Levada hiking track. The initial height was calculated by the Kinect, as the middle point between the hip and the knee, so that it adjusts to people of different height. The height of the hip and the knee were set, respectively, as the boundaries of maximum and minimum required heights during the adaptation.

2.3 Experimental Procedure

2.3.1 Pre-assessment

All participants performed a pre-assessment session on a different day, previous to the experiment. In this session, the HR at rest of each participant was measured to calculate their experimental target HR. The participants also performed the 3-min YMCA Step Test (Golding, 2000) to assess their physical fitness.

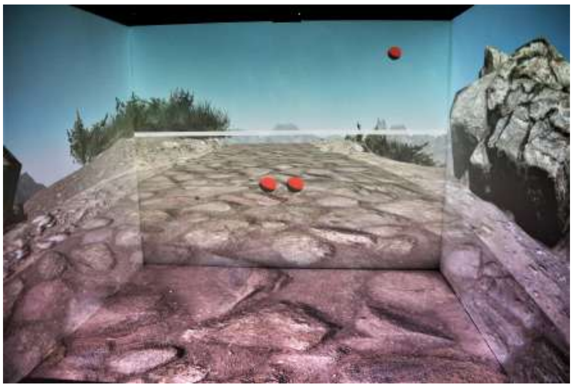


Figure 2: Example of our VR Levada hiking track. The red dots represent the knees of the participant. The white line represents the target height at which the knee had to be raised.

2.3.2 HR at Rest

Participants were asked to sit and relax in a chair placed in a quiet room for 5 minutes, without moving or speaking. Then the HR was computed using a PPG sensor with the biosignalsplux wearable device. The PPG sensor was placed on the index finger of the left hand. The HR at rest of the participants was calculated as the average HR of the 5 minutes using the Opensignals software, as mentioned in section 2.2.1.

2.3.3 Target HR

The target HR for the experiment was calculated using the Karvonen formula (Karvonen and Vuorimaa, 1988). After computing the heart rate at rest, the maximum HR ($\mathrm{HR_{max}}$) was calculated using Equation 1. Then the heart rate reserve (HRR), which is the difference between the maximum heart rate and the heart rate at rest, was calculated using Equation 2. Finally, the target HR was calculated using Equation 3, with a target exercise intensity of moderate to vigorous (approximately 60% of the HRR), according to (Dean et al., 1998).

$$HR_{\mathrm{max}} = 220 - Age \tag{1}$$

$$HRR = HR_{\mathrm{max}} - HR_{\mathrm{rest}} \tag{2}$$

$$TargetHR = (\%intensity * HRR) + HR_{\mathrm{rest}} \tag{3}$$

2.3.4 3-min YMCA Step Test

The 3-min YMCA Step Test (Golding, 2000) was used to assess the cardiorespiratory fitness of the participants. To perform this test, a 30 cm step, a digital chronometer and metronome were used. First the test procedure was explained to the participants by demonstrating the cadence stepping. The metronome was set to 96 beats per minute, with 4 clicks representing one step cycle: 1st beat - first foot up, 2nd beat - second foot up, 3rd beat - first foot down, 4th beat - second foot down. The duration of this test was 3 minutes. After completing the test, participants immediately sat down and the average HR for 1 min was assessed using the same sensor as in section 2.3.2. The classification of the cardiorespiratory fitness of our participants was performed by comparing the scoring of the 1-min post exercise average HR, with the age adjusted standard ratings for this test. Our classification is shown in Table 2.

Table 2: 3-min YMCA Step Test Classification.

	Males (n=9)	Females (n=11)
Excellent	2	4
Good	1	0
Above Average	0	0
Average	2	1
Below Average	2	3
Poor	0	3
Very Poor	2	0

2.3.5 Protocol

This study is divided into two components: the study of the adaptive control of HR and the study of the user experience in the virtual environment. Participants were provided with informed consent previously to the pre-assessment session (Section 2.3.1).

After the pre-assessment session, a within-subjects experimental design was used, in which participants performed the three following conditions, on consecutive days with an approximate time interval of 24 hours: *Adaptive VR* Levada experiment (Experimental condition for VR adaptive control of HR and user experience), *Non-Adaptive VR* Levada experiment (Control condition for adaptive control of HR) and *Adaptive Non-VR* experiment (Control condition for the user experience).

For each experiment participants were asked to wear the Polar HR chest band and the ActiGraph accelerometer placed on the hip. The experiment consisted of stepping in the same place at the pace of 125 beats per minute set by a metronome, with 2 clicks representing one step cycle, as the participants were stopped in the same place and had to raise their knees up to a target height, to progress in the virtual hiking track.

Each experiment had a total duration of 10 min: a 2-min warm-up to drive the participants to the target HR zone, a 7-min training in the target HR zone, and a 1-min cool-down. This timeline is shown in Figure 3.

At the end of each experiment, participants answered a sickness/dizziness questionnaire, classified the perceived exertion using the Rated Perceived Exertion Scale (RPE scale) (Borg, 1998), and for the test and control conditions of the user experience, participants answered the Witmer-Singer Presence Questionnaire (WSPQ) (McCall et al., 2004), the Slater-Usoh-Steed Questionnaire (Slater et al., 1995) and the Intrinsic Motivation Inventory (IMI) (Sheehan et al., 2017; Mcauley et al., 1989).

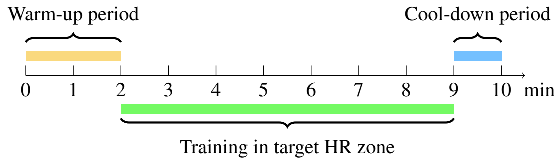


Figure 3: Timeline of each experiment.

2.4 Adaptive Control of HR

The main goal of the adaptive control of HR was to drive participants to reach the target heart rate zone, moderate to vigorous intensity (57% - 63%), as mentioned in section 2.3.3, and keep them inside that zone during the whole training phase.

The cardiorespiratory fitness adaptation based on the HR was performed using an updated version of the Biocybernetic Loop Engine (BLEngine) (Muñoz et al., 2017). The BLEngine received the real-time HR data from the Polar H10 chest band using UDP communication.

Then a proportional-integral-derivative controller (PID controller) was implemented to adapt the height to which the participants had to raise their knees while stepping in place. Then, target height was adapted every 5 seconds, according to the instantaneous HR (HR_{5sec}). For the warm-up phase, a linear regression was calculated to drive the participant's HR, between the initial HR of the participant and the target HR, to gradually increase the intensity of the exercise, so that after 2 minutes of exercise, the participant reached the intended HR zone.

The PID controller followed equation 4, with $K_p = 0.03$ is the proportional constant and $K_d = 5$ is the derivative constant. The PID parameters were tuned by performing several pilot tests prior to this study, until the desired performance of the controller was achieved.

These HR adaptive rules implemented on the BLEngine software, are shown in Figure 4.

$$PID = K_p * (HR_{target} - HR_{5sec}) +$$
$$K_d * \left(\frac{Error_{current} - Error_{previous}}{\Delta t} \right) \quad (4)$$

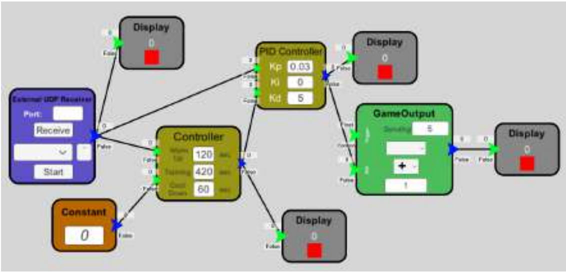


Figure 4: Adaptive HR rules used on the BLEngine software.

2.5 Instruments

2.5.1 Physical Exertion Metrics

The data acquisition for the physiological signals was performed with a custom-made log file implemented on the BLEngine, to record all the HR related signals, and then all the HR metrics were computed using Python. For the accelerometer signals, the ActiLife6 software provided all the required metrics.

Concerning the HR related metrics, the following metrics were computed: Average HR, Percentage of Time in Target HR Zone, considering 100% as being the 10 min condition, and the root mean square error (RMSE) between the HR and the target HR.

In terms of the accelerometer metrics, the METS, vector magnitude, MVPA, and Percentage in Sedentary and Light exercise, were computed using the Actilife6 software.

Finally, a digital version of the OMNI Rated Perceived Exertion (RPE) scale (Borg, 1998) was used to assess the perception of exertion from the participants after both conditions, in a 0 to 10 scale (0 - Extremely Easy, 10 - Extremely Hard).

2.5.2 User Experience

To assess the user experience, the sickness and dizziness experienced by the participants during the VR experience, a short brief questionnaire was answered with a 5-point Likert Scale (1-none, 5-A lot). Also, the Witmer-Singer's Presence Questionnaire (WSPQ) was used to assess the sense of presence. It includes 24 items addressing Involvement, Immersion, Visual Fidelity, Interface Quality, and Sound, rated on a 7-point Likert scale. Consistent with other studies, items 20-22 related to sound were excluded. Items 23-24 related to haptics were not applicable for this study (McCall et al., 2004).

The Intrinsic Motivation Inventory (IMI) was used to assess intrinsic motivation. It is a multi-dimensional measurement questionnaire, which is comprised of seven sub-scales and used for several studies including exercising and sports. The questionnaire contains the following sub-scales on a 7-point Likert scale: Interest/Enjoyment, which is considered to be the main self-report measure for this questionnaire (7 items), and Pressure/Tension, which is considered to be a negative predictor of intrinsic motivation (5 items) (Sheehan et al., 2017; Mcauley et al., 1989).

The System Usability Scale (SUS), created by (Brooke, 1995), was implemented to assess the application's usability. SUS comprises ten items and allows a quick evaluation of the usability of a wide variety of products and services, including hardware and software.

2.6 Statistical Analysis

For the physiological signals statistical analysis, the Kolmogorov-Smirnov normality test was used to assess the normality of the data. Since the data was not normally distributed, non-parametric statistical tests were used. The Wilcoxon matched-pair signed ranks test was used to compare conditions.

Regarding the statistical analysis for the questionnaires, all the data from the questionnaires are of ordinal nature (Likert Scale), thus non-parametric tests were used to assess the significance of the results. The Wilcoxon matched-pair signed ranks test was also performed for the questionnaires. All the statistical analysis was performed in SPSS Statistics version 26.

3 RESULTS

3.1 Adaptive Control of HR

Training in a specific heart rate zone has benefits and helps improve cadiorespiratory performance, according to the ACSM guidelines (Dean et al., 1998). To measure the accuracy of the algorithm implemented to drive and maintain the participants in the target heart zone, the metrics related to the HR mentioned in section 2.5.1 were analyzed.

When performing the statistical comparison, we found no significant difference in the average HR, between the *Non-Adaptive VR* (Mdn=142.02, Range=70.82) and the *Adaptive VR* condition (Mdn=138.90, Range=48.12).

In terms of the difference between the HR and the target HR, the RMSE revealed lower values in the *Adaptive VR* condition (Mdn=20.57, Range=18.46) compared to the *Non-Adaptive VR* condition (Mdn=25.08, Range=27.14). This result was significantly different, T=173,p-value<0.05,r=0.57 (Figure 5).

Finally, the *Adaptive VR* condition had significantly higher percentage of time (T=32.00,p-value<0.01, r=0.61) in the target HR zone (Mdn=26.83, Range=67.83) compared to the *Non-Adaptive VR* condition (Mdn=7.83, Range=49.67)(Figure 6).

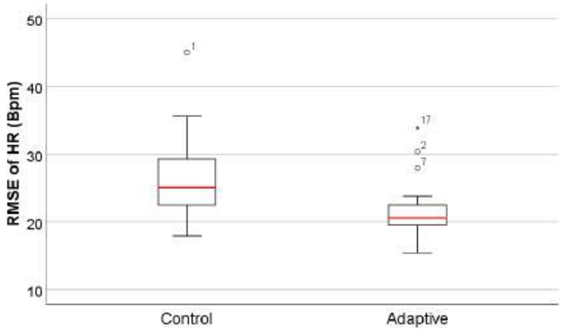


Figure 5: Boxplot of the RMSE for the *Non-Adaptive VR* Levada and *Adaptive VR* Levada conditions.

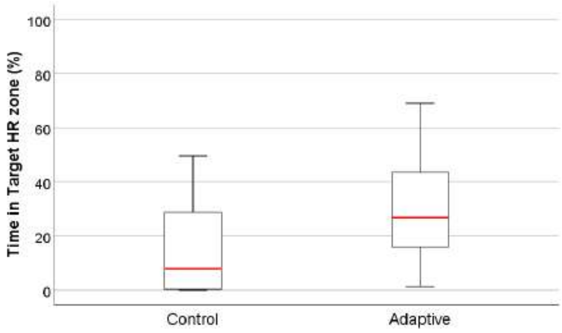
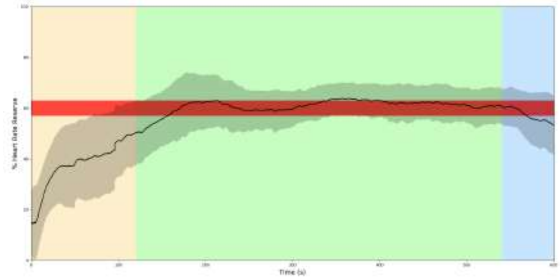
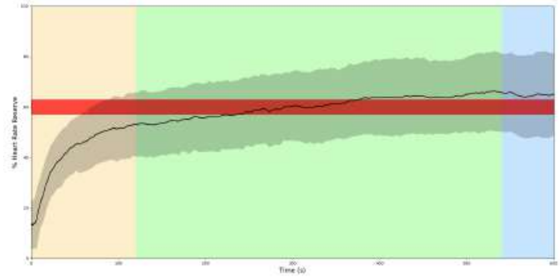


Figure 6: Boxplot of the Time in target HR zone in percentage for the *Non-Adaptive VR* Levada and *Adaptive VR* Levada conditions.

Figure 7 depicts the time evolution and relationship between participants' HR and their target HR over the 10 minutes of the experiment. HR data in Figure 7a (black line), shows that the *Adaptive VR* Levada condition spends more time inside the target HR zone (red band) compared to the *Non-Adaptive VR* Levada. Also, the variability of the data (black shadow) seems smaller than that of the control.



(a) *Adaptive VR* Levada.



(b) *Non-Adaptive VR* Levada

Figure 7: Average HR of all participants throughout the whole experiment, for the Adaptive and *Non-Adaptive VR* conditions. Black line - Average HR, Black Shadow - Average Standard Deviation, Red Band - Target HR zone, Yellow Band - Warm-up Phase, Green Band - Training Phase, Blue Band - Cool-down Phase.

3.2 Physical Exertion

Concerning the accelerometer metrics mentioned in section 2.5.1 it is possible to verify that in the *Adaptive VR* Levada condition the METS values were lower (Mdn=1.02, Range=1.59) than the *Non-Adaptive VR* Levada condition (Mdn=1.05, Range=2.33). In terms of the Percentage of time in Sedentary and Light exercise, in the *Non-Adaptive VR* Levada condition the participants spent more time in Sedentary exercise (Mdn=34.17, Range=85.83) compared to the *Adaptive VR* Levada (Mdn=29.00, Range=95.50). Consequently, the time spent in Light exercise was higher for the *Adaptive VR* Levada condition (Mdn=70.50, Range=95.00) than in the *Non-Adaptive VR* Levada (Mdn=59.67, Range=84.33). For the MVPA, the *Non-Adaptive VR* Levada condition values were higher (Mdn=0.05, Range=4.27) than the *Adaptive VR* Levada values (Mdn=0, Range=4.92). Finally, the magnitude vector values for the *Adaptive VR* Levada were higher (Mdn=27168.5, Range=36849.8) than the *Non-Adaptive VR* Levada condition values (Mdn=20891.1, Range=33329.1). Despite these results, no significant difference was found for all the metrics computed, between the *Non-Adaptive VR* Levada and *Adaptive VR* Levada conditions.

The results for the perceived exertion (RPE Scale) reported by the participants, revealed that the *Adaptive VR* Levada condition showed lower values of perceived exertion (Mdn=4.00, Range=8.00) compared to the *Non-Adaptive VR* Levada condition (Mdn=5.00, Range=6.00) (Fig.8). No significant difference was found between the *Non-Adaptive VR* Levada and *Adaptive VR* Levada conditions (p-value=0.089).

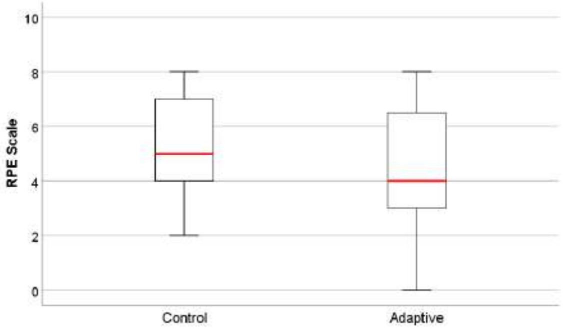


Figure 8: Boxplot of the Rated Perceived Exertion (RPE) Scale for the *Non-Adaptive VR* Levada and *Adaptive VR* Levada conditions.

3.3 User Experience

Participants reported a higher level of dizziness (Mdn=2.00, Range=3.00) on the *Adaptive VR* Levada condition compared to the *Adaptive Non-VR* condition (Mdn=1.00, Range=3.00). For the sickness question, the result reported were the same on both conditions (Mdn=1.00, Range=2.00). No significant difference was found between the *Adaptive Non-VR* and *Adaptive VR* Levada condition, regarding the sickness and dizziness short 5-point questionnaire.

Presence was measured with the WSPQ. The total mean score for the sum of all sub-scales was M=93.1(16.1), which indicates a presence level of 70%, similar to the result reported by (Ahmad, 2021), and higher than the result reported by (Gonçalves et al., 2021) (Table 3). The mean rating score of involvement suggested that the user was engaged with the experiment while the immersion score shows that user perceived the environment realistically. The visual fidelity and interface quality scores represented the clarity, perception depth and user-friendly application. The mean rating score of the sound also indicated the realistic sound coming from the application environment.

Regarding the results obtained between the *Adaptive Non-VR* and the *Adaptive VR* Levada conditions for the IMI questionnaire (Table 4), no significant differences were found for either Pressure/Tension or Interest/Enjoyment.

Table 3: Mean Rating Score for each sub-scale of the WSPQ. The scale ranges from 1 to 7 in a Likert Scale.

Sub-Scale	Mean Rating Score (SD)
Involvement	4.78 (0.95)
Immersion	5.23 (0.79)
Visual Fidelity	4.3 (1.6)
Interface Quality	5.3 (1.1)
Sound	4.7 (1.5)

Table 4: Intrisic Motivation Inventory Results.

Sub-Scale	VR Mean (SD)	Non-VR Mean (SD)	p-value
Interest/Enjoyment	4.62 (1.37)	4.42 (1.19)	0.37
Pressure/Tension	2.65 (0.99)	2.71 (1.26)	0.87

The usability of the application was assessed with the SUS (M=78.1 (3.2)). In this test, a score of 68 is the threshold that indicates that user satisfaction level is above average (Brooke, 1995). Hence, our results showed the excellent usability of the simulation application in terms of comfort and ease of use, and were similar to the result reported by (Ahmad, 2021).

4 DISCUSSION

Most studies related to exercising with adaptive control of HR are based on cycle ergometers or exergames (Muñoz et al., 2018; Hoffmann et al., 2015; Kiryu et al., 2001). This study assessed the feasibility of performing an adaptive control of cardio-respiratory training based on the participant's HR while performing a stepping activity in a virtual Reality hiking simulation. The results obtained from our study showed that the algorithm implemented was able to drive the participants to reach the target heart zone within, approximately, the first 2-3 minutes of the exercise, answering the first question (RQ1) regarding the manipulation of the training intensity using an adaptive system.

Regarding RQ2 and RQ3, the participants in the *Adaptive VR* Levada exerted more than 20% of the total duration of the experiment (10-min), in the target heart rate zone, compared to the *Non-Adaptive VR* Levada condition, while having an median RMSE of 20 beats per minute between the heart rate and the target heart rate.

Both of these results agree with the results obtained by (Muñoz et al., 2018), in which the time that the participants exerted in the target HR zone was 40% higher in the adaptive condition with a RMSE of 15 beats per minute, considering the entire experiment of 20 minutes.

Regarding the RPE scale, although no significant difference was found between the *Non-Adaptive VR* Levada and *Adaptive VR* Levada conditions, participants reported lower values of perceived exertion in the *Adaptive VR* Levada condition. This indicates that even though participants were training in the target HR zone for more time, their perception of effort was smaller, addressing the impact of VR feedback on perceived exertion levels (RQ4). This could suggest that lower levels of fatigue may come from training in a more controlled HR regime. These results are also in agreement with the results obtained by (Muñoz et al., 2018).

In terms of sense of presence, most of the papers in the literature report treadmills or cycling ergometers, which makes it difficult to compare with our study. In our experiment, the impact of VR on physical exertion and intrinsic motivation during the virtual hiking simulation was investigated in a stepping-in-place based application. From the results obtained, it is possible to observe that this simulation of a virtual hiking activity generated a high sense of presence, approximately 70%, with the sub-scale Immersion having the highest mean rating score of $M = 5.23$ compared to the other sub-scales. Regarding the intrinsic motivation, participants reported a higher value for intrinsic motivation in the *Adaptive VR* of approximately 66% compared to 63% in the *Adaptive Non-VR* Levada for the sub-scale Interest/Enjoyment, and a lower value of Pressure/Tension of 38% for *Adaptive VR* Levada and 39% for the *Adaptive Non-VR* Levada. Even though no significant effect was found for intrinsic motivation, the results found for the Interest/Enjoyment are in agreement with other studies. Buchner et al. (Buchner and Zumbach, 2018) also reported higher values for the sub-scale Interest/Enjoyment in augmented reality than a non-Augmented Reality application.

Finally, regarding the levels of dizziness and sickness while using the VR system, despite having a participant that was dropped from the study due to sickness problems, the median value reported for the sickness was of 1, and for the dizziness was of 2, in a 5-point scale, thus our system is not prone to induce virtual sickness or dizziness to the participants.

5 LIMITATIONS

Although the main goal for this study was achieved with success, there are some limitations implicit with this study. The effect of VR is specific for the design of our VR Levada experiment and for our particular CAVE, so we do not have information on what can happen on other VR delivery technologies or simulations, or the effect of adding gamification to the task. This study targeted a training intensity of 60% with a mandatory pace of stepping of 125 beats per minute set by a metronome. In order to generalize the application of this system to other situations, higher or lower training intensities, with a different pace set by the metronome should be tested. Also, the single variable adapted during the entire study was the target height at which the participants had to raise their knees. A variable could be added to adjust the pace set by the metronome to combine the adaptation with the target height. Finally, the acquisition of HR was performed on a consumer-grade device, the Polar H10 chest band.

6 CONCLUSION

This study aimed to create a stepping-based VR application simulating a hiking track, the Levadas, that could adapt to the physiological signals of the participant to provide adequate levels of exercise intensity. Our data indicates that the adaptation rules created on the closed-loop, according to the participant's HR, using BLEngine, could drive the participant to the desired target heart rate zone. Thus, successfully adjusting the intensity of training within the target heart rate zone of optimal effectiveness. This adaptation increased the time in which the participants were in the target heart rate zone by 20% compared to the *Non-Adaptive VR* Levada condition. In addition, participants perceived lower levels of exertion in the adaptive condition. In conclusion, we highlight the potential of personalized and adaptive VR applications to improve cardiorespiratory fitness, engagement and motivation of the participants.

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