

The effects of virtual reality exercise on the physical performance and fatigue of active young men in single-stage aerobic and anaerobic running

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Abstract

Objective: Exercise with virtual reality (VR) is a novel approach to the promotion of health and the components of fitness. Our objective was to investigate the effects of exercise with VR on physical performance, mental fatigue, and physical fatigue in single-stage aerobic and anaerobic running.

Materials and Methods: Twenty physically active, healthy, age-matched male university students executed the exercise test in aerobic and anaerobic groups in two separate sessions of VR (first-person perspective in a simulator) and non-VR (traditionally in the laboratory). The simulated environment was a graphic tunnel route. The aerobic and anaerobic groups engaged in the Bruce protocol and anaerobic speed test, respectively. Exercise test duration, blood serum lactate concentration, rating of fatigue (ROF), and heart rate were recorded at the end of both sessions.

Results: Intragroup comparisons using the dependent t-test indicated that the exercise test duration significantly increased in the VR session of the anaerobic group compared to the traditional method considering the effect size ($t_7=0.804$; $P=0.804$). However, the test duration remained unchanged in both sessions of the aerobic group ($t_9=1.373$; $P=0.203$). Serum lactate concentration significantly decreased in the VR session compared to the non-VR session in the aerobic group ($t_9=4.734$; $P=0.001$) and anaerobic group ($t_9=2.321$; $P=0.045$). ROF and heart rate of the aerobic and anaerobic groups remained unchanged in both sessions.

Conclusion: The findings indicated that as an alternative for improving physical performance in exercise, running with VR in an imaginative virtual environment decreased physical fatigue in a single stage of aerobic and anaerobic running.

1. Introduction

Inactivity and insufficient physical activity are leading causes of humans' mortality and morbidity. According to the World Health Organization (WHO) statistics, approximately 3.2 million deaths occur each year due to sedentary lifestyles (WHO, 2018b). Moreover, the statistics published in 2018 indicated that on average, one per every four adults has insufficient physical activity (WHO, 2018a).

Recently, diminished physical activity due to the novel coronavirus spread has become a major global health concern as it is a significant threat to public health. Physical exercise is the primary approach to the prevention of physical inactivity. Exercise refers to any form of physical activity that is carried out by individuals in a structured, planned, and persistent manner to enhance or maintain the components of fitness and general health (Wilmore et al., 1994).

Aerobic and anaerobic exercises are two main types of exercise activities, which differ in terms of intensity, duration, and targeted muscle fibers. Aerobic exercise refers to exercise activities with mild-to-moderate intensity, which may continue for several minutes or hours (Plowman & Smith, 2013). Anaerobic exercise is an intense activity aimed at increasing strength, energy, and speed, which may be

performed for several seconds or minutes (Medbo et al., 1988). Extensive research has been focused on the association of regular exercise activities with mental and physical health, and evidence attests to the positive impact of these activities on health improvement and decreased mortality (Haskell et al., 2007; Penedo & Dahn, 2005).

Recently, virtual reality (VR) technology has attracted the attention of researchers as an effective approach to increasing exercise performance and decreasing fatigue and pain (Malloy & Milling, 2010; Matsangidou et al., 2017; Ng et al., 2019). It is reported that using VR in exercise could influence physical activity by eliminating the undesired effects of the environment and increasing the motivation to exercise (Plante, Aldridge, Su, et al., 2003). Additionally, VR effectively reduces pain perception and increases enjoyment and effort while exercising (Matsangidou et al., 2019; Zeng et al., 2017). This combination improves exercise performance, while also influencing some psychological components (e.g., increasing enjoyment and energy and decreasing fatigue) (Liu et al., 2019; Plante, Aldridge, Bogden, et al., 2003).

The studies regarding the impacts of exercise with VR on healthy humans have mainly assessed fatigue from a psychological perspective. Due to the limitations imposed for maintaining safety during intense exercise with a headset, most of these investigations have chosen protocols with low-intensity activities and longer periods for physical exercise.

With the advancement of VR technology owing to the accessibility and cost-efficiency of VR equipment and software, new opportunities have arisen for the use of this technology in exercise to promote public health and optimize exercise performance. To effectively utilize VR exercise, it is essential to better recognize its impact on physical performance, mental fatigue, and physical fatigue in various aerobic and anaerobic exercises. Our objective was to use VR technology to evaluate exercise performance and fatigue in a single stage of aerobic and anaerobic exercise and determine the effects of the analysis of the psychological and physiological outcomes

Experiencing fatigue in physical exercise causes discomfort either due to actual tissue injury or the individual's discernment of injury (Merskey, 1994). According to the literature, altered visual information is an approach to influencing the experience of fatigue (Bayer et al., 1998; Zatzick & Dimsdale, 1990). By inducing the sensation of mental or physical presence in a different location, VR provides the user with large volumes of data and restricts their access to the data of the body. This gap allows the user to dissociate from the real world and be immersed in the virtual environment (Eichenberg & Wolters, 2012). To fully exploit the efficacy of this gap, we made the maximum difference between a traditional test environment and the VR environment in our study. The recorded VR film contained a simulator that differed from reality; in this environment, the movements were matched with the test speed. To evaluate performance, two reliable exercise tests were performed to exhaustion.

We hypothesized that physical performance in the exercises would be superior with VR compared to traditional exercises and using VR in exercise could decrease mental and physical fatigue more effectively than traditional exercises.

2. Methods

2.1. Participants

The participants were enrolled voluntarily by a call to participation and announcements on the university campus. All the eligible volunteers were selected, including healthy male students aged 19–26 years who were physically active and had no experience of using VR. Exclusion criteria were physical and psychological disorders, use of medications and dietary supplements, and injuries or muscle spasms.

Considering that multiple factors are involved in fatigue in daily life and we were not able to control all these factors, a recommendation form was sent to the volunteers. Through this form, they were asked to record their sleep adequacy and nutritional status within 48 hours before executing the tests in two identical sessions. Also, the participants were asked to refrain from any form of exercise in this period and comply with their routine diet during the study.

After receiving a file containing the information on the research procedures, all participants gave informed written consent for enrollment.

2.2. Exercise test and performance measurement

Initially, the participants were divided into two groups of 10, including aerobic and anaerobic groups. Their assigned exercise tests in two sessions of VR and non-VR at a 14-day interval. The participants in the aerobic group executed the Bruce protocol, and the anaerobic group performed the anaerobic speed test (AST) in two separate sessions of VR and non-VR so that the intragroup results could be compared independently. In both the VR and non-VR sessions, the subjects were asked to hold the treadmill grips while executing the tests to maintain balance and prevent lateral deviations while running. For the exercise test, we used a laboratory treadmill (model: pulsar@3p, h/p/cosmos, Germany) with a safety belt and a polar heart rate monitor. During the sessions, the temperature of the environment was kept normal, and sufficient water was provided to the volunteers.

The exercise test of the aerobic and anaerobic groups continued until fatigue (i.e., the time when the individual failed to maintain the exercise intensity). The performance of the aerobic group was assessed by the Bruce protocol (Bruce, 1972). In this standard aerobic treadmill exercise test, the subject starts stage I at the speed of 1.7 miles per hour and a 10% gradient, and the treadmill gradient and speed increase every three minutes based on the reference table (Supp. 1). In the current research, the protocol was implemented based on the default program of the treadmill. In the anaerobic group, exercise performance was measured using the AST (CUNNINGHAM & FAULKNER, 1969). This test is carried out on a treadmill with a speed of eight miles per hour and a 20% gradient and continues until fatigue.

2.3. VR tool and environment

For the aerobic and anaerobic groups, the non-VR session was held in the laboratory, and the VR session was implemented using a VR headset in a simulator for the exercise test (Fig. 1). To display the VR film,

we utilized the *Oculus Rift Cv1* VR headset (Oculus VR, America, 2016) and a specialized virtual reality computer set. The film was TAS-The Canyon 360° 4K (TAS Visuals) that shows a graphical simulation of an illuminated tunnel pathway, and the participants ran in the first-person perspective in the pathway (Fig. 2). The film was chosen given the spectacular and novel scene to ensure a new experience for the subjects. A repeated scenario of the film was also displayed to prolong the experiment. The movement speed of the participants in the film had been synchronized with the test speed in the pilot sessions to prevent cybersickness (dizziness and nausea). During the experiment, the exclusive sensors of the headset (gyro sensors and magnetometer) were utilized for tracking the head orientation in real-time and showing the respective images.

(Fig. 1 and Fig. 2 here)

2.4. Examination of mental and physical fatigue

Mental/central fatigue and physical/peripheral fatigue were evaluated in the aerobic and anaerobic groups after the exercise test in the VR and non-VR sessions. In addition to recording the time of the exercise test, the heart rate was measured immediately after the test using the heart rate monitor of the treadmill. To assess mental fatigue, the rating of fatigue (ROF) scale was used (Al Salman et al., 2013), which consists of a numerical score range (0–10), as well as five descriptive images and five diagrams to help the respondent.

To evaluate the perceived fatigue immediately after the test, the participants were asked to select a number that best described their degree of fatigue with honesty. Further, physical fatigue was measured based on the serum lactate concentration (Finsterer, 2012), which is a reliable biomarker of peripheral muscle fatigue in exercise. In both the aerobic and anaerobic groups, serum lactate was measured by blood sampling (22ccs) five minutes after the exercise test was over. Following that, chemical staining was performed using the lactate assay (*Roche Pharmaceutical Co., Basal, Switzerland*) to determine the serum concentration in the blood samples.

2.5. Statistical analysis

After selecting all the eligible subjects from the volunteers, their anthropometric data and activity history were determined. At the next stage, the participants were divided into aerobic and anaerobic groups to execute their assigned exercise tests in two sessions of VR and non-VR at a 14-day interval.

This clinical trial was conducted with a crossover design. After each exercise session, the dependent research variables were assessed, including performance (exercise duration), serum lactate concentration, ROF results, and heart rate. Data analysis was conducted using a series of dependent t-tests to separately evaluate the intragroup changes in the aerobic and anaerobic groups.

3. Results

3.1. Descriptive summary

In total, the data of 20 participants (10 in the aerobic group and 10 in the anaerobic group) were analyzed. Table 1 shows the means and standard deviations of the descriptive variables, including age, height, weight, body mass index (BMI), and activity history of the study groups.

In both the aerobic and anaerobic groups, we investigated the effects of VR exercise (independent variable) on the dependent variables, including performance (duration of exercise test), blood serum lactate concentration, ROF score, and heart rate, in the VR and non-VR sessions.

(Table 1 here)

3.2. Results of physical performance

Table 2 shows the results of the exercise test in both groups. Exercise test duration indicated different results in the aerobic and anaerobic groups. In the anaerobic group, AST duration in the VR session increased compared to the non-VR session, which was not considered statistically significant ($t_7 = 0.804$; $P = 0.804$; $d = 0.71$). However, physical-performance was enhanced given the effect size. Therefore, using VR in AST could improve performance compared to traditional exercise by increasing the exercise test duration. As for the aerobic group, the Bruce protocol duration in the VR session decreased compared to the non-VR session, which was not statistically significant ($t_9 = 1.373$; $P = 0.203$; $d = 0.44$). Therefore, it was concluded that using VR in Bruce protocol caused no significant difference in the exercise test duration compared to traditional exercise.

3.3. Results of serum lactate concentration

Table 2 shows the results of serum lactate concentration in the two exercise sessions of the aerobic and anaerobic groups. The results showed a change in serum lactate concentration in both aerobic and anaerobic groups. The mean serum lactate concentration of both groups was lower in the VR session compared to the non-VR session. Using VR in AST led to a significantly lower serum lactate concentration in the healthy, physically active young men compared to traditional exercise ($t_9 = 2.321$; $P = 0.045$; $d = 0.73$). Similarly, VR use in the Bruce protocol was associated with a significantly lower serum lactate concentration in the healthy, physically active young men compared to traditional exercise ($t_9 = 4.734$; $P = 0.001$; $d = 1.49$). Therefore, using VR in AST and the Bruce protocol lowered serum lactate compared to traditional exercise.

3.4. Results of heart rate and ROF

Table 2 also shows the ROF and heart rate results in two exercise sessions of aerobic and anaerobic groups. The mean ROF scores in the VR and non-VR sessions indicated no significant difference between the two sessions for an anaerobic group ($t_9 = 0.509$; $P = -0.688$; $d = 0.21$) and aerobic group ($t_9 = 1.909$; $P = 0.089$; $d = 0.61$). Therefore, the use of VR did not affect the ROF score in the Bruce protocol and AST compared to traditional implementation. Also, the results of the heart rate indicated no significant difference in the exercise test with and without VR between the anaerobic group ($t_9 = 0.324$; $P = -1.043$; $d =$

0.33) and aerobic group ($t_9 = -0.373$; $P = 0.717$; $d = -0.118$). Therefore, the use of VR did not affect the heart rate in the Bruce protocol and AST compared to traditional implementation.

(Table 2 here)

4. Discussion

We aimed to investigate the effects of exercise with VR on physical performance, mental fatigue, and physical fatigue in a single stage of aerobic and anaerobic exercise. Previous research regarding exercise with VR has confirmed the efficacy of this technology in the improvement of psychological components during exercise. Accordingly, VR is correlated with the influential factors in mental fatigue and could decrease pain perception, while reinforcing exercise attempts (Mahrer & Gold, 2009; Malloy & Milling, 2010; Matsangidou et al., 2017). On the other hand, the impact of VR use on physical fatigue remains unclear. Studies regarding exercise with VR and its effect on physical performance have proposed different results, which could be due to the differences in the applied exercise protocols and simulated VR environments (Matsangidou et al., 2019; Ng et al., 2019).

We used two exercise tests (Bruce protocol and AST) to minimize the difference between aerobic and anaerobic exercise protocols. Both these tests are executed with increasing intensity and continue until fatigue (i.e., exhaustion). Further, we used an entirely simulated film that was maximally distinct from reality in which the participants had no avatars so that the most possible difference would be created between performing traditional exercise and the VR environment. The participants executed the exercise tests that were specific to their groups (aerobic and anaerobic) in the VR and non-VR sessions.

The findings of the current research partly confirmed our hypotheses, indicating that using VR in exercise could influence physical fatigue and exercise performance. However, the comparison of the physical performance data in the VR and non-VR sessions showed different results in the aerobic and anaerobic groups. Accordingly, VR use increased the duration of AST in the anaerobic group, while causing no change in the duration of the Bruce protocol in the aerobic group. Both groups had a lower serum lactate concentration in the VR session compared to the non-VR session. Although lower lactate concentration could be a marker of reduced peripheral fatigue and physiological pressure, our participants reported no difference in their perceived fatigue. Besides, no significant differences were observed in the mean ROF scores and heart rate between the aerobic and anaerobic groups in the VR and non-VR sessions.

According to our findings regarding physical performance, the causes of diminished performance during exercise are a combination of the processes that occur in the brain and due to muscle changes (Zajac et al., 2015). Central fatigue occurs initially and is followed by peripheral fatigue (Rietjens et al., 2005). Previous findings have shown that increased psychological advantages and subsequent fatigue reduction are among the key psychological benefits of exercise with VR (Plante, Aldridge, Bogden, et al., 2003; Zeng et al., 2017). Therefore, it is expected that by affecting central fatigue, VR would delay the perception of fatigue and enhance physical performance in exercise.

Overall, our findings regarding physical performance are consistent with previous research, indicating that exercise with VR results in superior performance by prolonging exercise duration (Matsangidou et al., 2019; McClure & Schofield, 2019). However, using VR did not increase the physical performance of the aerobic group in the present study, which could be due to the applied VR film. Given the longer duration of the aerobic test, the attraction of the participants to the VR environment should also be considered an influential factor in this regard.

Initially, the subjects were divided into two groups of 10, including aerobic and anaerobic. The participants in the aerobic group executed the Bruce protocol, and the anaerobic group performed the anaerobic speed test (AST) in two separate sessions of VR and non-VR so that the intragroup results could be compared independently after the exercise tests with VR compared to traditional exercise in both the aerobic and anaerobic groups. Based on the integrated fatigue model, fatigue is a phenomenon caused by a combination of physiological factors (central and peripheral) and psychological factors (Lambert et al., 2005). Considering the imaging on fatigue in this model, the reduction of lactate concentration in the VR exercise session is partly attributed to the confirmed psychological effects of exercise with VR. As an important glycolytic biomarker, serum lactate is a prominent marker of peripheral fatigue in the standard exercise workload (Finsterer, 2012). Therefore, using VR technology in a single stage of exercise tests could effectively decrease peripheral muscle fatigue.

In the present study, ROF was applied to evaluate mental fatigue as a standard test with confirmed reliability and validity in measuring perceived fatigue in exercise (Micklewright et al., 2017). Moreover, heart rate was recorded as a parameter affected by mental and physical fatigue (Al Salman et al., 2013; Melo et al., 2017). The obtained results regarding heart rate were in line with the ROF data as both factors remained unchanged during the VR and non-VR sessions in the aerobic and anaerobic groups. This could be due to the format of the exercise tests as they continued until fatigue. Performing a single stage of intense exercise until the individual is able to maintain their performance could lead them to the maximum tolerable limit of fatigue. For this reason, the participants in our research stopped running within similar ranges of heart rate and perceived fatigue in both sessions.

In general, using VR could decrease physical fatigue in a single stage of aerobic or anaerobic exercise compared to traditional exercise. Notably, using the proper VR film could influence performance as well. VR changes the brain's perceptions of the surrounding environment by altering the visual perception data (Finsterer, 2012), while also attracting the attention of the individual to the virtual reality and disconnecting them from the reality by the simultaneous induction of diverse sensory signals (Matsangidou et al., 2019; Ng et al., 2019).

One of the limitations of our study was the small sample size, which restricts the generalizability of the findings. Additionally, field observations have indicated that the attraction of people to the VR environment (especially in prolonged exercises) is an important factor, and it is recommended that researchers take this influential factor into account in further investigations. Finally, we evaluated the

effects of VR in a single exercise session; therefore, other studies are required to assess the long-term effects and observe sustainable changes.

5. Conclusion

Exercise with VR using a film in contrast to reality could be an alternative for the application of this technology to enhance exercise performance and diminish physical fatigue. VR headsets are currently available to the public, and their increased application provides the opportunity to improve public health through VR fitness. Exercise in an imaginary environment than reality could further engage common people in exercise, while also helping professional athletes achieve optimal performance.

Declarations

6. Competing interests

No competing financial interests exist.

7. Consent for publication

Not applicable

8. Ethics approval and consent to participate

This study has been approved by the Research Ethics Committee of the Sport Sciences Research Institute of Iran IR.SSRI.REC.1399.679, IR.SSRI.REC.1398.666

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Tables

Table 1

Means and standard deviations of descriptive variables in aerobic and non-aerobic groups

Measurements	Aerobic Group	Anaerobic Group
Number	10	10
Age (year)	21.50±2.75	22.10±2.80
Height (cm)	178.85±6.06	180.20±5.51
Weight (kg)	74.35±8.34	68.30±9.22
BMI (kg/m ²)	23.35±3.24	20.96±2.58
Physical Activity (h/week)	10.10±2.27	10.50±3.27

BMI: body mass index

Table 2

Description of dependent variables in VR and non-VR sessions of aerobic and anaerobic exercise groups

Measurements	Aerobic		Anaerobic	
	VR	Non-VR	VR	Non-VR
Lactate (mg/dl)	47.05±15.29	74.39±21.77	61.09±13.02	72.33±21.82
Time (sec)	841.90±34.8	878.60±40.33	92.37±36.75	74.125±20.78
ROF (0-10)	8±1.24	8.70±1.41	7.90±0.99	7.70±1.05
Heart Rate (bpm)	195.60±8.97	194.40±9.29	187.60±11.01	185.20±12.10

ROF: rating of fatigue; P<0.05

Figures

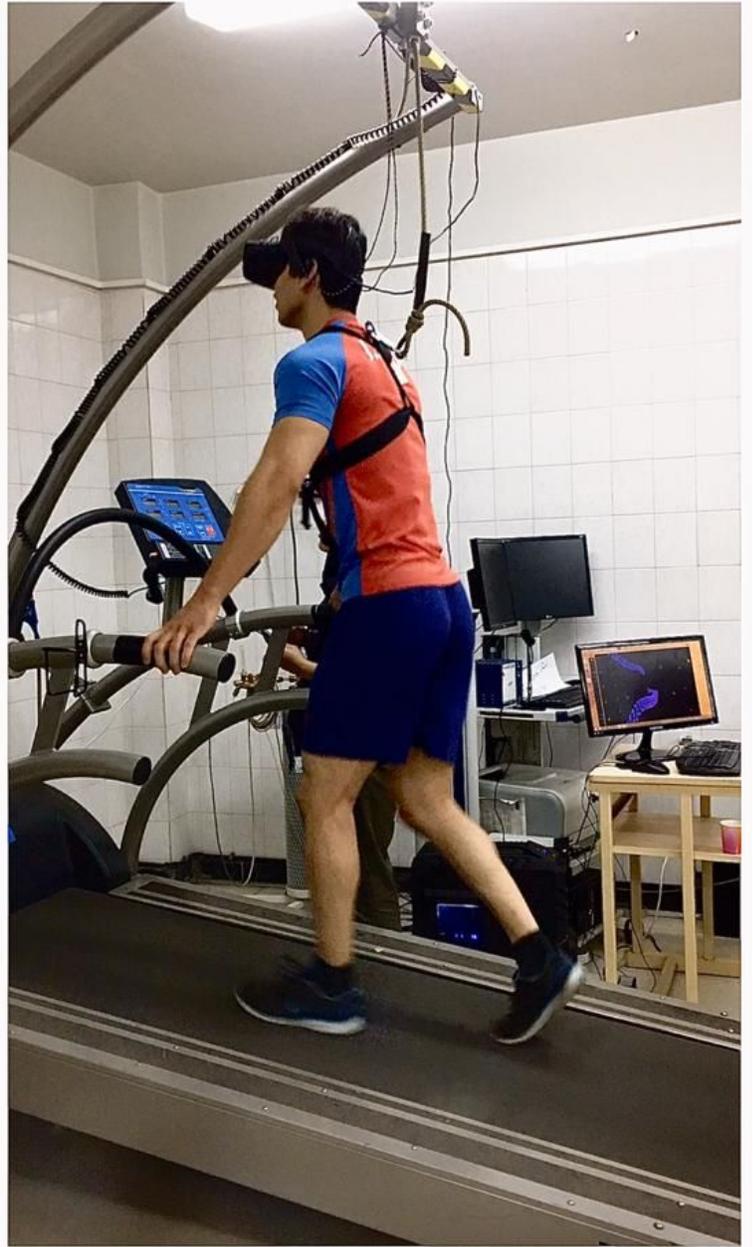


Figure 1

Execution of exercise test by participants of aerobic and anaerobic groups in VR and non-VR sessions



Figure 2

Simulated environment for exercise test with VR

Supplementary Files

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