Original Paper

Effects of a Modern Virtual Reality 3D Head-Mounted Display Exergame on Simulator Sickness and Immersion Under Specific Conditions in Young Women and Men: Experimental Study

Julia Ciążynska¹, MSc; Michał Janowski², PhD Eng; Janusz Maciaszek¹, PhD

¹Department of Physical Activity and Health Promotion Science, Poznan University of Physical Education, Poznan, Poland
²Department of Athletics, Strength and Conditioning, Poznan University of Physical Education, Poznan, Poland

Corresponding Author:
Julia Ciążynska, MSc
Department of Physical Activity and Health Promotion Science
Poznan University of Physical Education
61-871 Poznan
Królowej Jadwigi 27/39
Poznan, 61-871
Poland
Phone: 48 (61) 835 52 14
Email: ciazynska@a WF.poznan.pl

Abstract

Background: Many young adults do not reach the World Health Organization’s minimum recommendations for the amount of weekly physical activity. The virtual reality 3D head-mounted display (VR 3D HMD) exergame is a technology that is more immersive than a typical exercise session. Our study considers gender differences in the experience of using VR games for increasing physical activity.

Objective: The aim of this study was to examine the differences in the effects of VR 3D HMD gaming in terms of immersion, simulator sickness, heart rate, breathing rate, and energy expenditure during two 30-minute sessions of playing an exergame of increasing intensity on males and females.

Methods: To examine the effects of the VR 3D HMD exergame, we experimented with 45 participants (23 males and 22 females) exercising with VR 3D HMD Oculus Quest 1, hand controllers, and Zephyr BioHarness 3.0. Players exercised according to the Audio Trip exergame. We evaluated the immersion levels and monitored the average heart rate, maximum heart rate, average breathing rate, maximum breathing rate, and energy expenditure in addition to simulator sickness during two 30-minute exergame sessions of increasing intensity.

Results: Audio Trip was well-tolerated, as there were no dropouts due to simulator sickness. Significant differences between genders were observed in the simulator sickness questionnaire for nausea (F\(_{2,86}=0.80; P=.046\)), oculomotor disorders (F\(_{2,86}=2.37; P=.010\)), disorientation (F\(_{2,86}=0.92; P=.040\)), and total of all these symptoms (F\(_{2,86}=3.33; P=.040\)). The measurements after the first 30-minute VR 3D HMD exergame session for all the participants showed no significant change compared to the measurements before the first 30-minute exergame session according to the total score. There were no gender differences in the immersion (F\(_{1,43}=0.02; P=.90\)), but the measurements after the second 30-minute exergame session showed an increase in the average points for immersion in women and men. The increase in the level of immersion in the female group was higher than that in the male group. A significant difference between genders was observed in the average breathing rate (F\(_{2,86}=1.44; P=.047\)), maximum breathing rate (F\(_{2,86}=1.15; P=.047\)), and energy expenditure (F\(_{2,86}=10.51; P=.001\)) measurements. No gender differences were observed in the average heart rate and maximum heart rate measurements in the two 30-minute sessions.

Conclusions: Our 30-minute VR 3D HMD exergame session does not cause simulator sickness and is a very immersive type of exercise for men and women users. This exergame allows reaching the minimum recommendations for the amount of weekly physical activity for adults. The second exergame session resulted in simulator sickness in both groups, more noticeably in women, as reflected in the responses in the simulator sickness questionnaire. The gender differences observed in the breathing rates and energy expenditure measurements can be helpful when programming VR exergame intensity in future research.
virtual reality; HMD; simulator sickness; immersion; physical activity; exergame; Zephyr; gender differences; WHO recommendation; young adult; digital health; energy expenditure; exercise game

Introduction

Background

Several studies have shown evidence that excessive sedentary behavior can harm the health of people [1-4] and that programmed physical activity may increase health-related fitness [5,6]. According to the new recommendations of the World Health Organization, adults (18-64 years) should exercise for 150-300 minutes a week at moderate intensity or 75-150 minutes at vigorous intensity [7]. For moderate intensity activities, it is about 22-42 minutes of physical activity a day to improve health. Adults should also engage in a muscle-strengthening exercise of moderate or high intensity that engages all the major muscle groups for 2 or more days per week [7]. However, it should be emphasized that this is an absolute minimum that is often not achieved [8,9]. Studies have shown that young female adults typically engage less in physical activity than men [10], but both genders have difficulty achieving the World Health Organization recommendations for weekly physical activity [11]. Globally, in 2016, more than a quarter of all adults were not performing enough physical activity [11]. The world of computer devices is often blamed for low activity and a sedentary lifestyle [12], and the group at risk is people in their 20s and 30s because they are the most active gamers [13]. Over the past 2 decades, the number of female video game players has increased, and females today make up half of the gaming population [14]. The enthusiasm of young people should be channelized to play virtual reality (VR) games because of the positive enhanced heart rates and energy expenditure during exergames compared to those while playing on traditional computer displays [15]. In 2016, the VR games market began to develop dynamically, and the equipment used for VR gaming was modernized. Most studies until 2016 showed that women users experienced high simulator sickness and low immersion while using the same VR play equipment and content as men [16-20]. Males and females may be sensitive to different features of the simulated environment and may experience simulator sickness accordingly (females more for 2D environments, while males for 3D environments). Further, different studies have reported increased simulator sickness differences between men and women according to the type of the utilized head-mounted display (HMD) equipment and categories of VR content (female users experienced more discomfort compared to males when exposed to high emotional and arousing content). Recent studies have shown that proper modern equipment and properly selected game content can minimize the feelings of simulator sickness and increase immersion in both genders [21-24]. However, the previous studies do not refer to exergames based on programmed physical exercises in the VR 3D HMD. No study has shown VR exergaming as a form of physical activity that can be performed for fulfilling the weekly physical activity recommendations of the World Health Organization for adults.

Immersive VR 3D HMD exergaming systems are plain body movements and are close to the planned, structured, and repetitive elements of a typical moderate training session [25]. Immersion is one of the main factors required for enabling the game users to perceive all aspects to create a real-life impression [16]. VR 3D HMD exergame is a technology that is more immersive than a typical exercise session [20]. An exergame that is a whole-body exercise is important, and it should involve rhythmic activity from large muscle masses, require quick shuffling to change positions, and should include locomotor tasks or even defensive actions to promote increased energy expenditure [26].

Goal of This Study

Our study presents a VR device as a tool to reach the minimum recommendations of the World Health Organization for the amount of weekly physical activity and to counteract a sedentary lifestyle. As per the World Health Organization recommendation, we divided the exergame sessions into two 30-minute sessions to assess whether the minimum recommendation could be achieved by both the genders. The 30-minute sessions have also been used in another HMD study [27] and has shown a positive response in the mental health of young adults. We chose individuals in the age group of 19-29 years as the most vulnerable to a sedentary lifestyle. The aim of this study was to evaluate the effects of a modern 3D HMD exergame on simulator sickness and immersion under specific conditions in healthy people. Thus, the risk of influence of other factors such as poor health, chronic diseases, and low endurance was reduced. In our experiment, we chose such conditions for playing the exergame to minimize gender differences, and we matched the game type for a group of recipients. We chose Oculus Quest 1 with Audio Trip, a first-person perspective game with 3D vision and a low emotional VR environment, for both genders. As the sessions increased in intensity, we collected data on the heart rate, breathing rate, and energy expenditure.

Hypotheses

We formed 3 hypotheses in this study.

1. Hypothesis 1: playing Audio Trip with a modern VR 3D HMD would result in higher cardiovascular function in men.
2. Hypothesis 2: playing Audio Trip with a modern VR 3D HMD would not cause simulator sickness in both genders.
3. Hypothesis 3: playing Audio Trip with a modern VR 3D HMD would have an immersion level that is gender independent, regardless of the playing time.

Methods

Participants

Sample size estimations were conducted using G*Power 3.1 (Axel Buchner). Sample size estimations were done for all
analyses, and the final targeted sample size was selected such that the analysis requiring the largest number of participants can be adequately powered. Based on meta-analyses, we expect a medium effect size of Cohen’s $d=.26$. The sample size required to reach a level of significance of .05 with a power of .80 is 26 participants. By making 3 measurements considering gender and an assumed dropout rate of 25%, we needed to recruit 33 people to test our hypotheses. We evaluated all the participants who signed up; there was a total of 45 participants. All the participants completed this study. To be eligible for participation in this study, the individual had to be a physical education student, be between 19 and 29 years old, and have a good health condition (no neurological disorders, disability, mental disorders, psychotropic medicines, injuries, or fresh injuries), have a score of 10 or less on the Ruffer Squat Test scale, and have had no interactions with VR equipment or similar VR stimulation before. Individuals were invited to participate in the study through personal invitations and emails.

Technology
The VR Oculus Quest 64 GB system (Oculus Quest system software, Facebook Inc, released on May 21, 2019) was used as the immersive VR technology in this study. It consists of a wireless headset through which the VR environment can be viewed and played with 2 hand controllers that enable interaction with the VR environment. People wearing glasses could also take part in this study because a special overlay for glasses was applied. To ensure proper performance, the room size should be at least 2 meters × 2 meters. The VR Oculus Quest 64 GB has a display of 5.7 inches, resolution of 2880 pixels × 1600 pixels, reference resolution of 1440 pixels × 1600 pixels, organic light emitting diode display type, and refresh frequency of 72 Hz. The name of the game that was used was Audio Trip and was distributed from the Oculus Quest store app.

Instruments
Four methods were used for the usability evaluation: Audio Trip VR exergame, Simulator Sickness Questionnaire (SSQ), The Immersion Questionnaire, and BioHarness 3.0 measurements. One of the inclusion criteria for the study was the Ruffer Squat Test.

The purpose of the Audio Trip VR game (Andromeda Entertainment) [28] is to dance to the rhythm and immerse into the virtual musical and fitness environment. A player is obliged to follow the colored path by using their hands to catch 2 colored gems, smash drums, and dodge virtual barriers. In this study, players had to follow a special 30-minute playlist 2 times in the beginner and regular modes. A playlist is a proprietary idea in which the beats per minute increase during play, and the difficulty level increases in the second session, thereby increasing the intensity. The details of the playlist are shown in Figure 1.

The SSQ is one of the most frequently used simulator testing tools [29]. In this research, we used the SSQ by Kennedy et al [30], translated into Polish by Biernacki et al [31]. One of the essential aspects of research on simulators is how different test conditions affect the severity of the symptoms due to a simulator. Among the conditions in this study, one should specify both the movement of the platform and the type of visual stimuli. This questionnaire evaluates 26 symptoms due to the simulator. Questions on nausea (question numbers 1, 8, 10, 11, 12, 22, 25), oculomotor disorders (question numbers 1, 2, 5, 6, 7, 12, 15), and disorientation (question numbers 7, 1, 14, 15, 16, 17, 18) were asked in the questionnaire. The task of the person examined using SSQ consists of making a subjective assessment of the severity of specific symptoms. A 4-step scale was used: (1) none, no symptoms due to the simulator; (2) small, few symptoms due to the simulator; (3) moderate, moderate symptoms due to the simulator; and (4) significant, serious symptoms due to the simulator. The SSQ result includes both the overall levels of the symptoms from using a simulator (SSQ total), and the indicators consist of individual (unportioned relative to each other) scales: (1) nausea symptoms of increased salivation, sweating, nauseousness, and burping; (2) oculomotor disorder symptoms of fatigue, headache, eye fatigue, and difficulty in concentration; and (3) disorientation symptoms of dizziness, daze feeling (both with open and closed eyes), and blurriness (out of focus). The first step when calculating SSQ is to convert the results to a numerical form. The SSQ scales are expressed on a 4-stage Likert scale (where 0=none, 1=small, 2=moderate, and 3=significant). For calculating the score for SSQ, add raw values for the data of the symptoms assigned to the specified factor and multiply by a specific number. For individual scales, they are as follows: (1) nausea, 9.54 (score ranging from 0 to 200.34); (2) oculomotor disorders, 7.58 (scores ranging from 0 to 159.18); (3) disorientation, 13.92 (scores ranging from 0 to 292.32); and (4) SSQ total, 3.74 (scores ranging from 0 to 235.62).

The Immersion Questionnaire is a scale measuring video game engagement [32]. In this research, we used the Immersion Questionnaire by Jennett et al [32], which was translated into Polish by Strojny et al [33]. This questionnaire was used as a tool for measuring the player’s absorption/immersion while playing games. Researchers commonly consider immersion to be an important part of the videogame user experience [34-37]. The Polish adaptation consists of 27 test items instead of 31 questions of the original questionnaire, because 4 questions in the original questionnaire had a low correlation with the overall test score and are unnecessary [38]. The Immersion Questionnaire scales are expressed on a 5-stage Likert scale (where 1=very small, 2=small, 3=average, 4=more than average, 5=a lot/definitely). The total score to earn on the Immersion Questionnaire is 135.

A portable wireless piezoelectric recording system (BioHarness 3.0, OmniSense 3.9.7, Zephyr Technology Corp) [39] was used for monitoring energy expenditure, estimated according to the following formula: energy expenditure (kcal) = gender × (-20.4022 + 0.4472 heart rate – 0.1263 weight + 0.6309 heart rate + 0.1988 weight + 0.2017 age) + (1 – gender) × (-20.4022 + 0.4472 heart rate – 0.1263 weight + 0.074 age) (gender: 1 for male, 0 for female; heart rate, including average heart rate and maximum heart rate; and breathing rate, including average breathing rate and maximum breathing rate).

In the Ruffer Squat Test, participants are made to do 30 squats in 45 seconds [40]. Heart rate is recorded before the test (P1), at the end of 45 seconds (P2), and at 1 minute after the test (P3).
The test score is calculated in the form of an index—the Ruffier Index expressed as \((P1 + P2 + P3) – 200/10\). The range of the Ruffier Index given was 0 to 17, but higher than 10 is an adaptation to insufficient effort or even poor adaptation. The individual ranges are as follows: 0 is a very good adaptation to effort, between 0 and 5 is a good adaptation to effort, and between 5 and 10 (including 10) is the ability to adapt to the average effort. Ruffier originally developed this test for testing the European population.

**Figure 1.** Exergame playlist in beginner and regular modes of the Audio Trip virtual reality game, including the title, duration of songs, and beats per minute. BPM: beats per minute.

| **TITLE**       | **DURATION** | **BPM** |
|-----------------|--------------|---------|
| **(chronological)** | **(min:sec)** | **(beats per minute)** |
| DANCE MONKEY    | 03:28        | 98      |
| BANGARANG       | 03:32        | 110     |
| JUST DANCE      | 03:38        | 118     |
| KRISHNA         | 02:39        | 128     |
| RED             | 07:31        | 136     |
| SATISFACTION    | 04:44        | 136     |
| MANDALA         | 04:39        | 143     |

**Procedure**

Each participant came once to be examined and approved for research and to take part in the main study. Each participant attended an information meeting. They were informed of the study and encouraged to ask questions, after which they signed a written consent form if they agreed to participate. The study protocol is presented in a chronological order in Figure 2. The participants filled in the first 2 pages of SSQ (see Multimedia Appendix 1). The first page included preliminary information before starting the study about simulator experience and physical statements, that is, level of current physical fitness, the occurrence of diseases during a week, alcohol consumption, medications taken 24 hours before the study, and sleep duration. The second page collected information on cybersickness data before the first 30-minute VR 3D HMD exergame session. Before completing the SSQ, a BioHarness 3.0 sensor was attached to the chest by a strap and calibrated with a computer. The participants were weighed and their heights were measured, and then these data were entered into the OmniSense software (Zephyr BioHarness 3.0).

Each participant took part in a 5-minute warm-up, according to the instructions in a video prepared earlier (see Figure 3). The VR 3D exergame tutorial starts with the calibration of HMD and controllers. People wearing glasses could also take part in this study because a special overlay for glasses was applied. Moreover, left-handed people could take part in this study. The participants stood next to an imaginary console with songs and were then fitted with the VR equipment. At this point, researchers had a preview of the VR world on the screen of the mobile phone to be able to see what the participant saw during the experimental sessions. The safe space for the participant to move was a square of 2.5 meters × 2.5 meters. In the VR environment, the controllers were represented by hands in the console environment and by 2-color orbs in the exergame environment. The tutorial was built in steps, with each step being supported by instructions on what tasks to perform to meet the goal to proceed to the next step, and the tasks were graded from the easiest to the most difficult (see Multimedia Appendix 2). The details of the playlist are shown in Figure 1. The intensity of the game increases during each session and with the difficulty level. The participants were dressed in casual clothes (Figure 4) and had safety face pads between the HMD Oculus Quest headset and their face. The details on what the Audio Trip game looks like are shown in Figure 5. We determined whether a participant managed to perform each task by noting the points for every 7 songs from a playlist on the checklist box. Between the songs was a quick pause to select the next one from the playlist.

After the first 30 minutes of the exergame playlist session, participants proceeded to the measurements that were taken between the 2 sessions: The Immersion Questionnaire, SSQ, and BioHarness 3.0 measurements (Figure 2). The participants were expected to answer the questions alone, but some questions required clarification and affirmation by the researcher to confirm the proper interpretation. After completing the measurements in the interval between the 2 sessions, the second session of the exergame started. The interval time of 15-20 minutes was enough for the heart rates of all the participants to return to normal resting heart rate before the start of the next game session. The game was then launched on the regular level. After completing the second 30-minute playlist (60 minutes in total), the same measurements were performed as done between the 2 sessions.
Figure 2. Study protocol presented in the chronological order from left to right for the experimental group. Br-Ave: average breathing rate; Br-Max: maximum breathing rate; EE: energy expenditure; HR-ave: average heart rate; HR-Max: maximum heart rate; SSQ: Simulator Sickness Questionnaire; TIQ: The Immersion Questionnaire; VR: virtual reality; ZB3: Zephyr Bioharness 3.0.

| Duration | 20 min | 15-10 min | 30 min | 15-20 min | 30 min | 15-20 min |
|----------|--------|-----------|--------|-----------|--------|-----------|
| **Experimental group (n=45)** | **PREPARATION** (before first session) | **FIRST 30-MIN SESSION** | **INTER** (between sessions) | **SECOND 30-MIN SESSION** | **POST** (after second session) |
| Inclusion criteria check | SSQ | BEGINNER MODE | TIQ | REGULAR MODE (higher intensity) | TIQ |
| ZB3 calibration | ZB3 | ZB3: HR-Max, HR-Ave, Br-Max, Br-Ave, EE | SSQ | ZB3: HR-Max, HR-Ave, Br-Max, Br-Ave, EE | SSQ |
| Warm-up | ZB3 | ZB3 | ZB3 |

Figure 3. The various elements of the 5-minute warm-up (5: running in place, 4: arm swings, 3: torso twists, 2: torso bends, 1: warming the joints, that is, wrist and ankle) on the television.

Figure 4. Virtual reality exergame intervention in a safe area of 2.5 meters x 2.5 meters.
Figure 5. View of the Audio Trip game. From left: A. Selecting a track from the list.; To the rhythm of the music, hitting two-colored triangles as intended: B. touching by R/L hand C. hitting at a certain angle by R/L hand, D. smashing the drums by R/L hand, E. following the path by R/L hand and dodging the barriers.; F. Following the trainer (back perspective).

Data Interpretation
We analyzed the data measured from BioHarness 3.0 in the experiment by using the OmniSense software. The data measured from the experiment are maximum heart rate, average heart rate, maximum breathing rate, average breathing rate, and energy expenditure. Repeated-measures analysis of variance (ANOVA) was used to test the hypotheses. We analyzed the data using Statistica 13.3 (TIBCO Software Inc), and statistical significance was defined as $P \leq .05$.

Ethics Approval
This study was performed according to the ethical standards laid down in the Declaration of Helsinki. All participants provided signed informed consent, and the Bioethics Commission of Poznan University of Medical Sciences granted the ethical approval for this study (decision 32/20).

Results

Participant Characteristics
The mean age (in years) of the participants (N=45) was 21.69 (SD 2.76; range 19-28). The mean body weight (in kilograms) was 71.03 (SD 13.07; range 44.5-106.5). The mean body height (in centimeters) was 173.98 (SD 8.09; range 155.6-186.1). The mean body mass index (in kg/m$^2$) was 23.3 (SD 3.23; range 18.4-32.3). The experimental group was mixed; females constituted 49% (22/45) of the study population (Table 1).

| Participant characteristic | Value       |
|---------------------------|-------------|
| Mean age (years)          | 21.69       |
| Mean body weight (kg)     | 71.03       |
| Mean body height (cm)     | 173.98      |
| Mean BMI (kg/m$^2$)       | 23.3        |
| Females (n)               | 22          |
| Ruffier index             | 6.5         |

SSQ Results

Nausea
Significant differences between genders were observed in nausea symptoms (Table 2), that is, increased salivation, sweating, nauseousness, and burping. Analysis of the results with the ANOVA test showed that the size of the changes in the mean values for the SSQ nausea score was $F_{2,86}=0.80$ ($P=.46$).
Table 2. Gender differences in nausea during the 3 measurements.\(^a\)

| Simulator sickness questionnaire on nausea | Female group | Male group |
|-------------------------------------------|-------------|-----------|
| **Before the first 30-minute exergame session** |             |           |
| Average (SD)                              | 9.54 (9.74) | 10.37 (9.22) |
| Minimum points                            | 0           | 0         |
| Maximum points                            | 28.62       | 38.16     |
| **Between the exergame sessions**         |             |           |
| Average (SD)                              | 13.01 (10.54) | 18.25 (11.19) |
| Minimum points                            | 0           | 0         |
| Maximum points                            | 38.16       | 47.7      |
| **After the second 30-minute exergame session** |         |           |
| Average (SD)                              | 20.38 (13.05) | 22.40 (12.87) |
| Minimum points                            | 0           | 0         |
| Maximum points                            | 57.24       | 47.7      |

\(^aF_{2,86}=0.80; P=.046.\)

**Oculomotor Disorders**

Significant differences between genders were observed in oculomotor disorder symptoms (Table 3), that is, fatigue, headache, eye fatigue, and difficulty in concentrating. Analysis of the results with the ANOVA test showed that the size of the changes in the mean values for the SSQ oculomotor disorders score was \(F_{2,86}=2.37\) (\(P=.10\)).

Table 3. Gender differences in the simulator sickness questionnaire for oculomotor disorders during the 3 measurements.\(^a\)

| Simulator sickness questionnaire on oculomotor disorders | Female group | Male group |
|----------------------------------------------------------|-------------|-----------|
| **Before the first 30-minute exergame session** |             |           |
| Average (SD)                              | 18.26 (14.18) | 14.50 (12.25) |
| Minimum points                            | 0           | 0         |
| Maximum points                            | 60.64       | 30.32     |
| **Between the exergame sessions**         |             |           |
| Average (SD)                              | 22.74 (13.32) | 11.21 (14.01) |
| Minimum points                            | 0           | 0         |
| Maximum points                            | 53.06       | 30.32     |
| **After the second 30-minute exergame session** |         |           |
| Average (SD)                              | 34.11 (18.80) | 21.09 (15.33) |
| Minimum points                            | 0           | 0         |
| Maximum points                            | 83.38       | 53.06     |

\(^aF_{2,86}=2.37; P=.010\)

**Disorientation**

Significant differences between genders were observed in disorientation symptoms (Table 4), that is, dizziness, daze feeling (both with open and closed eyes), and blurriness (out of focus). Analysis of the results with the ANOVA test showed that the size of the changes in the mean values for the SSQ disorientation score was \(F_{2,86}=0.92\) (\(P=.40\)).
Table 4. Gender differences in the simulator sickness questionnaire on disorientation during the 3 measurements.\textsuperscript{a}

| Simulator sickness questionnaire on disorientation | Female group | Male group |
|--------------------------------------------------|--------------|------------|
| **Before the first 30-minute exergame session**   |              |            |
| Average (SD)                                      | 11.39 (11.42)| 7.87 (10.05)|
| Minimum points                                    | 0            | 0          |
| Maximum points                                    | 41.76        | 27.84      |
| **Between the exergame sessions**                |              |            |
| Average (SD)                                      | 16.45 (15.67)| 5.45 (7.49)|
| Minimum points                                    | 0            | 0          |
| Maximum points                                    | 55.68        | 55.68      |
| **After the second 30-minute exergame session**  |              |            |
| Average (SD)                                      | 24.68 (22.80)| 15.13 (10.65)|
| Minimum points                                    | 0            | 0          |
| Maximum points                                    | 69.60        | 83.52      |

\textsuperscript{a}F_{2,86}=0.92; \(P=.004\).

**SSQ Total Symptoms**

Audio Trip was well-tolerated, as there were no dropouts due to simulator sickness. Significant differences between genders were observed in SSQ total symptoms (oculomotor disorders + nausea + disorientation). Analysis of the results with the ANOVA test showed the size of changes in mean values for the SSQ total symptoms was \(F_{2,86}=3.33\) (\(P=.04\)); however, after the first 30-minute session, all participants showed no significant change compared to premeasurements according to SSQ total symptoms results (Table 5 and Figure 6). One-way ANOVA showed no significant differences between the measurements for men (\(P=.83\)) and women (\(P=.59\)) before the first 30-minute exergame session and between the sessions.

Table 5. Gender differences in the simulator sickness questionnaire for the total symptoms during the 3 measurements.\textsuperscript{a}

| Simulator sickness questionnaire on the total symptoms | Female group | Male group |
|-------------------------------------------------------|--------------|------------|
| **Before the first 30-minute exergame session**       |              |            |
| Average (SD)                                          | 15.47 (11.41)| 13.65 (10.68)|
| Minimum points                                        | 0            | 0          |
| Maximum points                                        | 48.62        | 33.66      |
| **Between the exergame sessions**                     |              |            |
| Average (SD)                                          | 21.93 (11.55)| 13.01 (9.22)|
| Minimum points                                        | 0            | 0          |
| Maximum points                                        | 52.36        | 33.66      |
| **After the second 30-minute exergame session**       |              |            |
| Average (SD)                                          | 32.98 (17.30)| 15.13 (16.60)|
| Minimum points                                        | 0            | 0          |
| Maximum points                                        | 74.80        | 59.84      |

\textsuperscript{a}F_{2,86}=3.33; \(P=.04\).
**Figure 6.** Gender differences in the total simulator sickness score during the three measurements. PRE: before the first 30-minute exergame session; INTER: between the exergame sessions; POST: after the second 30-minute exergame session; SSQ: Simulator Sickness Questionnaire.

![Simulator Sickness Score Graph](image)

**Table 6.** Gender differences for the simulator sickness questionnaire profile during the 3 measurements.

| Simulator sickness questionnaire profile | Female group | Male group |
|-----------------------------------------|--------------|------------|
| **Before the first 30-minute exergame session (mean points)** | | |
| Oculomotor disorder                     | 18.26        | 14.50      |
| Nausea                                  | 9.54         | 10.37      |
| Disorientation                          | 11.39        | 7.87       |
| **Between the exergame sessions (mean points)** | | |
| Oculomotor disorder                     | 22.74        | 11.21      |
| Nausea                                  | 13.01        | 18.25      |
| Disorientation                          | 16.45        | 5.45       |
| **After the second 30-minute exergame session (mean points)** | | |
| Oculomotor disorder                     | 34.11        | 21.09      |
| Nausea                                  | 20.38        | 22.40      |
| Disorientation                          | 24.68        | 15.13      |

**The Immersion Questionnaire**

No significant differences between genders were observed in the Immersion Questionnaire score (Table 7 and Figure 7).

**Table 7.** Gender differences in the immersion questionnaire during the 2 measurements.$^a$

| Immersion questionnaire                     | Female group | Male group |
|---------------------------------------------|--------------|------------|
| **Between the exergame sessions**           |              |            |
| Average (SD)                                | 106.23 (7.80)| 103.04 (10.68)|
| Minimum points                              | 72           | 78         |
| Maximum points                              | 121          | 121        |
| **After the second 30-minute exergame session** | | |
| Average (SD)                                | 110.05 (11.06)| 106.56 (10.83)|
| Minimum points                              | 79           | 76         |
| Maximum points                              | 129          | 129        |

$^aF_{1,43}=0.02; P=.89$
BioHarness Measurements

A significant gender difference was observed in the average breathing rate ($F_{2,86}=1.44; P=.04$), maximum breathing rate ($F_{2,86}=1.15; P=.047$), and energy expenditure ($F_{2,86}=10.513; P=.001$) measurements (Table 8). No gender differences appeared in the average heart rate and maximum heart rate measurements in the two 30-minute sessions.

Table 8. Gender differences in the average heart rate, maximum heart rate, average breathing rate, maximum breathing rate, and energy expenditure during the 3 measurements.

| BioHarness measurements          | Female group | Male group | Interaction, $F$ test (df) | $P$ value |
|---------------------------------|--------------|------------|---------------------------|-----------|
| **Average heart rate**          |              |            |                           |           |
| Before the first 30-minute exergame session | 90.95        | 80.87      | 0.19 (2,86)               | .83       |
| Between the exergame sessions   | 142.72       | 129.86     |                           |           |
| After the second 30-minute exergame session | 144.68       | 133.56     |                           |           |
| **Maximum heart rate**          |              |            |                           |           |
| Before the first 30-minute exergame session | 110.77       | 101.26     | 0.29 (2,86)               | .75       |
| Between the exergame sessions   | 171.82       | 158.17     |                           |           |
| After the second 30-minute exergame session | 172.77       | 160.52     |                           |           |
| **Average breathing rate**      |              |            |                           |           |
| Before the first 30-minute exergame session | 14.50        | 12.91      | 1.44 (2,86)               | .04       |
| Between the exergame sessions   | 27.95        | 28.99      |                           |           |
| After the second 30-minute exergame session | 27.05        | 28.70      |                           |           |
| **Maximum breathing rate**      |              |            |                           |           |
| Before the first 30-minute exergame session | 23.09        | 21.65      | 1.15 (2,86)               | .047      |
| Between the exergame sessions   | 37.27        | 35.04      |                           |           |
| After the second 30-minute exergame session | 36.27        | 36.65      |                           |           |
| **Energy expenditure**          |              |            |                           |           |
| Before the first 30-minute exergame session | 33.82        | 39.47      | 10.513 (2,86)             | .001      |
| Between the exergame sessions   | 267.95       | 340.96     |                           |           |
| After the second 30-minute exergame session | 272.77       | 356.82     |                           |           |
Discussion

Principal Findings

Hypothesis 1: Audio Trip Exergame With Modern VR 3D HMD Would Result in Higher Cardiovascular Function in Men

The findings from this study provide support for our first hypothesis. A significant gender difference was observed in the average breathing rate ($F_{2,86}=1.44; P=.04$), maximum breathing rate ($F_{2,86}=1.15; P=.047$), and energy expenditure ($F_{2,86}=10.513; P<.001$) measurements. Seebauer et al [41] suggested that the effect of exercise intensity on the occurrence of coordination between breathing rate and rhythms of exercise differs between men and women. A similar mechanism could have occurred in our study due to the use of a rhythmic music game. During heavy exercise, tidal volume plateaus and increase in minute ventilation can only be reached via an increase in the breathing rates and energy expenditure. Interestingly, even though women have smaller lung volumes compared to men [42], in our study, men adjusted their breathing rates more during the whole exergame session. Trinschek et al [43] proved that men showed significantly higher values in cardiorespiratory variables (by 12%-34%) during the running treadmill test until exhaustion [43]. Men users feel more excited when they do something they like very much or want to achieve something and are forced to breathe more frequently during an exercise session [44]. Additionally, the frequency of breathing increases energy expenditure [45]. Breathing can also change in response to changes in emotions. Due to the physical activity, the attractiveness of the task, perceived competence, and autonomy concerning emotional experience are especially important aspects [46]. Although our study showed a prominent level of immersion, it can be assumed that satisfaction influenced the need to increase breathing in male users. The values of average heart rate and maximum heart rate showed no gender differences in both sessions because the groups were well-matched in terms of physical performance, as per the Ruffier Squat Test inclusion criterion in this study.

Hypothesis 2: Audio Trip Exergame With Modern VR 3D HMD Will Not Cause Simulator Sickness in Both Genders

The findings from our study provide partial support for our second hypothesis. There were statistical differences between the genders in both sessions: men were more resistant to simulator sickness than women. After two 30-minute sessions, there was a change in simulator sickness ($F_{2,86}=3.33; P=.04$); however, after the first 30-minute session, all participants showed no significant change compared to premeasurements according to SSQ total results. Although there is a lack of studies about gender imbalance in the susceptibility to simulator sickness in the context of modern HMDs, some studies do elucidate this point [23,24,47]. Female participants may experience discomfort only in specific conditions (movements in first-person perspective). Males and females may be sensitive to different features of the simulated environment and experience simulator sickness accordingly (females more for 2D environments, while males for 3D). Studies have shown the causes for simulator sickness in men and women, which are different by the type of the utilized HMD equipment and categories of VR content (female participants experienced more discomfort compared to males when exposed to highly emotional and arousing content) [22]. A systematic review on gender differences in VR HMD [23] showed that women are commonly more sensitive to simulator sickness when the realism of the content is low or when the game is highly emotional. Such an increase in SSQ total score in women can be partially explained that female users may be more willing to report distress and discomfort during the experiment [48]. This may be due to the social biological differences and social expectations [49]. The newest HMD technology can provide a more advantageous experience [27,50] and if this is combined with a careful selection of VR content, the risk of VR simulator sickness can be leveled off. Furthermore, Giammarco et al [51] suggested that gender differences in SSQ scores may be differentially related to gender differences in cognitive functions like spatial attention depending on the VR environment. Another aspect is that the VR HMD simulator sickness has been found to increase after 10 minutes [52]. Our study showed that only the second session (a total of 60 minutes of VR exergaming) of VR content caused statistically significant differences in simulator sickness. Therefore, the hypothesis was confirmed partially, because only the first 30-minute of the Audio Trip exergame will not cause simulator sickness in adults, which is a positive finding in the field of SSQ. A new type of VR HMD and appropriately selected content and intensity can help delay the appearance of the effects of simulator sickness for men and women, as shown in other VR studies [50,53]. Szpak et al [53] suggested that the exposure duration did not influence any visual measure, and observable changes in accommodation and vergence did occur within the first 10 minutes of VR exposure and did not significantly change for exposures up to 50 minutes. The results of our study should encourage men and women to try VR HMD exercise, without fearing that playing may have a high probability of causing them discomfort during 30 minutes of exergaming. The development of VR equipment and more modern games in the future should extend the effect of non–simulator sickness.

Hypothesis 3: Immersion Level is Gender Independent Regardless of the Playing Time

The findings from this study provide support for our third hypothesis. There were no gender differences in the level of immersion ($F_{1,43}=0.02; P=.90$) but the second 30-minute session showed an increase in the average points for both women and men. The increase in the level of immersion in the female group was higher than that in the male group. As we mentioned, immersion is one of the main factors required to enable the game users to perceive all aspects to create a real-life impression [16]. Studies until 2011 show that men are more frequent immersive users of VR devices. Men, regardless of their prior game experience, expressed more sensory immersion and more control over the environment than women. The golden period of VR was the year 2016. Since 2016, VR devices were contemporary and were found to be suitable for users (weightless, wireless, etc). Our study suggests that there are no
gender differences concerning the level of immersion with contemporary VR equipment (Oculus Quest) if the VR content is suitable for both genders. Our experiment was performed with physical education students who had not interacted with VR equipment or similar VR stimulation before, and we made sure that the content of the game was interesting for both genders (physical exercise for physical education students). Physical exergame content (Audio Trip) and technical capabilities (wireless HMD, hand controllers) can probably contribute to the reduction of gender differences.

Limitations
The first limitation in this study was the assessment of the breathing rate based on chest movements alone. Based upon the principle of a strain gauge sensor, thoracic expansion and contraction cause size differentials that induce changes in capacitance because of the resultant changes in impedance. The change in impedance is manifested as a change in the waveform signal amplitude represented as a sine wave with downward and upward deflections, indicating chest expansion (increased impedance) and contraction (decreased impedance), respectively [54]. Incorrect tension on the chest strap may prevent adequate sensor response to chest expansion and contraction [39]. To eliminate the effects of these variances, we recommend the use of additional tools such as spirometry for future studies measuring physiological effort and energy expenditure.

The second limitation in this study was the acceptance of the necessity to be a physical education student as one of the inclusion criteria in this study. The aim was to study the effects the VR 3D HMD exergame on fully healthy and fit people. This allowed reducing the risk of the influence of other factors, for example, poor health, chronic diseases, and low endurance. In addition, what we tried to highlight in our study, which mattered the most, was the interest in the type of game and the gathering of the appropriate number of people for research who would meet the inclusion criteria, including the Ruffier Squat Test score. We chose people interested in sports by the type of studies selected (physical education students).

Conclusions
This study showed that a 30-minute session of the VR 3D HMD exergame does not cause simulator sickness and is a very immersive type of exercise for men and women users. This exergame gives the opportunity to reach the minimum recommendations for the amount of weekly physical activity for adults. The second exergame session resulted in simulator sickness in both groups, more noticeably in women, as indicated by the responses in the SSQ. Gender differences were observed in the breathing rate and energy expenditure measurements, and this information can be helpful when programming VR exergame intensities in future research. Our findings provide a foundation for future research on VR exergames with no simulator sickness but as a refreshing and an enjoyable type of exercise for male and female users. Motivating the public to be physically active is perhaps one of the most important and difficult tasks. Gamification of physical exercises can facilitate more weekly physical activity than that recommended by the World Health Organization for minimum weekly physical activity for adults. Future immersive exergaming concepts should focus on increasing the intensity while considering user susceptibility to simulator sickness.

Authors’ Contributions
JC conducted the experimental procedure; wrote the manuscript; provided data for Tables 1-7, Figures 1-7, multimedia appendices, and TOC image; and conducted all the statistical analyses. MJ provided data for Table 8. JC, MJ, and JM reviewed the final manuscript.

Conflicts of Interest
None declared.

Multimedia Appendix 1
The simulator sickness questionnaire.
[DOCX File, 244 KB-Multimedia Appendix 1]

Multimedia Appendix 2
Audio Trip virtual reality tutorial video.
[MP4 File (MP4 Video), 19379 KB-Multimedia Appendix 2]

References
1. Dunstan D, Howard B, Healy GN, Owen N. Too much sitting-a health hazard. Diabetes Res Clin Pract 2012 Sep;97(3):368-376. [doi: 10.1016/j.diabres.2012.05.020] [Medline: 22682948]
2. Grøntved A, Hu FB. Television viewing and risk of type 2 diabetes, cardiovascular disease, and all-cause mortality: a meta-analysis. JAMA 2011 Jun 15;305(23):2448-2455 [FREE Full text] [doi: 10.1001/jama.2011.812] [Medline: 21673296]
3. Thorp AA, Owen N, Neuhaus M, Dunstan DW. Sedentary behaviors and subsequent health outcomes in adults a systematic review of longitudinal studies, 1996-2011. Am J Prev Med 2011 Aug;41(2):207-215. [doi: 10.1016/j.amepre.2011.05.004] [Medline: 21767729]
4. Jezewska-Zychowicz M, Gębki J, Guzek D, Świątkowska M, Stangierska D, Plichta M, et al. The Associations between Dietary Patterns and Sedentary Behaviors in Polish Adults (LifeStyle Study). Nutrients 2018 Aug 01;10(8):1004 [FREE Full text] [doi: 10.3390/nu10081004] [Medline: 30071656]

5. Adamczyk J, Celka R, Splemplewski R, Ceynowa K, Kamińska P, Maciaszek J. The Impact of 12-Week Jaques-Dalcroze Eurhythms Programme on the Dynamic Agility in Single-Dual-Task Conditions in Older Women: A Randomized Controlled Trial. Biomed Res Int 2020 Jul 01;2020:9080697 [FREE Full text] [doi: 10.1155/2020/9080697] [Medline: 32714989]

6. Ratajczak M, Skrypnik D, Bogdański P, Mądry E, Walkowiak J, Szulińska M, et al. Effects of Endurance and Endurance-Strength Training on Endothelial Function in Women with Obesity: A Randomized Trial. Int J Environ Res Public Health 2019 Nov 05;16(21):4291 [FREE Full text] [doi: 10.3390/ijerph16214291] [Medline: 31694237]

7. Guidelines on physical activity, sedentary behaviour and sleep for children under 5 years of age. World Health Organization. 2019. URL: https://apps.who.int/iris/handle/10665/311664 [accessed 2020-12-12]

8. Althoff T, Sosić R, Hicks JL, King AC, Delp SL, Leskovec J. Large-scale physical activity data reveal worldwide activity inequality. Nature 2017 Jul 20;547(7663):336-339 [FREE Full text] [doi: 10.1038/nature23018] [Medline: 28693034]

9. UNESCO. Final report MINEPS VI. 2017 Presented at: International Conference of Ministers and Senior Officials Responsible for Physical Education and Sport, 6th, Kazan, Russian Federation, 2017; September; Kazan URL: https://unesdoc.unesco.org/ark:/48223/pf0000259362

10. DeVWolfe CEJ, Watt MC, Romero-Sanchiz P, Stewart SH. Gender differences in physical activity are partially explained by anxiety sensitivity in post-secondary students. J Am Coll Health 2020 Apr;68(3):219-222. [doi: 10.1080/07448481.2018.1549048] [Medline: 30645185]

11. Guthold R, Stevens GA, Riley LM, Bull FC. Worldwide trends in insufficient physical activity from 2001 to 2016: a pooled analysis of 358 population-based surveys with 1·9 million participants. Lancet Glob Health 2018 Oct;6(10):e1077-e1086 [FREE Full text] [doi: 10.1016/S2214-109X(18)30357-7] [Medline: 30193830]

12. Cam H, Nur N. A Study on the prevalence of Internet addiction and its association with psychopathological symptoms and obesity in adolescents. TAF Prev Med Bull 2015;14(3).181. [doi: 10.5455/pmh.201410033024]

13. Matsui H, Sugiura J, Kikkawa T. The Current Status of Japanese Game Players and Its Impact on the Society. Translational Systems Sciences 2022;73-89. [doi: 10.1007/978-981-19-0348-9_5]

14. Lopez-Fernandez O, Williams JA, Griffiths MD, Kuss DJ. Female Gaming, Gaming Addiction, and the Role of Women Within Gaming Culture: A Narrative Literature Review. Front Psychiatry 2019;10:454 [FREE Full text] [doi: 10.3389/fpsyt.2019.00454] [Medline: 31354536]

15. Mouatt B, Smith AE, Mellow ML, Parfitt G, Smith RT, Stanton TR. The use of virtual reality to influence engagement and enjoyment during exercise: A scoping review. Journal of Science and Medicine in Sport 2019 Oct;22:S98 [FREE Full text] [doi: 10.1016/j.jsmas.2019.08.124]

16. Slater M, Wilbur S. A Framework for Immersive Virtual Environments (FIVE): Speculations on the Role of Presence in Virtual Environments. Presence: Teleoperators & Virtual Environments 1997 Dec;6(6):603-616. [doi: 10.1162/pres.1997.6.6.603]

17. Lombard M. Direct Responses to People on the Screen: Television and Personal Space. Communication Research 2016 Jun 22;29(3):288-324. [doi: 10.1177/00936509156039002]

18. Lachlan K, Krcmar M. Experiencing Presence in Video Games: The Role of Presence Tendencies, Game Experience, Gender, and Time Spent in Play. Communication Research Reports 2011 Feb 02;28(1):27-31. [doi: 10.1177/009365095022003002]

19. Slater M, Steed A, McCarthy J, Maringelli F. The influence of body movement on subjective presence in virtual environments. Hum Factors 1998 Sep;40(3):469-477. [doi: 10.1518/001872098785991368] [Medline: 9849105]

20. Oh Y, Yang S. University of Wisconsin-Madison. 2010. URL: https://meaningfulplay.msu.edu/proceedings2010/mp2010_paper_63.pdf [accessed 2022-11-16]

21. Al Zayer M, Adhanom IB, MacNeillage P, Fonler E. The effect of field-of-view restriction on sex bias in VR sickness and spatial navigation performance. 2019 Presented at: CHI Conference on Human Factors in Computing Systems; May; Glasgow p. 1-12. [doi: 10.1145/3290605.3300584]

22. Gaggioli A. An Open Research Community for Studying Virtual Reality Experience. Cyberpsychology, Behavior, and Social Networking 2017 Feb;20(2):138-139. [doi: 10.1089/cyber.2017.29063.csi]

23. Grassini S, Laumann K. Are Modern Head-Mounted Displays Sexist? A Systematic Review on Gender Differences in HMD-Mediated Virtual Reality. Front Psychol 2020;11:1604 [FREE Full text] [doi: 10.3389/fpsyg.2020.01604] [Medline: 32903791]

24. Munafò J, Diedrick M, Stoffregen TA. The virtual reality head-mounted display Oculus Rift induces motion sickness and is sexist in its effects. Exp Brain Res 2017 Mar;235(3):889-901. [doi: 10.1007/s00221-016-4846-7] [Medline: 27915367]

25. Fedoroff B, Konstantinidis I, Frobose I. Effects of Full Body Exergaming in Virtual Reality on Cardiovascular and Muscular Parameters: Cross-Sectional Experiment. JMIR Serious Games 2019 Aug 28;7(3):e12324 [FREE Full text] [doi: 10.2196/12324] [Medline: 31464194]
26. Perrin T, Faure C, Nay K, Cattozzo G, Sorel A, Kulpa R, et al. Virtual Reality Gaming Elevates Heart Rate but Not Energy Expenditure Compared to Conventional Exercise in Adult Males. Int J Environ Res Public Health 2019 Nov 11;16(22):4406 [FREE Full text] [doi: 10.3390/ijerph16224406] [Medline: 31717971]

27. Xu W, Liang H, Baghaei N, Ma X, Yu K, Meng X, et al. Effects of an Immersive Virtual Reality Exergame on University Students' Anxiety, Depression, and Perceived Stress: Pilot Feasibility and Usability Study. JMIR Serious Games 2021 Nov 22;9(4):e29330 [FREE Full text] [doi: 10.2196/29330] [Medline: 34813487]

28. Audio Trip press kit. Andromeda Entertainment. URL: https://www.enterandromeda.com/press-kit [accessed 2020-12-12]

29. Walch M, Frommel J, Rogers K, Schüssel F, Hock P, Dobbelstein D, et al. Evaluating VR driving simulation from a player experience perspective. 2017 Presented at: The CHI Conference Extended Abstracts On Human Factors In Computing Systems; May 06-11; Denver, CO, USA p. 1-8. [doi: 10.1145/3027063.3053202]

30. Kennedy RS, Lane NE, Berbaum KS, Lilienthal MG. Simulator Sickness Questionnaire: An Enhanced Method for Quantifying Simulator Sickness. The International Journal of Aviation Psychology 2009 Nov 13:203-220 [FREE Full text] [doi: 10.1207/s15327108iap0303_3]

31. Biernacki MP, Kennedy RS, Dzida Ł. Simulator sickness and its measurement with Simulator Sickness Questionnaire. Medycyna Pracy 2016;67(4):545-555 [FREE Full text] [doi: 10.13075/mp.5893.00512]

32. Jennett C, Cox AL, Cairns P, Dhoparee S, Epps A, Tijs T, et al. Measuring and defining the experience of immersion in games. International Journal of Computer-Student Studies 2008 Sep;66(9):641-661. [doi: 10.1016/j.ielbsc.2008.04.004]

33. Strojny P, Strojny A. The Immersion Questionnaire: Polish adaptation and empirical verification of the scale. Homo Ludens. 2014. URL: https://www.researchgate.net/publication/276905865_The_Immersion_Questionnaire_-_Polish_adaptation_and_empirical_verification_of_the_scale [accessed 2022-11-16]

34. Michalidis L, Balagué-Ballester E, He X. Flow and Immersion in Video Games: The Aftermath of a Conceptual Challenge. Front Psychol 2018;9:1682 [FREE Full text] [doi: 10.3389/fpsyg.2018.01682] [Medline: 30233477]

35. Mochocki M. Heritage Sites and Video Games: Questions of Authenticity and Immersion. Games And Culture 2021;16(8):951-977 [FREE Full text] [doi: 10.1177/15544125211005369]

36. Škola F, Rizvić S, Cozza M, Barbieri L, Bruno F, Skarlatos D, et al. Virtual Reality with 360-Video Storytelling in Cultural Heritage: Study of Presence, Engagement, and Immersion. Sensors (Basel) 2020 Oct 16;20(20):5851 [FREE Full text] [doi: 10.3390/s20205851] [Medline: 33081154]

37. Xiaoping Fu J. The Influence of Background Music of Video Games on Immersion. J Psychol Psychother 2015;05:4 [FREE Full text] [doi: 10.4172/2161-0487.1000191]

38. Dužmarška N, Strojny P, Strojny A. Can Simulator Sickness Be Avoided? A Review on Temporal Aspects of Simulator Sickness. Front Psychol 2018;9:2132 [FREE Full text] [doi: 10.3389/fpsyg.2018.02132] [Medline: 30459688]

39. User manual. Zephyr BioHarness 3. URL: https://www.zephyryx.com/ [accessed 2021-12-12]

40. Richet X, Ruffier J. Faut-il avoir peur des usines chinoises? Comp Monit, 2011; 17(7): CR397-403. Med Sci Monit 2011 Sep;17(9):LE7-LE8. [doi: 10.12659/msm.881916]

41. Seebauer M, Sidler MA, Kohl J. Gender Differences in Workload Effect on Coordination between Breathing and Cycling. Perspect 2007 Sep 15;2007(3):3. [doi: 10.4000/chinaperspectives.2433]

42. Seebauer M, Sidler MA, Kohl J. Gender Differences in Workload Effect on Coordination between Breathing and Cycling. Medicine & Science in Sports & Exercise 2003;35(3):495-499. [doi: 10.1249/01.mss.0000053657.42138.34]

43. No Authors. Lung function testing: selection of reference values and interpretative strategies. American Thoracic Society. Am Rev Respir Dis 1991 Nov;144(5):1202-1218. [doi: 10.1164/ajrccm/144.5.1202] [Medline: 1952453]

44. Trinschek J, ZIELIŃSKI J, ŻARĘBSKA EA, KUSY K. Male and female athletes matched for maximum oxygen uptake per skeletal muscle mass: equal but still different. J Sports Med Phys Fitness 2022 Mar 01:1-5 [FREE Full text] [doi: 10.23736/S0022-4707.22.13605-4] [Medline: 35230070]

45. Boiten FA. The effects of emotional on components of the respiratory cycle. Biological Psychology 1998 Sep;49(1-2):29-51. [doi: 10.1016/s0301-0511(98)00025-8]

46. Telles S, Singh N. High frequency yoga breathing increases energy -expenditure from carbohydrates. Comment to: Assessment of sleep patterns, energy expenditure and circadian rhythms of skin temperature in patients with acute coronary syndrome Hadil Al-Otair, Mustafa Al-shamiri, Mohammed Bahobail, Munir M. Sharif, Ahmed S. BaHammam Med Sci Monit, 2011; 17(10): CR397-403. Med Sci Monit 2011 Sep;17(9):LE7-LE8. [doi: 10.12659/msm.881916] [Medline: 21873954]

47. Leister R, Jekač D. Students' Emotional Experience in Physical Education-A Qualitative Study for New Theoretical Insights. Sports (Basel) 2019 Jan 03;7(1):10 [FREE Full text] [doi: 10.3390/sports7010010] [Medline: 30609809]

48. Boyd D. Is the Oculus Rift sexist? Quartz. 2014 Mar 28. URL: http://qz.com/192874/is-the-oculus-rift-designed-to-be-sexist/ [accessed 2021-12-12]

49. Meulders A, Vansteenvenegen D, Vlaeyen JWS. Women, but not men, report increasingly more pain during repeated (un)predictable painful electrocutaneous stimulation: Evidence for mediation by fear of pain. Pain 2012 May;153(5):1030-1041. [doi: 10.1016/j.pain.2012.02.005] [Medline: 22401700]

50. Barsky AJ, Peekna HM, Borus JF. Somatic symptom reporting in women and men. J Gen Intern Med 2001 Apr;16(4):266-275 [FREE Full text] [Medline: 11318929]
50. Kourtesis P, Collina S, Doumas LAA, MacPherson SE. Technological Competence Is a Pre-condition for Effective Implementation of Virtual Reality Head Mounted Displays in Human Neuroscience: A Technological Review and Meta-Analysis. Front Hum Neurosci 2019;13:342 [FREE Full text] [doi: 10.3389/fnhum.2019.00342] [Medline: 31632256]

51. Giammarco EA, Schneider TJ, Carswell JJ, Knipe WS. Video game preferences and their relation to career interests. Personality and Individual Differences 2015 Jan;73:98-104. [doi: 10.1016/j.paid.2014.09.036]

52. Moss JD, Muth ER. Characteristics of head-mounted displays and their effects on simulator sickness. Hum Factors 2011 Jun;53(3):308-319. [doi: 10.1177/0018720811405196] [Medline: 21830515]

53. Szpak A, Michalski SC, Loetscher T. Exergaming With Beat Saber: An Investigation of Virtual Reality Aftereffects. J Med Internet Res 2020 Oct 23;22(10):e19840 [FREE Full text] [doi: 10.2196/19840] [Medline: 33095182]

54. Robergs R, Landwehr R. THE SURPRISING HISTORY OF THE “HRmax=220-age” EQUATION. J Exer Physiol Online 2002;5(2):1-10. [doi: 10.1163/2352-0272_emho_dum_023107]

Abbreviations

ANOVA: analysis of variance
HMD: head-mounted display
SSQ: Simulator Sickness Questionnaire
VR: virtual reality

©Julia Ciążyńska, Michał Janowski, Janusz Maciaszek. Originally published in JMIR Serious Games (https://games.jmir.org), 29.11.2022. This is an open-access article distributed under the terms of the Creative Commons Attribution License (https://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work, first published in JMIR Serious Games, is properly cited. The complete bibliographic information, a link to the original publication on https://games.jmir.org, as well as this copyright and license information must be included.