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Desktop vs. Headset: A Comparative Study of User Experience and Engagement for Flexibility Exercise in Virtual Reality

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Abstract

This study aimed to investigate the effectiveness of Virtual Reality (VR) technology for flexibility exercise and compare the physical outcomes, user experience, and engagement of VR desktops and VR headsets. The VR exercise application was designed using motion capture technology and exported to different VR devices. Each of the devices was used by 30 participants to perform a flexibility exercise in VR. Physical outcomes were measured using the sit-and-reach test, and user experience and engagement were evaluated using questionnaires and group discussions. The results showed that VR desktop participants had higher sit-and-reach scores. However, VR headset participants reported a more immersive experience (reality judgment) and motivation (value and usefulness). They also had higher engagement (focused attention and reward) levels than VR desktop participants. There were no significant differences between the two approaches in terms of enjoyment, effort, pressure, choice, correspondence, absorption, perceived usability, and aesthetic appeal. The study highlights the importance of considering physical outcomes, user experience, and engagement by comparing two different VR approaches for flexibility exercise. Further research is needed to explore the limitations and potential benefits of VR technology for physical activity.

Keywords:

Virtual Reality;

User Experience;

User Engagement;

Exercise; Exergame.

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1- Introduction

Virtual Reality (VR) is a computer-generated environment that can simulate real-world experiences [1]. With this capability, VR enables technology integration into exercise [2]. VR devices like head-mounted displays (VR headsets) and desktop displays (VR desktops) offer an immersive experience that can be used for exercise. Exercise through VR can provide users with a sense of presence in a virtual world [3, 4], making it an ideal tool for encouraging physical activity and improving health. Video game exercises, or exergames, are becoming increasingly popular for promoting physical activity and improving health and performance [5-8]. Exergames offer several advantages, including improved mobility [9, 10], muscular strength [11], balance control [12], and cognitive function [13, 14], which can encourage strategic exercise [15–17] and provide assessment, feedback, and skill practice [18]. Studies have shown that integrating VR into exercise can enhance the effectiveness and efficiency of physical activities and have attempted to compare it with traditional exercises in various aspects. However, previous studies have not adequately addressed the differences between VR headsets and VR desktops. First, there is a lack of a control group to evaluate the effect of physical outcomes between VR headsets compared to VR desktops. Second, the evaluation of the VR exercise application was primarily concerned with the physical outcomes but overlooked user experience (UX) and user engagement (UE) aspects.

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To address these gaps, this study aims to investigate the effectiveness of VR headsets compared to VR desktops in promoting VR exercise. The research question is: *To what extent can VR headsets make exercise more effective than VR desktops?* The study involved participants who used either a VR headset or a VR desktop to exercise using an exercise application with a virtual trainer. The study compared exercise results and user experiences between the two groups. The study's findings can guide the development of VR exercise programs to optimize their effectiveness, regardless of whether a VR headset or VR desktop is used. This study contributes to the research on exergames and their potential to encourage physical activity, providing insights that can benefit VR exercise developers to improve their application and performance.

The following section reviews the existing literature on VR exercise applications and highlights the research question. Section 3 describes the research methodology. Section 4 proposes the empirical study, including the data collected and hypotheses. Section 5 presents the results and significant differences between the VR desktop and the VR headset. Section 6 provides a detailed discussion and compares the findings of this study with those of previous studies. The final section of the paper presents the conclusion of the study.

2- Literature Review

In this section, we reviewed the literature on the different types of exercise and the application of VR technology to exercise. Moreover, we examined the effect of VR displays on user immersion, motivation, and physical outcomes. Then, we explored the evaluation of VR exercise applications, which is applicable to this investigation.

2-1- VR Exercise

When considering exercise or sport-related tasks, it is possible to categorize them into four categories: aerobic, strength, balance, and flexibility [19, 20]. Aerobic activities, such as walking, jogging, swimming, bicycling, and dancing, are essential for developing and maintaining cardio endurance [21, 22]. Strength conditioning exercises develop bone strength, muscular strength, and connective tissue. Strengthening improves force development, power, jumping, sprinting, direction changes, potentiation, and running [23]. Balance training, such as yoga poses, can increase the body's capacity to maintain its upright position, especially the legs and core [24]. The body's balance facilitates movement and prevents injury [25]. Flexibility training is activities that extend and stretch muscles or functional abilities, such as reaching, bending, and stooping, contributing to flexibility [26].

Previous studies have examined the use of VR technology in various exercise categories. In the category of aerobic exercises, researchers have explored the effectiveness of VR for activities such as cycling, rowing, and running [27-29]. Studies have shown that VR can simulate outdoor environments and provide a more engaging and enjoyable experience [30, 31], improving motivation and adherence [32, 33] to the exercise program. However, many aerobic exercises in VR require additional equipment [18], such as treadmills or stationary bikes, which can be expensive and take up space.

In strength training, researchers have investigated the use of VR for resistance exercises, such as weightlifting [34], and found that VR can provide a more varied and engaging workout experience and also provide real-time feedback on form and technique, which can help individuals avoid injury and optimize their performance [35]. Balance training using VR technology has also been investigated, with studies examining the effects of VR on postural stability and proprioception [36-40]. VR can provide a safe and controlled environment for balance exercises and offer users real-time feedback, improving their ability to maintain balance. However, many studies on VR balance training focus on the elderly [36] because this training has traditionally been considered a form of rehabilitation.

While there are many studies on the effectiveness of VR exercise for aerobic activities with additional equipment and balance activities in the elderly, there is a lack of research on using VR for flexibility exercises. Ultimately, flexibility is needed for stretching and range-of-motion exercises [41]. This exercise does not require additional equipment and requires less movement than other exercises. Therefore, it is suitable for exercising if having to use a VR device while exercising. However, there needs to be more comparison between VR display technologies, particularly between VR desktops and VR headsets. This comparison supports us in understanding which display technology may be more effective in enhancing user experience and engagement for flexibility exercises. Additionally, there is a need to investigate the factors that make VR-based exercises effective and how they can be optimized to promote physical activity and health outcomes.

2-2- VR Desktops and VR Headsets

VR desktops and VR headsets are the two most popular devices currently being used. While there are many benefits associated with using these technologies, there are also several restrictions and drawbacks that must be considered.

When using a VR desktop, the user typically interacts with a virtual environment displayed on a traditional computer monitor, TV, or projection system. In order to interact with the virtual environment, the user may use a variety of input devices, such as a keyboard or mouse [42]. The user remains seated in a stationary position while interacting with the virtual environment, and the virtual environment is typically displayed on a 2D screen, although some specialized VR displays can provide a more immersive 3D experience. In addition, VR desktop offers a more streamlined and immersive computer interface that can enhance productivity, reduce distractions, and provide a more natural way to interact with technology. By eliminating the need for multiple devices and allowing users to work in a stationary position, VR desktop can be a valuable tool for those with limited space or mobility issues. Overall, these advantages make VR desktops an innovative and useful alternative to traditional computer interfaces [43].

On the other hand, when using a VR headset, the user wears a special head-mounted display that fills the user's entire field of vision and gives them a very immersive 3D experience [44]. The user may also use specialized input devices, such as handheld controllers, to interact with the virtual environment. Unlike with a VR desktop, the user can move around in physical space while interacting with the virtual environment, and the virtual environment is displayed in stereoscopic 3D, which creates a greater sense of depth and realism. For example, the study of using VR in medical education as an additional tool for training professional skills. A simulator for dental students was developed for tooth drilling, which helps develop motor skills and hand-eye coordination. The simulator was developed for the Oculus Quest 2 VR headset with the Marching Cubes algorithm. The VR scene was piloted at the university, and a satisfaction questionnaire was used to evaluate the realism of the tooth 3D model drilling and the VR scene's creation of a dentist's office atmosphere. The study found that training with simulators improved fine motor skills and hand-eye coordination for dentists and surgeons in pre-clinical conditions [45].

In terms of user experience, the use of a VR headset could be more immersive and engaging compared to a VR desktop, as the user is fully immersed in the virtual environment and can move around in physical space to interact with virtual objects [46]. However, the use of a VR headset can also be more physically demanding, as the user may need to move around and perform physical actions and may experience motion sickness or other physical discomfort due to the highly immersive nature of the experience [47].

In assessing the effectiveness and possible uses of VR desktops and headsets, it is crucial to consider factors such as physical outcomes, user experience, and engagement. Therefore, it is necessary to conduct research to gain a thorough understanding of the physical and psychological impacts of VR technology, as well as how to enhance its design and implementation to encourage user engagement.

2-3- User Experience and Engagement

VR is a technology that has the potential to improve UX significantly [48] and UE [49]. Although many have used UX and UE interchangeably, both phrases are distinct. UX refers to the usability aspects during interaction with a digital application that involves perception and responses [50, 51] described that UX is a two-focus dimension representation that involves fundamental interaction elements (user, system, context) and experience typologies (ergonomic, cognitive, and emotional). Popular methods used to study UX include UEQ, meCUE, and attrakDiff [52].

UX is defined as the overall experience a user has while interacting with a product or system. In VR exercise, UX is an essential factor that influences the user's engagement, motivation, and enjoyment. For example, a study of UX conducted by Ijaz et al. [53] investigated motivation and engagement in immersive VR exergames. The study evaluated two different VR environments and found that personalized environments are crucial for motivating users with different needs and expectations. It also identified two typical groups, characterized as exercise-focused and entertainment-focused, who experienced the immersive experience differently due to differences in expectations from a VR exercise session. Moreover, the results of a study on the effects of virtual reality on VR sickness and user experience. Participants watched two different panoramic videos on four different head-mounted displays and a 2D television. The simulator sickness and UX questionnaires were used to assess discomfort levels and experience. They found a strong correlation between VR sickness discomfort levels and negative experiences. The results showed that the presence of VR sickness symptoms affects the overall experience [54]

UE refers to the degree of involvement and interaction a user has with a system or product. In VR exercise, UE plays a crucial role in promoting physical activity and achieving fitness goals. For example, a study by Pyae [55] explored the potential benefits of VR-based exercises for promoting physical and cognitive well-being. A two-week survey study was conducted to assess UE and enjoyment in VR exercises. The study found that users were more engaged and enjoyed VR exercises more than conventional exercises. These preliminary findings suggested that VR exercises had the potential to be a useful and enjoyable alternative to conventional exercises for users. Furthermore, a study was conducted to investigate the feasibility of using immersive VR as a tool to support physical activity for people living with dementia. The researchers designed two VR environments to support upper-body exercises and tested them with six participants living with dementia. The results showed that VR exercises were comparable to human-guided exercises in terms of motion and fitness parameters, and the participants reported feelings of enjoyment, engagement, interest, easiness, comfort, and level of effort. The researchers suggested that head-mounted VR has promising potential to support physical activity for people living with dementia [56-58].

Due to the complex nature and nature of UX and UE, evaluation with VR is very challenging. Nonetheless, comprehending these two fundamental features of VR technology was enlightening. UX and UE are two ideas used to create interactive systems that are inextricably linked. UX places high value on the experiencing side of human-computer interaction, which encompasses a wide range of emotional responses, with engagement being a crucial characteristic. On the other hand, UE refers to the adhesiveness of users with an application gained from good experience.

In conclusion, both UE and UX are crucial factors to consider when evaluating the effectiveness of using VR exercises. Positive UX and UE can enhance user motivation, enjoyment, and adherence to the exercise program, while negative UX and UE can lead to decreased adherence and lower effectiveness. Measuring UX and UE can also identify areas for improvement in VR exercise systems, ultimately improving the effectiveness of the exercise program. Therefore, evaluating UX and UE in VR exercise is essential to ensure a positive experience and optimize the effectiveness of the exercise.

3- Research Methodology

In this section, we introduce questionnaires and interviews, then describe how the investigations were carried out. Following that, we describe how the VR application was designed to apply a flexibility exercise for use in the research framework.

3-1- Questionnaires and Interviews

Two study approaches – questionnaire and group discussion – were applied to evaluate the user experience of the VR application. Before interacting with the VR application, participants were required to complete the following two questionnaires:

- The Exercise Thoughts Questionnaire (ETQ) [59] measures the frequency of exercise-avoidant thoughts using 25 statements about an individual's exercise-related thoughts. Responses are provided on a five-point scale ranging from 1 = not at all to 5 = all of the time. The sum of the scores indicates the frequency of exercise avoidance thoughts. The ETQ can help identify potential barriers to exercise and negative thoughts that participants may have before joining the VR exercise. For instance, if participants' ETQ scores indicate that they have negative automatic thoughts related to exercise, we may investigate whether using VR can help replace these thoughts with more positive ones and lead to a more positive exercise experience.
- The Immersive Tendencies Questionnaire (ITQ) [60] measures how immersed participants can become in everyday activities. The 18-item questionnaire is measured on a seven-point scale that varies depending on the question, such as 1 = never to 7 = often, or 1 = not at all to 7 = very well. The ITQ can be used to identify participants who are more likely to become fully engaged and immersed in the VR exercise. By identifying participants with high immersive tendencies, we can explore whether these individuals have a more positive experience and better outcomes with VR exercise.

After interacting with the VR application, participants were asked to complete the following questionnaires.

- The Post-Experimental Intrinsic Motivation Inventory (IMI) [61], which assessed participant motivation throughout the exercise task. The IMI has seven potential subscales, but only two were used: effort/importance and perceived pressure/tension. Out of this, the scale contained ten first-person statements that participants scored from 1 = not true at all to 7 = very true. The IMI can be used to understand how VR affects participants' intrinsic motivation to engage in exercise. By measuring the different subscales of intrinsic motivation, such as interest/enjoyment and perceived competence, we can gain insight into which aspects of the VR experience are motivating for participants. This information can be used to optimize the design and implementation of VR exercises.
- The Reality Judgment and Presence Questionnaire (RJPQ) [62] analyzed the participant's perception of the realism of the VR environment. On a 10-point scale ranging from 0 (not at all) to 10 (extremely), the 16-item questionnaire was scored (absolutely). The RJPQ is divided into three subscales: reality judgment, internal/external correspondence, and attention/absorption. The RJPQ is useful in measuring the sense of presence or the feeling of "being there" in virtual environments. It is important to assess how the participants perceive the virtual environment, how immersive they find it, and whether they feel like they are really present in the environment.
- The 12-item of User Engagement Scale-Short Form (UES-SF) [63] represents four dimensions of engagement: focused attention (FA), perceived usability (PU), aesthetic appeal (AE), and reward (RW). The UES-SF was found to have strong psychometric properties [64]; this property, associated with the instrument's relevance to our research topic, justifies our selection of this instrument for our empirical study. The UES-SF is an important tool for studying the effectiveness of using VR in flexible exercise after participants join the VR exercise. It measures user engagement and identifies areas for improvement in the VR exercise. By analysing the results, we can identify which aspects of the VR experience were engaging for participants and which need improvement.

Afterward, semi-structured interviews (group discussion) were undertaken to get additional information regarding user experience. Both the questionnaire and interview took roughly ten minutes to complete on average.

3-2- Research Framework

As stated in the introduction, this study aimed to evaluate the effectiveness of a VR application for supporting individuals in performing flexibility exercises. Figure 1 shows a diagram of the methodology framework. As a result, the research methodology was carried out. It was developed using the Human-centred design (HCD) (ISO9241-210:2019) approach [63], which involved users and an exercise trainer, who were critical stakeholders in the intervention throughout the development process to understand their needs and desires. The phases of the HCD design were listed as follows:

- Expert Interview: Interview the trainers to understand how they train flexibility exercises.
- Specify the context of use: Studying the situation in which the VR application would be used. Understanding the scenario in which participants were using the VR for flexibility training.
- Specify requirement: Identifying user needs that must be satisfied for the VR to benefit.
- Produce design solution: The VR was carried out during this phase. It was constructed from a conceptual idea to a final product: the VR interface was included in the application design and how users interacted with the VR.
- Evaluate designs: the VR was evaluated with users in the context and used the identified requirements to see how well the design responded. Interviews with trainers were also conducted to evaluate their intention to use VR to train users on flexibility exercises.

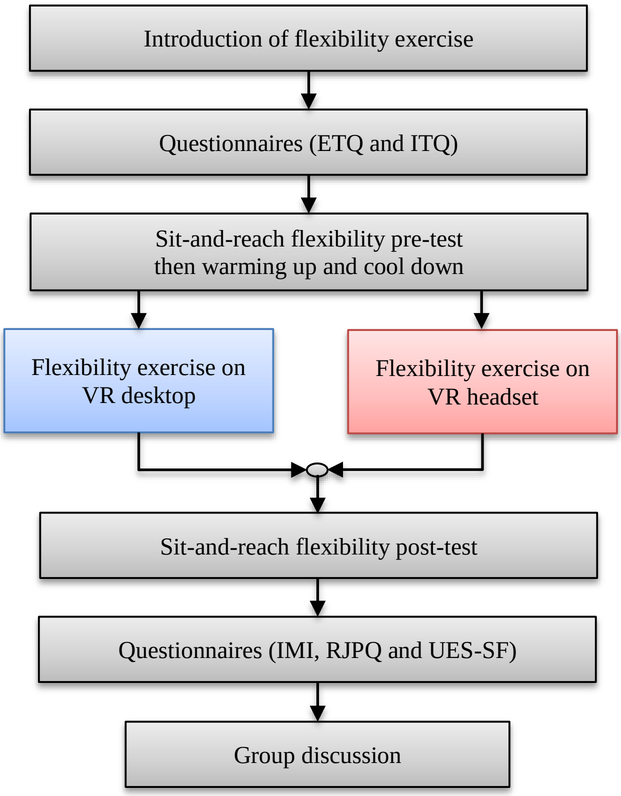

Figure 1. The research methodology and framework

The between-subject approach was used in the experimental design. The two independent variables (IVs) were physical outcomes, which were measured using the flexibility exercise test (i.e., the sit-and-reach [64, 65] pre-test and post-test), user experience, which were measured using the IMI and RJPQ, and the standardized UES-SF questionnaire. Participants were recruited and randomly assigned to one of two groups, each subjected to a different condition. Using the VR desktop approach was evaluated in comparison to the use of the VR headset approach.

3-3- Development of the VR Application

In this section, we presented the development of the VR exercise application. The lunge twist was chosen as the exercise post for this experiment, which can be a useful tool for this study investigating the impact of VR headsets, as it provides a standardized and controlled way to assess user experience and engagement during a dynamic activity that simulates some of the movements involved in virtual reality experiences. In the development, we employed an exercise trainer with the ability and expertise to perform the lunge twist as a model for capturing poses. We provided the VR application with 3D avatars performing exercise posture animations and exported them to different devices. The transformation of exercise trainer poses into 3D animation required accuracy and precision. Then motion capture with a very precise motion detection technology for sports [66] was used to detect and transform motion into 3D animation.

Motion capture technology is used in medical rehabilitation, sports kinematics, and film special effects to record physical and kinetic characteristics [67]. This technology collects kinematic and kinetic data by attaching markers to each body position and recording movements. We used the motion capture technology (Motion Analysis) consisting of 8 Raptor-4 cameras [68] and 8 Eagle Digital cameras [69] with a resolution of 1280×1024 pixels with a frame rate of 500 Hz. The motion capture system monitors the three-dimensional position with the 43 passive markers.

The trainer wore the Motion Capture Suit with 43 markers to detect and record the trainer's exercise postures throughout one set of lunge twists (Figure 2). All movements were recorded in a three-dimensional point cloud data and cleaned using the Cortex Motion Analysis Software. After that, the .trc file was imported into the Motion Builder Software for actor mapping, retargeting, and editing procedures with the selected 3D avatar. Then exercise poses from the trainer were transformed into the virtual avatar (Figure 3). The complete avatar with animation was loaded into the Unity3D Game Engine to develop an exercise application. The application was exported into two display devices: the VR desktop connected to the television (TV) and the VR headset with the HMD device.

Figure 2. **The sport trainer on the Motion Capture Suit during recording**

Figure 3. **The trainer avatar in the VR exercise application**

4- Empirical Study

This section presented a study protocol that includes procedures from the beginning until the interview. The participants who met the inclusion criteria are then outlined, followed by the hypotheses.

4-1- Procedures

The exercise processes on the VR desktop and VR headset approaches were the same but with different visualization. The total time required for each experiment was approximately 27 minutes. The experiment began with an explanation of the procedure and the registration of a consent form. After informed consent, participants were asked to scan a QR code to complete a Google form with primary personal data collection and the pre-test questionnaires. After completing the questionnaires, the body's flexibility was assessed using the sit-and-reach method [70], and the result was recorded in centimeters.

Then the participant warm-up the body with six specified postures (jogging, front kicking, back kicking, arms stretch and full, foot touching, and knee lifting). During the relaxation period following the completion of the warm-up, the correct lunge twist is explained. The experiment was initiated. In the VR desktop approach, participants were positioned approximately 2 meters away from the TV screen (Figure 4). For the VR headset approach (Figure 5), participants must wear an HMD device (Oculus Quest 2 [71]). Both groups performed 12 sets of the same lunge twists, which were used for flexibility testing as recommended by trainers in the field. This number of sets was chosen as it provides a sufficient sample size to evaluate the testing and minimize the effects of individual variability. After completing all tasks, sit-and-reach was tested (Figure 6), and the data was recorded again. After getting a water break, the participant scanned a QR code to complete the post-test questionnaire. A group discussion regarding the user experience follows. In Table 1, every procedure detail was presented.

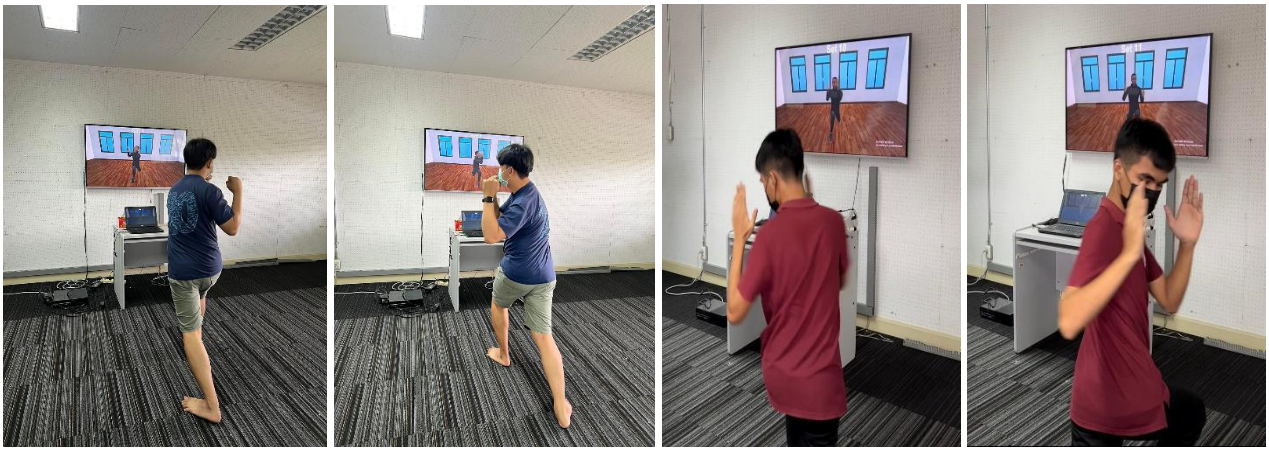

Figure 4. Participants during performing an exercise with a virtual trainer using the VR desktop approach.

Figure 5. Participants during performing an exercise with a virtual trainer using the VR headset approach (casting the VR headset to a TV allows researchers to observe what participants see in VR)

Figure 6. The sit-and-reach flexibility test for pre-test and post-test after the VR exercise

Table 1. The experiment procedures

No.	Tasks	Descriptions	Duration
1.	Introduction	Explanation of each process in the experiment and sign the consent form.	1 min
2.	Pre-test questionnaire	Collecting personal information such as age, gender, weight, and height and doing pre-test questionnaires ETQ and ITQ.	5 mins
3.	Sit-and-reach pre-test	A standard measure of flexibility, the score is recorded to the nearest centimetre as the distance reached by the hand.	30 seconds
4.	Warming up	Warming up with six poses: jogging, front kicking, arms stretch and full, foot touching, knee lifting, and back kicking. 30 times or 1 minute for each pose.	6 mins
5.	Cool down and lunge twist presentation	Cool down after warming up, and explain step by step to do the lunge twist pose with the application. There are 12 sets of the lunge twist pose to do.	1 min
6.	Start application	There was an introduction about the lunge twist pose and counting down 3 seconds before starting. Then, exercise with a virtual trainer in a virtual gym.	2 mins 30 seconds
7.	Lunge twist set 1-2	Beginning set 1 with the slower speed.	-
9.	Lunge twist set 3-12	Continue to set 3-12 with average speed.	-
10.	Sit-and-reach post-test	The sit-and-reach testing again after exercise.	30 seconds
11.	Cool down and drinking	Give drinking water and pause for a moment.	1 min
12.	Post-test questionnaire	Doing post-test questionnaires about feeling after exercise: IMI, RJPQ, and UES-SF.	5 mins
13.	Interview	Interviews about the VR experience.	5 mins

4-2- Participants

Walailak University's Ethics Review Committee approved the empirical inquiry with approval number WUEC-20-191-01. The experiment was conducted on the university campus, announcing volunteers via social media. Participants with no medical contraindications to exercise were invited. There were 60 participants aged 18 to 26 years old involved in the study, divided into two independent groups randomly chosen by their preferred. The first group consisted of 30 participants who exercised with the VR desktop and visualization on TV (16 males, 14 females; average age: 20.63). The second group consisted of 30 participants who exercised with immersive visualization on the VR headset (19 males, 11 females; average age: 20.10). Only data from participants who completed all tasks, including the pre-and post-questionnaires and exercise tests were collected.

4-3- Hypotheses

The data gathered in this study was used to analyze the research model (Figure 7) and to verify the three associated hypotheses (H) regarding physical outcomes, user experience, and user engagement.

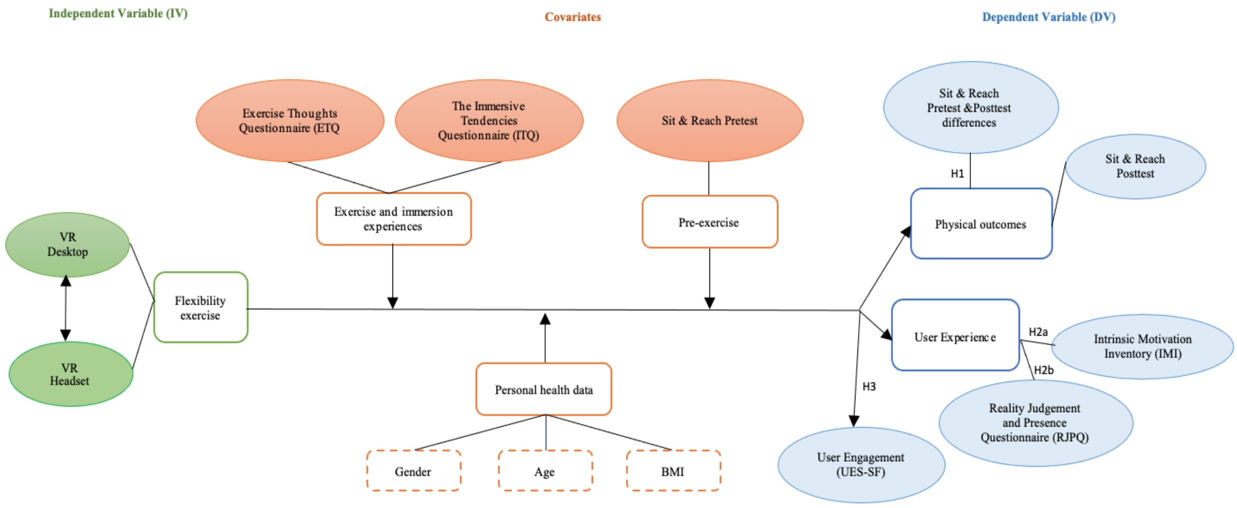

Figure 7. The diagram of the research model with the hypotheses

The primary assumption supporting the hypothesis is whether the VR headset approach enables participants to perform the flexible exercise more effectively than the VR desktop approach. The following hypotheses are formulated as null hypotheses that assume that all statistical tests are $p = 0.05$, evaluated with the empirical data collected.

H1: There is no statistically significant difference in physical outcomes (sit-and-reach scores) between the VR desktop and the VR headset approaches.

H2: There is no statistically significant difference in user experience between the VR desktop and the VR headset approaches.

H2a: There is no statistically significant difference in IMI scores between the VR desktop and the VR headset approaches.

H2b: There is no statistically significant difference in RJPQ scores between the VR desktop and the VR headset approaches.

H3: There is no statistically significant difference in user engagement (UES-SF scores) between the VR desktop and the VR headset approaches

5- Results

In this section, Table 2 shows the descriptive statistics of age, weight, height, and BMI of the participants. The mean and standard deviation values for each variable were reported. To assess the normality of the data, the Shapiro-Wilk Test was used, which is a statistical test that checks if the data are normally distributed. The results of the Shapiro-Wilk Test showed that the data, including all questionnaire results, were not normally distributed. As a result, non-parametric statistical Mann-Whitney U Test was used for hypothesis testing to analyze non-normally distributed data. The participants in the VR desktop and VR headset approaches were not significantly different in BMI (p=0.9442>0.05). Moreover, the results of the sit-and-reach pre-test of the two groups were not different (p=0.45326>0.05) as shown in Table 5. In addition, the results showed that there were no significant differences in the ETQ scores (p=0.45326>0.05) and ITQ scores (p=0.56192>0.05) between the VR desktop and VR headset groups. It showed that the two random groups were not different in the experiment, indicating that the two groups had similar exercise thoughts and immersive tendencies (See Tables 3 to 4).

Table 2. The personal data of VR desktop and VR headset participants

	VR desktop	VR headset	*p*-value
Number of participants	30	30	-
Age	20.63	20.10	-
Weight	67.7 kg.	65.5 kg.	-
Height	168.93 cm.	167.7 cm.	-
BMI	23.5 kg/m^2	23.2 kg/m^2	0.9442

Table 3. The average and standard deviation results of the ETQ questionnaire (5-point Likert Scales)

Question	VR desktop		VR headset	
	Mean	SD.	Mean	SD.
1. I am too tried to exercise.	2.67	1.269	2.77	1.305
2. I need to sleep	3.80	1.186	3.40	1.037
3. I would rather get some sleep.	3.67	1.093	3.47	0.900
4. There are more important things I have to do.	3.47	1.196	3.00	0.830
5. I am too busy.	3.10	1.155	2.80	1.064
6. I have not got time.	2.97	1.299	2.43	1.073
7. It's not that important right now.	2.17	1.289	2.17	1.315
8. I would rather relax.	3.50	0.861	3.60	0.814
9. I would rather watch TV.	2.33	1.446	2.47	1.167
10. I would rather socialize.	2.73	1.081	2.77	0.858
11. I would rather do something else.	3.07	1.230	2.83	1.289
12. I have social obligations.	2.37	1.159	2.07	0.944
13. I don't feel good enough to exercise.	2.37	1.326	2.53	1.432
14. Exercising will only make me more tired.	2.07	1.112	2.23	1.223
15. It will talk a lot of energy.	3.50	1.042	3.93	1.015
16. It will take too long.	2.40	1.070	2.40	0.814
17. I am just not motivated enough to exercise.	3.17	1.533	2.63	1.520
18. I don't feel like exercise.	2.17	1.234	2.47	1.332
19. I will make it up later.	3.17	1.289	3.13	1.224
20. I will do it tomorrow.	2.70	1.291	2.67	1.373
21. I will do it later.	2.90	1.062	2.60	1.037
22. I will work out extra hard tomorrow.	1.80	1.031	1.93	1.143
23. I will cut down on eating instead.	2.23	1.278	2.27	1.258
24. Missing one day won't make that much of a difference.	3.10	1.348	3.13	1.279
25. I can afford to miss one day.	3.83	1.392	3.87	1.332

Table 4. The average and standard deviation results of the ITQ questionnaire (7-point Likert Scales)

Question	VR desktop		VR headset	
	Mean	**SD.**	**Mean**	**SD.**
1. Do you easily become deeply involved in movies or tv dramas?	5.67	1.028	5.77	1.104
2. Do you ever become so involved in a television program or book that people have problems getting your attention?	3.50	1.717	3.47	1.776
3. How mentally alert do you feel at the present time?	5.20	1.270	5.40	1.276
4. Do you ever become so involved in a movie that you are not aware of things happening around you?	4.87	1.332	4.87	1.432
5. How frequently do you find yourself closely identifying with the characters in a story line?	4.30	1.055	4.27	1.015
6. Do you ever become so involved in a video game that it is as if you are inside the game rather than moving a joystick and watching the screen?	4.27	1.874	4.13	1.978
7. How physically fit do you feel today?	4.07	1.874	4.10	2.006
8. How good are you at blocking out external distractions when you are involved in something?	5.43	0.728	5.10	1.185
9. When watching sports, do you ever become so involved in the game that you react as if you were one of the players?	3.27	1.437	3.33	1.422
10. Do you ever become so involved in a daydream that you are not aware of things happening around you?	4.00	1.486	3.73	1.507
11. Do you ever have dreams that are so real that you feel disoriented when you awake?	4.87	1.456	4.53	1.655
12. When playing sports, do you become so involved in the game that you lose track of time?	3.40	1.831	3.17	1.859
13. How well do you concentrate on enjoyable activities?	5.27	0.691	4.93	1.081
14. How often do you play arcade or video games? (OFTEN should be taken to mean every day or every two days, on average).	4.33	1.900	4.30	2.087
15. Have you ever gotten excited during a chase or fight scene on TV or in the movies?	5.63	1.245	5.57	1.406
16. Have you ever gotten scared by something happening on a TV show or in a movie?	5.57	0.935	5.53	0.973
17. Have you ever remained apprehensive or fearful long after watching a scary movie?	5.40	1.476	5.30	1.442
18. Do you ever become so involved in doing something that you lose all track of time?	5.53	1.676	5.07	1.911

5-1- Sit-and-Reach Results

The statistical results from the sit-and-reach pre-test and post-test were shown in Table 5. The table showed the results of the sit-and-reach testing for the VR desktop and VR headset approaches, including the pre-test and post-test means and standard deviations. The *p*-values for the two groups were also shown. The physical outcomes were calculated by subtracting the pre-test score from the post-test score. The results indicated that there was no significant difference between the pre-test ($p=0.45326>0.05$) and post-test ($p=0.85716>0.05$) scores for both groups. However, when considering the physical outcomes, there was a significant difference between the two groups ($*p=0.03<0.05$), suggesting that the VR desktop approach may have had a greater improvement in flexibility compared to the VR headset approach.

Table 5. Results of sit-and-reach testing on VR desktop and VR headset approaches

Sit-and-reach testing (CM)		VR desktop	VR headset	*p*-value
Pre-test	Mean	1.07	2.53	0.45326
	SD.	7.629	6.678	
Post-test	Mean	6.53	6.77	0.85716
	SD.	7.291	5.063	
Physical outcomes (post-test – pre-test)	Mean	5.47	4.23	0.03*
	SD.	3.093	2.501	

(sig. * $p<0.05$, ** $p<0.01$)

5-2- Users Self-Report Results

All participants in the VR desktop and VR headset approaches completed the questionnaires on the user experience and engagement in the VR exercise application. The mean and standard deviation results and details of each questionnaire are shown in Tables 6 to 8, while the line graph of the average is in Figures 8 to 10. The Mann-Whitney U test results of all user experience and engagement scores between the two groups are shown in Tables 9 to 11. The results indicated significant differences between the VR desktop and VR headset approaches regarding user experience and engagement.

Table 6. The average and standard deviation results of the IMI questionnaire (7-point Likert Scales)

	Question	VR desktop		VR headset	
		Mean	SD.	Mean	SD.
IMI-IE: Interest/enjoyment	IE-1. I enjoyed doing this activity very much	5.50	0.900	5.57	1.357
	IE-2. This activity was fun to do.	5.57	0.898	5.72	1.327
	IE-3. I thought this was a boring activity. (R)	6.00	0.910	5.82	1.544
	IE-4. I would describe this activity as very interesting.	5.90	0.803	5.88	1.344
	IE-5. I thought this activity was quite enjoyable.	5.83	0.834	5.88	1.301
	IE-6. While I was doing this activity, I was thinking about how much I enjoyed it.	5.07	1.202	5.84	1.374
	IE-7. This activity did not hold my attention at all. (R)	6.20	1.186	5.62	1.711
IMI-EF: Effort	EF-1. I put a lot of effort into this.	5.90	0.759	5.80	1.344
	EF-2. I tried very hard on this activity.	4.83	1.577	4.94	1.444
	EF-3. It was important to me to do well at this task.	6.10	0.960	5.69	1.393
	EF-4. I did not try very hard to do well at this activity. (R)	5.33	1.516	4.88	1.991
	EF-5. I did not put much energy into this. (R)	5.80	0.925	5.62	1.548
IMI-PT: Pressure/tension	PT-1. I did not feel nervous at all while doing this. (R)	2.47	1.279	2.24	1.137
	PT-2. I was very relaxed in doing these. (R)	2.27	0.944	1.88	1.140
	PT-3. I was anxious while working on this task.	2.63	1.450	1.85	1.152
	PT-4. I felt very tense while doing this activity.	1.83	0.913	2.78	2.082
IMI-CH: Choice	CH-1. I believe I had some choice about doing this activity.	5.13	1.570	5.34	1.485
	CH-2. I felt like it was not my own choice to do this task. (R)	6.00	1.114	4.79	1.975
	CH-3. I did not really have a choice about doing this task. (R)	6.07	1.015	5.54	1.583
	CH-4. I felt like I had to do this. (R)	4.60	1.429	4.40	1.761
	CH-5. I did this activity because I wanted to.	6.00	0.910	6.17	1.414
	CH-6. I did this activity because I had no choice. (R)	5.60	1.163	5.90	1.511
	CH-7. I did this activity because I had to. (R)	5.40	1.380	5.09	2.141
IMI-VU: Value/usefulness	VU-1. I believe this activity could be of some value to me.	5.97	1.098	6.24	1.305
	VU-2. I think that doing this activity is useful.	6.17	0.913	6.43	1.303
	VU-3. I think this is important to do.	5.23	1.736	5.70	1.541
	VU-4. I would be willing to do this again because it has some value to me.	5.87	1.106	6.43	1.302
	VU-5. I think doing this activity could help me.	5.87	0.900	6.32	1.318
	VU-6. I believe doing this activity could be beneficial to me.	5.87	0.973	6.31	1.289
	VU-7. I think this is an important activity.	5.73	1.143	6.16	1.308

Table 7. The average and standard deviation results of the RJPQ questionnaire (10-point Likert Scales)

	Question	VR desktop		VR headset	
		Mean	SD.	Mean	SD.
RJPQ-RJ: Reality judgment	RJPQ-18. To what extent did the experience seem real to you?	7.60	1.653	7.27	2.273
	RJPQ-11. In your opinion, how was the quality of the images in the virtual world?	6.67	1.647	7.47	2.255
	RJPQ-2. To what extent was what you saw in the virtual world similar to reality?	6.67	1.605	6.67	2.454
	RJPQ-37. How real did the virtual objects seem to you?	6.33	1.688	6.93	2.545
	RJPQ-38. To what extent was what you experienced in the virtual world congruent to other experiences in the real world?	6.67	1.768	7.80	2.107
	RJPQ-17. To what extent did you feel you "went into" the virtual world?	7.00	1.576	7.60	2.253
	RJPQ-32. To what extent did your interactions with the virtual world seem natural to you, like those in the real world?	6.73	1.413	7.13	2.751
	RJPQ-9. To what extent did you feel you "were" physically in the virtual world?	6.27	1.911	7.80	2.929

RJPQ-IC: Internal/external-correspondence	RJPQ-40. To what extent could you move around the virtual world?	6.50	1.978	7.03	2.327
	RJPQ-60. To what extent were the events in the virtual world congruent to your actions?	6.63	1.938	6.73	2.243
	RJPQ-36. To what extent could you interact with the virtual world?	6.70	2.037	6.33	2.771
	RJPQ-21. To what extent did the virtual world respond to your actions?	6.73	1.799	6.70	2.322
	RJPQ-54. To what extent did your actions produce changes in the virtual world?	6.33	2.218	6.43	2.569
	RJPQ-56. To what extent were you yourself while experiencing the virtual environment?	6.17	2.151	7.07	3.140
RJPQ-AA: Attention/absorption	RJPQ-61. To what extent did you feel it was necessary to devote all your attention to what you were doing in the virtual world?	7.60	1.545	6.83	2.914
	RJPQ-30. To what extent did you feel like you “went into” the virtual world and you almost forgot about the world outside?	5.47	2.675	6.30	2.781
	RJPQ-48. To what extent did you have to pay excessive attention to what was going on in the virtual world?	7.47	1.871	7.67	2.023
	RJPQ-70. To what extent did you forget you were in a room wearing a helmet?	5.20	2.905	6.53	2.700

Table 8. The average and standard deviation results of the UES-SF questionnaire (5-point Likert Scales)

Question		VR desktop		VR headset	
		Mean	SD.	Mean	SD.
UES-FA: focused attention	FA-1. I lost myself in this experience	3.30	0.988	3.47	0.730
	FA-2. The time I spent using this VR just slipped away	3.37	0.850	3.87	0.819
	FA-3. I was absorbed in this experience	3.53	0.819	4.33	0.606
UES-PU: perceived usability	PU-1. I felt frustrated while using this VR	2.17	1.234	2.27	1.388
	PU-2. I found this VR confusing to use	2.40	1.329	2.70	1.418
	PU-3. Using this VR was taxing	2.50	1.225	2.53	1.383
UES-AE: aesthetic appeal	AE-1. This VR was attractive	4.00	0.743	4.10	0.803
	AE-2. This VR was aesthetically appealing	4.07	0.868	4.10	0.803
	AE-3. This VR appealed to my senses	3.80	0.551	3.87	0.629
UES-RW: reward	RW-1. Using this VR was worthwhile	3.93	0.583	4.13	0.730
	RW-2. My experience was rewarding	3.83	0.834	4.40	0.498
	RW-3. I felt interested in this experience	3.87	0.819	4.33	0.711

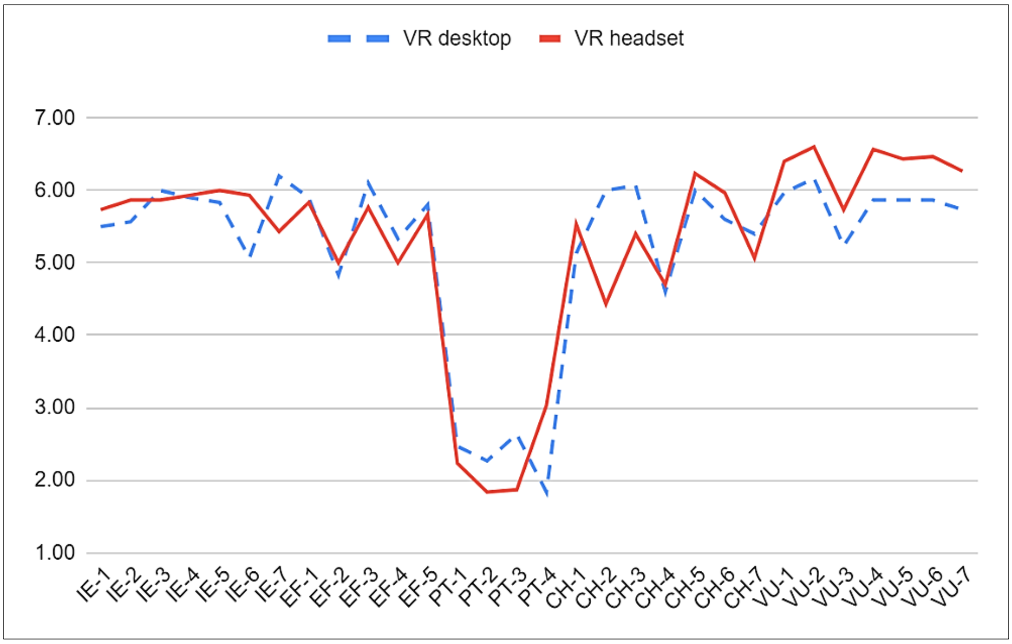

Figure 8. The average IMI scores of the VR desktop and the VR headset

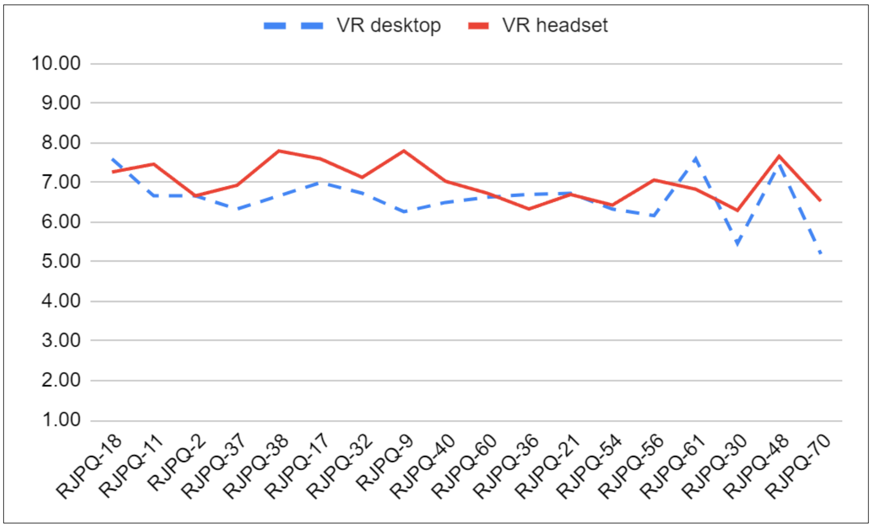

Figure 9. The average RJPQ scores of the VR desktop and the VR headset

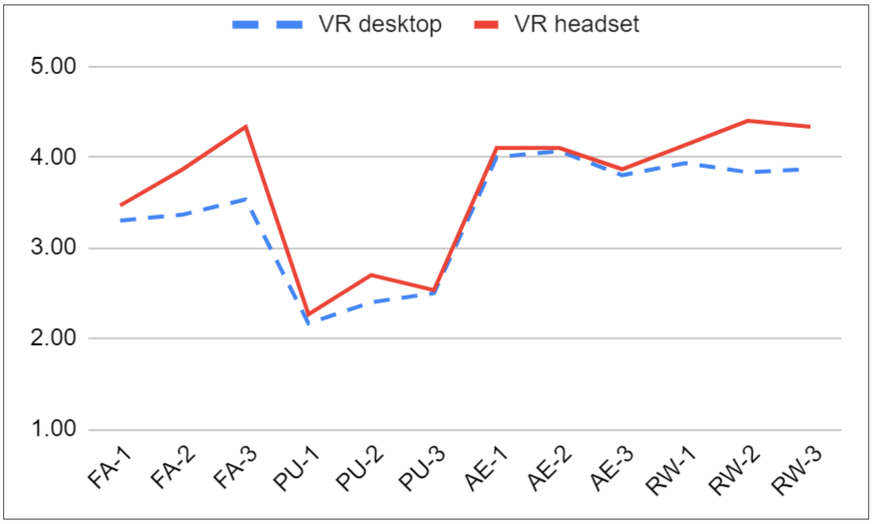

Figure 10. The average UES-SF scores of the VR desktop and the VR headset

Table 9. The Mann-Whitney U test results of IMI scores between the VR desktop and the VR headset approach

Statistics	IMI-IE	IMI-EF	IMI-PT	IMI-CH	IMI-VU
U	422	447	414	389.5	283
Z	-0.40657	0.03696	0.52485	0.88707	-2.46161
p-value	0.6818	0.9681	0.60306	0.37346	0.0139*

(*significant p < 0.05, **highly significant p < 0.01)

Table 10. The Mann-Whitney U test results of RJPQ scores between the VR desktop and the VR headset approach

Statistics	RJPQ-RJ	RJPQ-IC	RJPQ-AA
U	316	377.5	359
Z	-1.97372	-1.06448	-1.33799
p-value	0.04884*	0.28914	0.18024

(*significant $p < 0.05$, **highly significant $p < 0.01$)

Table 11. The Mann-Whitney U test results of UES-SF scores between the VR desktop and the VR headset approach

Statistics	UES-FA	UES-PU	UES-AE	UES-RW
U	245	407	445	297
Z	-3.02341	-0.62834	-0.06653	-2.25462
p-value	0.00252**	0.5287	0.9442	0.02444*

(*significant $p < 0.05$, **highly significant $p < 0.01$)

The results in Table 9 showed that participants in the VR desktop had the same motivation level as those in the VR headset, as measured by the IMI scores in IMI-IE, IMI-EF, IMI-PT, and IMI-CH, whereas for IMI-VU the two groups did not have the same motivation level ($*p=0.0139<0.05$), the VR headset performed significantly better.

The results in Table 10 showed no statistically significant difference in the scores of RJPQ-IC and RJPQ-AA between the two approaches. However, the results showed a statistically significant difference in the scores of RJPQ-RJ ($*p=0.048844<0.05$) between the two approaches.

The results in Table 11 showed no statistically significant difference in the scores of UES-PU and UES-AE between the two approaches. However, the results showed a statistically significant difference in the scores of UES-FA ($**p=0.00252<0.01$) and UES-RW ($*p=0.02444<0.05$) between the two approaches.

In summary, the following results are the evaluation of each hypothesis:

H1: Rejected. A statistically significant difference in physical outcomes (sit-and-reach scores) between the VR desktop and the VR headset approaches.

H2a: Rejected. A statistically significant difference in IMI scores of IMI-VU between the VR desktop and the VR headset approaches.

H2b: Rejected. A statistically significant difference in RJPQ scores of RJPQ-RJ between the VR desktop and the VR headset approaches.

H3: Rejected. A statistically significant difference in UES-SF scores of UES-FA and UES-RW between the VR desktop and the VR headset approaches.

5-3- Interview

We conducted a group discussion with groups of five participants each. Based on the user's emotional experience, the use of the VR headset for flexibility exercise made the participants feel like it was the traditional way of exercise because the basic features of the 3D environment in VR were the same as those in a real-world environment. When compared to the exercise by using the VR desktop approach, the VR headset was better because virtual environments enabled the participants to view the trainer from all angles. In contrast, the VR desktop display only offered a single perspective. However, the participants suggested that both approaches should be redesigned to allow them to see their performance, so they may be able to ensure that their workout posture matches that of the trainer. For an instrumental experience, the participants mentioned that a smaller VR headset device would enable it even more convenient to use the VR headset for exercise in the future. Regarding motivational experience, the participants appreciated the set count revealed when they reached their workout's end. Furthermore, some participants suggested that points or progress bars could be implemented in the VR system to increase player motivation. As a result, we have summarized some of the essential comments shared. In future work, we propose using gamification [72, 73], which could enhance their motivation. The participants can be given the option of choosing the type of gamification element they prefer for VR flexibility exercises.

6- Discussions

Our empirical research revealed some intriguing observations about the utilization of two alternative flexibility exercise approaches – VR desktop and VR headset. Our primary objective was to determine whether these factors had varying experience and engagement impacts, which could affect the user's performance during flexibility exercises

6-1- Revisiting the Hypotheses

H1: the finding of this study suggested that there is a statistically significant difference in flexibility exercise between the VR desktop and VR headset approaches, as measured by the sit-and-reach scores. This result has implications for using VR technology in exercise interventions, the different approaches may lead to different physical outcomes.

One possible explanation for the observed difference in physical outcomes between the two approaches is how VR technology is utilized. For example, the VR headset approach may require the device to be worn during exercise, resulting in less body movement than usual. While the VR desktop does not require wearing additional equipment, making gestures more convenient. For this reason, it can result in different sit-and-reach scores. This finding provides a new insight into the use of VR technology for exercise interventions and highlight the need for further research to fully understand the impact of different VR approaches on physical outcomes. Unlike flexibility exercises, this finding is inconsistent with the existing research studies, which showed that VR games can increase physical performance in aerobic training. Participants in the VR group had a longer travel distance and higher levels of presence and psychological arousal compared to the non-VR group, which played on a traditional PC set-up on a flat screen [74].

H2: the study found that the VR desktop and VR headset approaches differ significantly in terms of user experience. The study suggests that the VR headset approach may be more effective in creating a sense of presence and more motivated to interact with VR. The results are detailed in two sub-hypotheses:

H2a: The results indicated no statistically significant difference in the motivation levels between the VR desktop and VR headset approaches, as measured by the IMI-IE, IMI-EF, IMI-PT, and IMI-CH subscales. Their enjoyment, effort, pressure, or choice related to the exercise tasks were not different. However, the result showed a statistically significant difference in the IMI-VU subscale (*p=0.0139<0.05), indicating that the VR headset users perceived the activity as more valuable and useful than the VR desktop users.

Although the motivation levels of participants were generally similar between the two approaches, the VR headset approach may be more effective for promoting motivation in the value and usefulness of the exercise. Consistent with previous research [75], low-immersion VR did not increase exercise motivation. This finding could have implications for the design and implementation of VR-based exercise interventions, as it suggests that the use of VR headset technology could potentially improve users' experience and adherence to the exercise program. It can be useful for researchers to enhance the effectiveness of VR technology in exercise interventions.

H2b: The results showed that there was no statistically significant difference in the scores of RJPQ-IC and RJPQ-AA between the VR desktop and VR headset approaches. However, there was a statistically significant difference in the RJPQ-RJ score. The VR headset performed significantly better than the VR desktop regarding the reality judgment. This suggests that VR headset users have perceived a more immersive and realistic experience than VR desktop users. However, we observe that the correspondence or level of attention and absorption were not different. This means that using a VR desktop for exercising is no different from using a VR headset regarding correspondence and absorption.

The design and development of VR exergames should consider the type of display device used when designing VR applications, as it may impact the level of realism and immersion experienced by users. A strong sense of presence and immersion is crucial for enhancing the user experience and achieving desired outcomes. As suggested with the previous research [76, 77], realistic judgment indicate that VR can enhance mental training.

H3: The finding indicated significant differences in user engagement between the VR desktop and VR headset approaches. The results showed that VR headset users had significantly higher levels of focused attention (UES-FA) and reward (UES-RW) than VR desktop users. These results support the notion that VR technology can be effective in promoting engagement and enhancing attention in exercise activities. The VR headset approach may provide more opportunities for users to focus their attention and feel rewarded during the exercise. Higher levels of immersive attention in VR were associated with positive effects or activation during exercise, consistent with previous research [27,78-80].

However, no differences in perceived usability (UES-PU) and aesthetic appeal (UES-AE) scores suggest that both approaches were equally user-friendly and visually appealing. The interaction design of the flexibility exercise used in the virtual environment and the virtual trainer avatar did not affect the participants' feelings. It would be interesting to see the outcomes if it were designed as a VR exergame with complex interactions and a more interactive game environment.

6-2- Limitations

Due to the COVID-19 epidemic, all participants were required always to wear masks during the experiment. Consequently, participants might feel uncomfortable and more exhausted than usual. However, this experiment measured the flexibility of the body with sit-and-reach measurements. There was no major impact in this case. Although the IMI questionnaire may have influenced the assessment, both groups were tested under the same conditions. In addition, participants using the VR headset approach may experience less transparency during exercise due to the blurred vision caused by wearing a mask; however, all participants were able to complete the experiment without any issues. Although the questionnaire results allowed us to comprehend the user experience and engagement of the VR application, we could gain a more in-depth understanding of their exercise movements if we were able to record video of them interacting with the VR application. Adding a capture system can be useful for observing their verbal (thinking aloud) and non-verbal (facial expressions) behaviors to determine changes in their engagement.

7- Conclusion

This study has shed light on the differences between VR desktop and VR headset approaches in the context of flexibility exercise. The results show that the two approaches have significant differences in physical outcomes, user experience, and user engagement. Regarding the physical outcomes, our findings indicate that the VR desktop approach was more effective in improving flexibility, while the experience of the VR headset approach was more effective in creating a sense of presence and enhancing the user's perception of the exercise's value and usefulness. In terms of engagement, our study found that the VR headset approach provided users with a more immersive and realistic experience, which might be affecting higher levels of focused attention and reward compared to VR desktop users. This suggests that VR headsets can be effective in promoting engagement and enhancing attention in exercise activities.

Furthermore, while our study focused on the impact of VR technology on flexibility exercise, future research can investigate the potential of VR in other types of exercise interventions, such as strength training, and balance training. Additionally, studies can explore the use of VR technology in combination with other interventions such as cognitive-behavioral therapy, mindfulness, or social support to enhance the effectiveness of exercise interventions.

In conclusion, our study highlights the potential benefits and limitations of using VR technology in exercise. The findings provide important insights for healthcare professionals, researchers, and technology developers to design effective and accessible VR-based exercise programs. The integration of VR technology into exercise can provide a unique and personalized experience for users, increasing engagement in physical activity.

8- Declarations

8-1- Author Contributions

Conceptualization, P.T., C.K., and P.P.; methodology, P.T., C.K., and P.P.; software, C.K.; validation, P.P. and D.N.; formal analysis, P.P. and C.K.; investigation, P.T. and P.P.; resources, P.T., C.K., and P.P.; data curation, P.T., C.K., and D.N.; writing—original draft preparation, P.T. and P.P.; writing—review and editing, P.T., C.K., and D.N.; visualization, P.T., C.K., and P.P.; supervision, C.K. and D.N.; project administration, C.K.; funding acquisition, C.K. All authors have read and agreed to the published version of the manuscript.

8-2- Data Availability Statement

The data presented in this study are available in the article.

8-3- Funding

This research was funded by the Walailak University Research Fund, contract number WU6٤٢١٧.

8-4- Institutional Review Board Statement

Not applicable.

8-5- Informed Consent Statement

Informed consent was obtained from all subjects involved in the study. This study was approved by the Ethics Committee of Human Rights Related to Research Involving Human Subjects, Walailak University, Thailand (WUEC-20-191-01).

8-6- Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

9- References

[1] Newman, M., Gatersleben, B., Wyles, K. J., & Ratcliffe, E. (2022). The use of virtual reality in environment experiences and the importance of realism. Journal of Environmental Psychology, 79, 101733. doi:10.1016/j.jenvp.2021.101733.

[2] Neumann, D. L. (2016). on the Use of Virtual Reality in Sport and Exercise: Applications and Research Findings. International Journal of Computer Research, 23(3), 273–293.

[3] di Fronso, S., Aquino, A., Bondár, R. Z., Montesano, C., Robazza, C., & Bertollo, M. (2020). The influence of core effect on cyclo-ergometer endurance performance: Effects on performance outcomes and perceived exertion. Journal of Sport and Health Science, 9(6), 578–586. doi:10.1016/j.jshs.2019.12.004.

[4] Bird, J. M., Karageorghis, C. I., Baker, S. J., Brookes, D. A., & Nowicky, A. V. (2021). Ready Exerciser One: Effects of music and virtual reality on cycle ergometer exercise. British Journal of Health Psychology, 26(1), 15–32. doi:10.1111/bjhp.12445.

[5] Brauner, P., Calero Valdez, A., Schroeder, U., & Ziefle, M. (2013). Increase Physical Fitness and Create Health Awareness through Exergames and Gamification. Human Factors in Computing and Informatics. SouthCHI 2013, Lecture Notes in Computer Science, 7946, Springer, Berlin, Germany. doi:10.1007/978-3-642-39062-3_22.

[6] Yu, T. C., Chiang, C. H., Wu, P. T., Wu, W. L., & Chu, I. H. (2020). Effects of exergames on physical fitness in middle- aged and older adults in Taiwan. International Journal of Environmental Research and Public Health, 17(7), 2565. doi:10.3390/ijerph17072565.

[7] Cao, L., Peng, C., & Dong, Y. (2021). Ellic's Exercise Class: promoting physical activities during exergaming with immersive virtual reality. Virtual Reality, 25(3), 597–612. doi:10.1007/s10055-020-00477-z.

[8] Miller, C. A., Hayes, D. M., Dye, K., Johnson, C., & Meyers, J. (2012). Using the nintendowii fit and bodyweight support to improve aerobic capacity, balance, gait ability, and fear of falling: Two case reports. Journal of Geriatric Physical Therapy, 35(2), 95–104. doi:10.1519/JPT.0b013e318224aa38.

[9] Pacheco, T. B. F., De Medeiros, C. S. P., De Oliveira, V. H. B., Vieira, E. R., & De Cavalcanti, F. A. C. (2020). Effectiveness of exergames for improving mobility and balance in older adults: A systematic review and meta-analysis. Systematic Reviews, 9(1), 1–14. doi:10.1186/s13643-020-01421-7.

[10] Thalmann, M., Ringli, L., Adcock, M., Swinnen, N., de Jong, J., Dumoulin, C., Guimarães, V., & de Bruin, E. D. (2021). Usability study of a multicomponent exergame training for older adults with mobility limitations. International Journal of Environmental Research and Public Health, 18(24), 13422. doi:10.3390/ijerph182413422.

[11] Stanmore, E. K., Mavroeidi, A., De Jong, L. D., Skelton, D. A., Sutton, C. J., Benedetto, V., Munford, L. A., Meekes, W., Bell, V., & Todd, C. (2019). The effectiveness and cost-effectiveness of strength and balance Exergames to reduce falls risk for people aged 55 years and older in UK assisted living facilities: A multi-centre, cluster randomised controlled trial. BMC Medicine, 17(1), 1–14. doi:10.1186/s12916-019-1278-9.

[12] Phu, S., Vogrin, S., Al Saedi, A., & Duque, G. (2019). Balance training using virtual reality improves balance and physical performance in older adults at high risk of falls. Clinical Interventions in Aging, 14, 1567–1577. doi:10.2147/cia.s220890.

[13] Sadeghi, H., Hakim, M. N., Hamid, T. A., Amri, S. Bin, Razeghi, M., Farazdaghi, M., & Shakoor, E. (2017). The effect of exergaming on knee proprioception in older men: A randomized controlled trial. Archives of Gerontology and Geriatrics, 69, 144–150. doi:10.1016/j.archger.2016.11.009.

[14] Valenzuela, T., Okubo, Y., Woodbury, A., Lord, S. R., & Delbaere, K. (2018). Adherence to Technology-Based Exercise Programs in Older Adults: A Systematic Review. Journal of Geriatric Physical Therapy, 41(1), 49–61. doi:10.1519/JPT.0000000000000095.

[15] Qian, J., McDonough, D. J., & Gao, Z. (2020). The effectiveness of virtual reality exercise on individual's physiological, psychological and rehabilitative outcomes: A systematic review. International Journal of Environmental Research and Public Health, 17(11), 4133. doi:10.3390/ijerph17114133.

[16] Gao, Z., Lee, J. E., McDonough, D. J., & Albers, C. (2020). Virtual reality exercise as a coping strategy for health and wellness promotion in older adults during the COVID-19 pandemic. Journal of Clinical Medicine, 9(6). doi:10.3390/jcm9061986.

[17] Segura-Ortí, E., & García-Testal, A. (2019). Intradialytic virtual reality exercise: Increasing physical activity through technology. Seminars in Dialysis, 32(4), 331–335. doi:10.1111/sdi.12788.

[18] Neumann, D. L., Moffitt, R. L., Thomas, P. R., Loveday, K., Watling, D. P., Lombard, C. L., Antonova, S., & Tremeer, M. A. (2018). A systematic review of the application of interactive virtual reality to sport. Virtual Reality, 22(3), 183–198. doi:10.1007/s10055-017-0320-5.

[19] Stenger, L. (2018). What is Functional/Neuromotor Fitness? ACSM'S Health Fitness Journal, 22(6), 35–43. doi:10.1249/fit.0000000000000439.

[20] Türker, A., & Yüksel, O. (2021). The effect of functional and supportive classic strength trainings in basketball players on aerobic strength, dynamic balance and body composition. Pedagogy of Physical Culture and Sports, 25(1), 47–58. doi:10.15561/26649837.2021.0107.

[21] Cornelissen, V. A., Verheyden, B., Aubert, A. E., & Fagard, R. H. (2010). Effects of aerobic training intensity on resting, exercise and post-exercise blood pressure, heart rate and heart-rate variability. Journal of Human Hypertension, 24(3), 175–182. doi:10.1038/jhh.2009.51.

[22] Niu, Y., Zhou, D., & Ma, Z. (2018). Effect of aerobic exercises on students' physical health indicators. Science & Sports, 33(2), e85–e89. doi:10.1016/j.scispo.2018.01.003.

[23] Maestroni, L., Read, P., Bishop, C., Papadopoulos, K., Suchomel, T. J., Comfort, P., & Turner, A. (2020). The Benefits of Strength Training on Musculoskeletal System Health: Practical Applications for Interdisciplinary Care. Sports Medicine, 50(8), 1431–1450. doi:10.1007/s40279-020-01309-5.

[24] Kenney, W. L., Wilmore, J. H., & Costill, D. L. (2021). Physiology of sport and exercise. Human kinetics, Windsor, Canada.

[25] Hübscher, M., Zech, A., Pfeifer, K., Hänsel, F., Vogt, L., & Banzer, W. (2010). Neuromuscular training for sports injury prevention: A systematic review. Medicine and Science in Sports and Exercise, 42(3), 413–421. doi:10.1249/MSS.0b013e3181b88d37.

[26] Alter, M. J. (2004). Science of flexibility. Human Kinetics, Windsor, Canada.

[27] Neumann, D. L., & Moffitt, R. L. (2018). Affective and attentional states when running in a virtual reality environment. Sports, 6(3), 71. doi:10.3390/sports6030071.

[28] Parton, B. J., & Neumann, D. L. (2019). The effects of competitiveness and challenge level on virtual reality rowing performance. Psychology of Sport and Exercise, 41, 191–199. doi:10.1016/j.psychsport.2018.06.010.

[29] Khundam, C., & Nöel, F. (2021). A Study of Physical Fitness and Enjoyment on Virtual Running for Exergames. International Journal of Computer Games Technology, 2021, 1–16. doi:10.1155/2021/6668280.

[30] Calogiuri, G., Litleskare, S., Fagerheim, K. A., Rydgren, T. L., Brambilla, E., & Thurston, M. (2018). Experiencing Nature through Immersive Virtual Environments: Environmental Perceptions, Physical Engagement, and Affective Responses during a Simulated Nature Walk. Frontiers in Psychology, 8. doi:10.3389/fpsyg.2017.02321.

[31] McGloin, R., & Embacher, K. (2018). "Just Like Riding a Bike": A Model Matching Approach to Predicting the Enjoyment of a Cycling Exergame Experience. Media Psychology, 21(3), 486–505. doi:10.1080/15213269.2017.1311269.

[32] Da Cruz, M. M. A., Ricci-Vitor, A. L., Borges, G. L. B., Da Silva, P. F., Turri-Silva, N., Takahashi, C., Grace, S. L., & Vanderlei, L. C. M. (2021). A Randomized, Controlled, Crossover Trial of Virtual Reality in Maintenance Cardiovascular Rehabilitation in a Low-Resource Setting: Impact on Adherence, Motivation, and Engagement. Physical Therapy, 101(5), 71. doi:10.1093/ptj/pzab071.

[33] García-Bravo, S., Cuesta-Gómez, A., Campuzano-Ruiz, R., López-Navas, M. J., Domínguez-Paniagua, J., Araújo-Narváez, A., Barreñada-Copete, E., García-Bravo, C., Flórez-García, M. T., Botas-Rodríguez, J., & Cano-de-la-Cuerda, R. (2021). Virtual reality and video games in cardiac rehabilitation programs. A systematic review. Disability and Rehabilitation, 43(4), 448–457. doi:10.1080/09638288.2019.1631892.

[34] Czub, M., & Janeta, P. (2021). Exercise in virtual reality with a muscular avatar influences performance on a weightlifting exercise. Cyberpsychology, 15(3). doi:10.5817/CP2021-3-10.

[35] Nambi, G., Abdelbasset, W. K., Elsayed, S. H., Alrawaili, S. M., Abodonya, A. M., Saleh, A. K., & Elnegamy, T. E. (2020). Comparative Effects of Isokinetic Training and Virtual Reality Training on Sports Performances in University Football Players with Chronic Low Back Pain-Randomized Controlled Study. Evidence-Based Complementary and Alternative Medicine, 2020. doi:10.1155/2020/2981273.

[36] Cano Porras, D., Siemonsma, P., Inzelberg, R., Zeilig, G., & Plotnik, M. (2018). Advantages of virtual reality in the rehabilitation of balance and gait. Neurology, 90(22), 1017–1025. doi:10.1212/wnl.0000000000005603.

[37] Lee, I. W., Kim, Y. N., & Lee, D. K. (2015). Effect of a virtual reality exercise program accompanied by cognitive tasks on the balance and gait of stroke patients. Journal of Physical Therapy Science, 27(7), 2175–2177. doi:10.1589/jpts.27.2175.

[38] Lee, D., Ng, P. M., & Wut, T. M. (2022). Virtual Reality in Festivals: A Systematic Literature Review and Implications for Consumer Research. Emerging Science Journal, 6(5), 1153-1166. doi:10.28991/ESJ-2022-06-05-016.

[39] Park, E. C., Kim, S. G., & Lee, C. W. (2015). The effects of virtual reality game exercise on balance and gait of the elderly. Journal of Physical Therapy Science, 27(4), 1157–1159. doi:10.1589/jpts.27.1157.

[40] Tsang, W. W. N., & Fu, A. S. N. (2016). Virtual reality exercise to improve balance control in older adults at risk of falling. Hong Kong Medical Journal, 22(22), S19–S22.

[41] Stathokostas, L., Little, R. M. D., Vandervoort, A. A., & Paterson, D. H. (2012). Flexibility training and functional ability in older adults: A systematic review. Journal of Aging Research, 2012. doi:10.1155/2012/306818.

[42] Pham, D.-M., & Stuerzlinger, W. (2019). Is the Pen Mightier than the Controller? A Comparison of Input Devices for Selection in Virtual and Augmented Reality. 25th ACM Symposium on Virtual Reality Software and Technology. doi:10.1145/3359996.3364264.

[43] Sousa Santos, B., Dias, P., Pimentel, A., Baggerman, J. W., Ferreira, C., Silva, S., & Madeira, J. (2009). Head-mounted display versus desktop for 3D navigation in virtual reality: A user study. Multimedia Tools and Applications, 41(1), 161–181. doi:10.1007/s11042-008-0223-2.

[44] Marek, K., Zubrycki, I., & Miller, E. (2022). Immersion Therapy with Head-Mounted Display for Rehabilitation of the Upper Limb after Stroke—Review. Sensors, 22(24), 9962. doi:10.3390/s22249962.

[45] Dyulicheva, Y. Y., Gaponov, D. A., Mladenovic, R., & Kosova, Y. A. (2021). The virtual reality simulator development for dental students training: a pilot study. 4th International Workshop on Augmented Realty in Education, 11 May, 2021, Kryvyi Rih, Ukraine.

[46] Buttussi, F., & Chittaro, L. (2021). A Comparison of Procedural Safety Training in Three Conditions: Virtual Reality Headset, Smartphone, and Printed Materials. IEEE Transactions on Learning Technologies, 14(1), 1–15. doi:10.1109/TLT.2020.3033766.

[47] Tychsen, L., & Foeller, P. (2020). Effects of Immersive Virtual Reality Headset Viewing on Young Children: Visuomotor Function, Postural Stability, and Motion Sickness. American Journal of Ophthalmology, 209, 151–159. doi:10.1016/j.ajo.2019.07.020.

[48] Kim, Y. M., Rhiu, I., & Yun, M. H. (2020). A Systematic Review of a Virtual Reality System from the Perspective of User Experience. International Journal of Human-Computer Interaction, 36(10), 893–910. doi:10.1080/10447318.2019.1699746.

[49] Houzangbe, S., Christmann, O., Gorisse, G., & Richir, S. (2020). Effects of voluntary heart rate control on user engagement and agency in a virtual reality game. Virtual Reality, 24(4), 665–681. doi:10.1007/s10055-020-00429-7.

[50] BS EN ISO. (2010). Ergonomics of human-system interaction, British Standard, London, United Kingdom. Available online: https://webstore.ansi.org/preview-pages/BSI/preview_30193611.pdf (accessed on April 2023).

[51] Berni, A., & Borgianni, Y. (2021). From the definition of user experience to a framework to classify its applications in design. Proceedings of the Design Society, 1, 1627–1636. doi:10.1017/pds.2021.424.

[52] Díaz-Oreiro, I., López, G., Quesada, L., & Guerrero, L. (2019). Standardized Questionnaires for User Experience Evaluation: A Systematic Literature Review. Multidisciplinary Digital Publishing Institute Proceedings, 31(1), 14. doi:10.3390/proceedings2019031014.

[53] Ijaz, K., Ahmadpour, N., Wang, Y., & Calvo, R. A. (2020). Player Experience of Needs Satisfaction (PENS) in an Immersive Virtual Reality Exercise Platform Describes Motivation and Enjoyment. International Journal of Human-Computer Interaction, 36(13), 1195–1204. doi:10.1080/10447318.2020.1726107.

[54] Somrak, A., Humar, I., Hossain, M. S., Alhamid, M. F., Hossain, M. A., & Guna, J. (2019). Estimating VR Sickness and user experience using different HMD technologies: An evaluation study. Future Generation Computer Systems, 94, 302–316. doi:10.1016/j.future.2018.11.041.

[55] Pyae, A. (2021). Towards Understanding Users' Engagement and Enjoyment in Immersive Virtual Reality-Based Exercises. Adjunct Publication of the 23rd International Conference on Mobile Human-Computer Interaction. doi:10.1145/3447527.3474872.

[56] Eisapour, M., Cao, S., & Boger, J. (2020). Participatory design and evaluation of virtual reality games to promote engagement in physical activity for people living with dementia. Journal of Rehabilitation and Assistive Technologies Engineering, 7, 205566832091377. doi:10.1177/2055668320913770.

[57] Gabrhelová, G., & Čepelová, S. (2022). Are Activation Teaching Methods Really Effective?. HighTech and Innovation Journal, 3(4), 443-471. doi:10.28991/HIJ-2022-03-04-06.

[58] Souza, V., Maciel, A., Nedel, L., & Kopper, R. (2022). Measuring Presence in Virtual Environments: A Survey. ACM Computing Surveys, 54(8), 1–37. doi:10.1145/3466817.

[59] Monteiro, V., Mata, L., & Peixoto, F. (2015). Intrinsic motivation inventory: Psychometric properties in the context of first language and mathematics learning. Psicologia: Reflexao e Critica, 28(3), 434–443. doi:10.1590/1678-7153.201528302.

[60] Baños, R. M., Botella, C., Garcia-Palacios, A., Villa, H., Perpiña, C., & Alcañiz, M. (2000). Presence and reality judgment in virtual environments: A unitary construct? Cyberpsychology and Behavior, 3(3), 327–335. doi:10.1089/10949310050078760.

[61] O'Brien, H. L., Cairns, P., & Hall, M. (2018). A practical approach to measuring user engagement with the refined user engagement scale (UES) and new UES short form. International Journal of Human Computer Studies, 112, 28–39. doi:10.1016/j.ijhcs.2018.01.004.

[62] Andrade, P., & Law, E. L. C. (2021). Improving Student Experience and Learning Performance with Traditional Instructional Methods and New Digital Media. Human-Computer Interaction – INTERACT 2021, INTERACT 2021, Lecture Notes in Computer Science, 12934. Springer, Cham, Switzerland. doi:10.1007/978-3-030-85613-7_7.

[63] Chen, E., Leos, C., Kowitt, S. D., & Moracco, K. E. (2020). Enhancing Community-Based Participatory Research Through Human-Centered Design Strategies. Health Promotion Practice, 21(1), 37–48. doi:10.1177/1524839919850557.

[64] Holt, L. E., Pelham, T. W., & Burke, D. G. (1999). Modifications to the Standard Sit-and-Reach Flexibility Protocol. Journal of Athletic Training, 34(1), 43.

[65] López-Miñarro, P. A., Andújar, P. S. de B., & Rodríguez-García, P. L. (2009). A comparison of the sit-and-reach test and the back-saver sit-and-reach test in university students. Journal of Sports Science and Medicine, 8(1), 116–122.

[66] van der Kruk, E., & Reijne, M. M. (2018). Accuracy of human motion capture systems for sport applications; state-of-the-art review. European Journal of Sport Science, 18(6), 806–819. doi:10.1080/17461391.2018.1463397.

[67] Nagymáté, G., & M. Kiss, R. (1970). Application of OptiTrack motion capture systems in human movement analysis. Recent Innovations in Mechatronics, 5(1.). doi:10.17667/riim.2018.1/13.

[68] MotionAnalysis. (2023). Raptor-E Digital RealTime System. Motion Analysis Corporation, Santa Rose, United States, Available online: https://sitetist.com/uicon/download/product-brochure/motion-analysis/Raptor4_System.pdf (accessed on April 2023).

[69] Sharkey N. (2023). MotionAnalysis, Eagle Digital Real Time System. Pennsylvania State University, Pennsylvania, United States. Available online: https://biomechanicslab.psu.edu/motion-analysis-eagle-system/ (accessed on 21 February 2023).

[70] Shephard, R. J., Berridge, M., & Montelpare, W. (1990). On the generality of the "sit and reach" test: An analysis of flexibility data for an aging population. Research Quarterly for Exercise and Sport, 61(4), 326–330. doi:10.1080/02701367.1990.10607495.

[71] Wikipedia (2023), Oculus Quest 2. Available online: https://en.wikipedia.org/wiki/Oculus_Quest_2 (accessed on 21 February 2023).

[72] Prieto-Andreu, J. M., Gómez-Escalonilla-Torrijos, J. D., & Said-Hung, E. (2022). Gamification, motivation and performance in education: A systematic review. Revista Electrónica Educare, 26(1), 1–23. doi:10.15359/ree.26-1.14. (In Spanish).

[73] Nor, N., Sunar, M., & Kapi, A. (2020). A Review of Gamification in Virtual Reality (VR) Sport. EAI Endorsed Transactions on Creative Technologies, 6(21), 163212. doi:10.4108/eai.13-7-2018.163212.

[74] Yao, S., & Kim, G. (2019). The Effects of Immersion in a Virtual Reality Game: Presence and Physical Activity. HCI in Games. HCII 2019, Lecture Notes in Computer Science, 11595. Springer, Cham, Switzerland. doi.org/10.1007/978-3-030-22602-2_18.

[75] Mouatt, B., Smith, A. E., Mellow, M. L., Parfitt, G., Smith, R. T., & Stanton, T. R. (2020). The Use of Virtual Reality to Influence Motivation, Affect, Enjoyment, and Engagement During Exercise: A Scoping Review. Frontiers in Virtual Reality, 1, 564664. doi:10.3389/frvir.2020.564664.

[76] Gray, R. (2019). Virtual environments and their role in developing perceptual-cognitive skills in sports. In Anticipation and Decision Making in Sport (pp. 342–358). Routledge. doi:10.4324/9781315146270-19.

[77] Frank, C. (2020). Virtual reality and mental training. Advancements in Mental Skills Training, 177-186. Routledge, Milton Park, United Kingdom. doi:10.4324/9780429025112-16.

[78] Murray, E. G., Neumann, D. L., Moffitt, R. L., & Thomas, P. R. (2016). The effects of the presence of others during a rowing exercise in a virtual reality environment. Psychology of Sport and Exercise, 22, 328–336. doi:10.1016/j.psychsport.2015.09.007.

[79] Martin-Niedecken, A. L., Rogers, K., Turmo Vidal, L., Mekler, E. D., & Márquez Segura, E. (2019). ExerCube vs. Personal Trainer. Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems. doi:10.1145/3290605.3300318.

[80] Bird, J. M., Karageorghis, C. I., Baker, S. J., & Brookes, D. A. (2019). Effects of music, video, and 360-degree video on cycle ergometer exercise at the ventilatory threshold. Scandinavian Journal of Medicine & Science in Sports, 29(8), 1161–1173. doi:10.1111/sms.13453.