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Correlates of Presence in a Virtual Reality Gamification Environment for Rehabilitation after Musculoskeletal Injury

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Abstract: Virtual reality (VR) has emerged as a powerful option for rehabilitation by providing real-time performance feedback and a safe and customized training environment. This study aimed: (1) to investigate the association between the presence in the virtual environment, the usability of the system, the intrinsic motivation, and immersion in VR gaming designed for rehabilitation after musculoskeletal injury; and (2) to examine the users' emotional response in terms of pleasure, arousal, and dominance, after participating in VR gaming. Thirty-seven individuals aged 23.69 ± 6.98 years participated in five customized VR games designed to provide a complete rehabilitation session after a musculoskeletal injury. Pearson product-moment correlation coefficients and multiple regression analyses were used to investigate the relationship between presence in virtual environments and immersive tendencies, the usability of the system, and intrinsic motivation. The Wilcoxon Signed Rank Test was conducted to evaluate the impact of participation in VR gaming on participants' presence in virtual environments. Significant correlations were found between presence and immersive tendencies (r = –.40, p = .017), intrinsic motivation (r = .42, p = .013), and usability of the system (r = .64, p < .001). The linear regression model explained 59% of the total variance in the presence of virtual environments. There was a statistically significant increase in the pleasure scores from the beginning to the end of the session. Our results indicate that VR may be useful in increasing adherence to treatment to recover musculoskeletal injuries.

1. Introduction

Virtual reality (VR) gaming is a technology-based approach that provides interaction in multisensory activities (Brütsch et al., 2010). On the other hand, musculoskeletal rehabilitation is a complex and long process based on exercise therapy that frequently affects individuals' motivation (Asadzadeh et al., 2021). Nowadays, VR has emerged as a powerful therapy option with promising results in various functional and physiological domains. Some examples include improved functional ability (Sims et al., 2013), muscular strength (Kim et al., 2013; Martinho et al., 2016), depressive mood (Gao et al., 2021) and pain management (Bahat et al., 2015; Yilmaz Yelvar et al., 2017). From a clinical point of view, VR allows real-time performance feedback, a safe practising and training environment, more engaging and motivating, and the ability to customize treatment as needed (Kim, 2005; Sveistrup, 2004).

VR allows users to engage in environments that appear and feel like real-world objects and events (Weiss et al., 2006). Indeed, VR technology aims to give users a convincing sense of presence and interaction within these computer-generated environments. The concept of presence, defined as the interpretation of an artificial environment as if it were real, has been related to the users' enjoyment (Yang & Zhang, 2022) and is commonly used to evaluate virtual environments (Skarbez et al., 2017; Slater, 2003). On the other hand, immersion and engagement in interactivity are also some of the recognized characteristics of VR that make interventions in rehabilitation advantageous (Rose et al., 2018). Immersion refers to the degree to which VR systems can provide extensive experiences (i.e., multimodality sensory stimuli), surrounding (i.e., omnidirectional stimuli), inclusive (i.e., no external interaction with the physical environment), vivid (i.e., provides multiple sensory information), and matching (i.e., user movement and system information match) (Slater et al., 1996). According to the literature, immersion is probably the most crucial feature in VR since it reflects the user's sense of presence, which resumes the virtual environment sensation (Rose et al., 2018; Schuemie et al., 2001). Enhanced presence has been described to improve learning outcomes and positively affect users' motivation and/or engagement (Ratcliffe & Tokarchuk, 2020). Indeed, motivational effects are widely accepted as beneficial for task performance, and games have been seen as a means to enhance intrinsic motivation (Ratcliffe & Tokarchuk, 2020). On the other hand, the system's usability is commonly used to assess the levels of acceptability, ease of use, learnability, and confidence (Meldrum et al., 2012), providing meaningful feedback according to the user's perspective.

Meanwhile, to assess VR systems in terms of immersion and engagement, the literature has also relied on a three-dimensional emotional index that includes pleasure (ranging from pleasant to unpleasant), arousal (ranging from calm to excited), and dominance (ranging from controlled to in-control) of the system (Zhang et al., 2017). Rating these parameters allows the understanding of emotional responses to virtual stimuli. Therefore, adjustments in virtual embodiment (e.g., visual representation, sensory feedback and input, level of interaction) can determine the level of the user's immersion and engagement with VR tasks (Gall et al., 2021), being crucial for developers, researchers, and clinicians who work with VR technology.

The use of VR for rehabilitation has been explored in previous literature. The majority of the research on this topic has targeted individuals with specific medical conditions, such as prolonged pain (Bahat et al., 2015), Parkinson's disease (Dockx et al., 2016), Stroke rehabilitation (Gao et al., 2021), phobia and anxiety treatment (Cieślik et al., 2020) or some sensorimotor impairment (Valentina et al., 2013). Generally, it has been reported a positive impact of VR therapy in various clinical and therapeutic domains. However, regarding musculoskeletal injury rehabilitation, the use of VR systems is still relatively new and developing. For example, it is still a long path toward a better understanding of user preference in a VR gamification environment. It is essential to investigate how patients' preferences for specific VR experiences and the level of customization impact their sense of presence. Continued research in these areas will deepen our understanding of the role of presence in VR gamification environments for rehabilitation and inform the development of effective, patient-centered interventions in the future. As the field of VR technology advances, ongoing research and collaboration between researchers, healthcare professionals, and VR developers are essential to optimize the use of VR in rehabilitation practices.

Therefore, this study emerges based on two primary research questions: (1) are there associations between the presence in this specific virtual environment built for musculoskeletal injury rehabilitation and the perceived system's usability, motivation, and immersion?; and (2) does the users' emotional response enhance after participation in the proposed VR session? To clarify these questions, the present study objectives are twofold: (1) to investigate the association between the presence in virtual environments and the usability of the system, the intrinsic motivation, and immersion in a VR session designed rehabilitation after musculoskeletal injury; and (2) to analyze the variation of the emotional response in terms of pleasure, arousal, and dominance, after the participation in a VR session designed rehabilitation after musculoskeletal injury. It was hypothesized that the presence of VR gaming would be positively related to the system's usability, intrinsic motivation, and immersion. Secondly, it was expected an increase in pleasure, arousal, and dominance from the beginning to the end of the session, which aligns with common psychological responses to engaging experiences.

2. Methods

2.1. Participants

This study involved 37 participants, 18 males and 19 females, aged between 19 to 53 years (M = 23.69; SD = 6.98 years), recruited at the academic institute. All participants were Caucasian students from different engineering, tourism, physical education, and sports courses. Key inclusion criteria were: (1) students aged 18 years or older from an academic institute; (2) voluntary motivation to participate in the study. The only exclusion criterion was any medical contraindications to sub-maximum exercise according to the guidelines of the American College of Sports Medicine (Riebe et al., 2018). All procedures applied were approved by the Ethics Committee of the Faculty of Human Kinetics, CEIFMH No. 39/2021. The investigation was conducted following the Declaration of Helsinki, and informed consent was obtained from all participants.

2.2. Study Design

This study consisted of a within-subjects design. Repeated measures were taken during an experimental study where participants experienced a full VR session composed of five customized games with a total duration of nearly 30 min. In the first phase, before the interaction with the VR system, participants were asked to fill out a pre-study form, where they had to answer questions related to their demographics (age, gender, nationality), previous experience with similar technology, and assess their emotional state through SAM (The Self-Assessment Manikin). Secondly, a brief explanation of how the system works was given and then the sensors of the HTC Vive Pro were provided for the participant to place on their body. After placing these sensors, the E4 was supplied to place on the wrist. In the third phase, after performing each customized game, participants were asked to report their perceived exertion. Finally, in the fourth phase, right after the interaction with the five VR games (i.e., post-study phase), the SAM was collected again to obtain comparisons before and after the experience, to understand if there was any significant impact on the emotional bond caused during the interaction. Also, the System Usability Scale (SUS), Intrinsic Motivation Inventory (IMI), immersive tendencies, presence, and emotional response were evaluated through proper questionnaires. In addition, the real total time experience and the subjective estimated time experience were recorded for each person after the full experience. All experimental sessions and data collection were deployed for two weeks.

2.3. Virtual Reality Gaming Development

A set of five customized VR games (i.e., “Weight Transfer”, “Military March”, “Side Squat”, “Progressive March”, and “Walking along a Straight Line”) for soccer players were used to simulate an entire rehabilitation session designed for musculoskeletal injury (Figure 1). The development of these VR games required exploratory research based on open interviews with physiotherapists. The session was developed in a soccer environment and contained specific soccer motives and other gamification techniques that keep the users involved (i.e., feedback and progress visualization, personalization and customization, leaderboards and competitions, and progression and levelling up). Each VR game has been designed to cover the main training domain (e.g., aerobic endurance, upper/lower strength, and motor ability). The order of the games was previously organized considering the intensity requested throughout the three training session phases (warm-up, conditioning, cool-down). There were no breaks between trials. Just the time needed to change the game environment. The participants only performed the virtual rehabilitation session.

Insert Figure 1: Customized VR games designed for musculoskeletal injury rehabilitation.

Regarding the technical specifications for the virtual reality method implemented in this experiment, the HTC Vive Pro Set, Unity3D game engine, inverse kinematics, and personalized avatars within a realistic soccer stadium environment were used to create an immersive full-body tracking experience. Specifically, the hardware consisted of physical equipment, including sensors placed at key body points (hands, waist, and feet) to track the user's movements during exercises. For this purpose, the HTC Vive Pro Set was selected, which included a Head-Mounted Display (HMD), two controllers, four SteamVR base stations 2.0, and three trackers.

To develop the full-body tracking experience, Unity3D was used as the game engine. Unity3D allowed for rapid prototyping and deployment of the application on various VR devices. Additionally, a plugin for Unity was utilized to support VR content for HTC Vive, Oculus Rift, and Valve Index, facilitating the handling of input from controllers and estimating hand movements. To achieve full-body tracking, an inverse kinematics library was implemented in Unity. Inverse kinematics automatically calculated joint angles based on the position of the end effector (e.g., foot or hand), allowing avatars to mimic human motions with a limited number of sensor points. Creating the virtual environment and avatar was essential for an immersive experience. The virtual environment was designed as a soccer stadium replica to enhance realism and user familiarity. Blender was used for modelling the stadium based on 2D floor plans. The avatar, representing the user in the virtual world, was personalized using three photographs to create empathy. The avatar skeleton was linked with the FinalIK library in Unity, enabling full-body tracking.

2.4. Description of each VR game

2.4.1. Weight Transfer

Short description of the conventional exercise presented by the physiotherapist: the weight transfer exercise requires the user to put one foot forward and one behind.

VR Gamification process: the game developed required the user to lift the left toe to select a colour to "shoot" signalled in the goal. When the user selects the right circle by pressing the trigger from the command, they get points, and if they choose the wrong one or do not select it in the supposed time, they lose points.

Exercise purpose: transfer the weight forward and back.

The main functional fitness capacity involved: balance.

2.4.2. Military March

Short description of the conventional exercise presented by the physiotherapist: the task requires the user to raise the left knee until it forms a 90-degree angle with the belly and stretches the right arm simultaneously. Then repeat for the opposing members.

VR Gamification process: a dartboard was created that the user had to point with his knee and only shoot when the hand was lifted. Two balloons in the air were put in the environment responsible for knowing if the user raised the requested hand. To make the user raise his knee, an integrated laser only appeared when the user lifted his knee to the height he wanted. When the user accomplished these two movements, the user could aim at the dartboard and press the hand's controller, which was lifted and got points.

Exercise purpose: raise the left knee (90º) and stretches the right arm.

The main functional fitness capacities involved: balance and coordination.

2.4.3. Side Squat

Short description of the conventional exercise presented by the physiotherapist: the side squat requires the user to step sideways while pushing the hips back and bringing the torso toward the floor. Stand on the other side and prepare to repeat the back-and-forth movement.

VR Gamification process: it was implemented a system with a ball that goes to the left and right sides, and o catches the ball. It was chosen to put inside the virtual environment an object that would indicate if the user did not crouch down when changing sides. The height of the object was determined after the calibration of the avatar. If the user touches his head on the object inside the virtual environment, he loses the opportunity to catch the ball.

Exercise purposes: side-to-side squats.

The main functional fitness capacities involved: lower body strength.

2.4.4. Progressive March

Short description of the conventional exercise presented by the physiotherapist: the progressive march requires the user to raise the knee until it forms a 90-degree angle with the belly.

VR Gamification process: The user would start in the middle of the field, and when he raised his leg, the avatar in the virtual environment was "pushed" forward, having a virtual movement of the avatar whenever the user raised his leg. When approaching the goal, opponents would appear (opponents of another team that will trip the user), and the user could "shoot" at them by pressing the command button. The user gains points for each "exterminated" adversary, and the user loses points for each adversary that manages to trip. The user could shoot for extra points when getting close to the goal.

Exercise purposes: forward progressive march exercise.

The main functional fitness capacities involved: aerobic capacity and lower body strength.

2.4.5. Walking along a Straight Line

Short description of the conventional exercise presented by the physiotherapist: walking along a straight line requires the user to follow a straight line with the left foot on the floor, the heel of the right foot touching (on the floor) the left toes, then move the left foot forward of the right foot with the heel of the left foot touching the right toes, repeat until the end of the line.
VR Gamification process: The gamification of the exercise was based on allowing the user to "shoot" to the circles with the color shown in the flag while walking in a straight line in the virtual environment on top of a pole, like the previous exercise.
Exercise purposes: tandem walks forward and back forward.
The main functional fitness capacities involved: semi-balance and coordination.
A full description of each game in terms of the conventional exercise required by the physiotherapist, the VR Gamification process including scoring, exercise purposes, main functional fitness capacities involved, system quality of the movement assessment, and Software and Hardware can be found in (Gouveia et al., 2023).

2.5. Instruments

2.5.1. E4 wristband

The E4 wristband is an empathic band that offers real-time physiological data through four sensors: (1) an electrode for electrodermal activity (EDA), (2) a 3-axis accelerometer, (3) a temperature sensor, and (4) a photoplethysmography (PPG) to measure blood volume pulse (BVP), from which it derives heart rate (HR) and the inter-beat interval (IBI) (Empatica, 2022). In this study, E4 wristband was used only to monitor the heart rate frequency throughout the experiment to characterize the intensity of the activity in terms of means.

2.5.2. Rate of Perceived Exertion (RPE) Scale

The RPE is a scale that measures the intensity level of physical activity. This study used the OMNI rating of perceived exertion (Robertson et al., 2003). Before the VR game, all participants were individually instructed on the specifics of the OMNI Scale. Then, right after each VR game, the researcher interviewed each participant using the OMNI picture system that elucidated the different levels of effort and the different possible response options (with 0 indicating a minimum response and 10 indicating a maximum response). In this study, RPE was assessed throughout the experiment to characterize the intensity of the activity in terms of means.

2.5.3. System Usability Scale (SUS)

The usability of the VR games was evaluated through the European Portuguese Validation of the System Usability Scale (SUS) (Martins et al., 2015). This self-administered instrument allows for examining the system's usability and user interface. The criteria help assess the system's effectiveness, efficiency, and satisfaction. The scale contains 10 questions rated from 1 to 5, with 1 being "Strongly Disagreed" and 5 "Strongly Agree". Immediately following the VR games session, the System Usability Scale was evaluated.

2.5.4. Intrinsic Motivation Inventory (IMI)

The Portuguese version of the Intrinsic Motivation Inventory was applied to assess the intensity of intrinsic motivation concerning the performance of VR games (Fonseca & de Paula Brito, 2001). Intrinsic motivation refers to behavior driven by internal rewards. Engaging in a behavior arises within the individual because it naturally satisfies the behavior (McAuley et al., 1989; McAuley et al., 1991). The score was obtained by averaging the results of the items for each dimension. A "Global Intrinsic Motivation" may be considered, with higher scores indicating a greater intrinsic motivation to perform the target activity. Right after engaging in the VR games session, the Intrinsic Motivation Inventory was evaluated.

2.5.5. Immersive Tendencies

The level of immersion in the VR games system was assessed using The Immersive Tendencies Questionnaire (Witmer & Singer, 1998). This instrument comprises 18 items and utilizes a scale of 1 (never) to 7 (often), organized into three subdimensions, namely, involvement (seven items), attentional focus (seven items), and tendency to play video games (two items). The subdimensions do not include two items (item 9 and item 13). The Immersive Tendencies were assessed right after interacting with the VR games session.

2.5.6. Presence

The Witmer-Singer Presence Questionnaire was used to characterize the experience in the VR games environment (Witmer et al., 2005; Witmer & Singer, 1998). The Presence Questionnaire is a questionnaire that measures the extent to which a user feels present in the virtual experience, consisting of 24 questions divided into four components: involvement, sensory fidelity, adaptation/immersion, and interface quality. This instrument uses a scale of 1 to 7, with 1 being "Not Convincing" and 7 "Very Convincing". Immediately after participating in the VR games session, the Presence was assessed.

2.5.7. Emotional response (SAM)

The Self-Assessment Manikin (SAM) assessed the emotional response (Bradley & Lang, 1994). This instrument is a five-pointer scale that directly measures pleasure, arousal, and dominance. In this study, participants performed the assessment twice: pre- and post-experience.

2.6. Statistical Analysis

Descriptive statistics (median, mean, standard deviation, and 95% confidence interval for mean) were calculated for all variables. Also, preliminary analyses were performed to ensure no violation of normality, linearity, and homoscedasticity assumptions. Then, the relationship between presence in virtual environments and immersive tendencies, the usability of the system, and intrinsic motivation were investigated using Pearson product-moment correlation coefficient. Multiple regression analyses were performed no investigate how much of the variance in the presence of the virtual environment variable can be explained by immersive tendencies, the usability of the system, and intrinsic motivation. Finally, the Wilcoxon Signed Rank Test was conducted to evaluate the impact of participation in a VR gaming session on participants' emotional responses in virtual environments. Effect size (r) was interpreted using (Cohen, 2013) criteria of .1 = small effect, .3 = medium effect, .5 = large effect. The level of confidence was set at 95%. Data were analyzed using IBM SPSS statistics v.26.

3. Results

Sociodemographic characteristics and the variables related to the participant's experience during the Virtual Reality games for rehabilitation after musculoskeletal injury are present in Table 1. Considering the heart rate average of the sessions, the intensity was near 51% of the maximum heart rate. Also, the information collected by RPE, on average, confirms that this type of session has a low-intensity impact.

Table 1. Descriptive statistics for gender, age, time experience (real and self-estimated), presence in virtual environments, immersive tendencies, the usability of the system, intrinsic motivation inventory, emotional response, heart rate, and rated perceived exertion are presented.

	Median	Mean	SD	95% Confidence Interval for Mean	
Variables				Lower Bound	Upper Bound
Gender n (%)	Males 18 (51.4%); Females 17 (48.6%)				
Age (years)	22	23.69	6.978	21.29	26.08
TTexpe(min)	29	28.74	3.74	27.46	30.03

TEexpe (min)	20	22.63	9.24	19.45	25.80
SUS (1-5)	4.3	4.11	0.56	3.92	4.31
IMI (1-5)	4	3.98	0.56	3.79	4.17
QÉP (24-168)	127	123.74	24.59	115.30	132.19
QPI (17-119)	80	79.40	13.95	74.61	84.19
SAM - pleasure a	4	3.97	0.62	3.76	4.18
SAM - pleasure b	4	4.37	0.69	4.13	4.61
SAM - arousal a	3	3.09	0.95	3.40	4.09
SAM - arousal b	3	3,31	1.11	2.93	3.69
SAM - dominance a	4	3.86	0.88	3.56	4.16
SAM - dominance b	4	3.74	1.01	3.40	4.09
HR - average (bat./min)	97.36	99.64	14.46	94.67	104.61
RPE - average (0-10 pts)	3.2	3.31	1.05	2.95	3.67

SD (standard deviation), TTexpe (total time experience), TEexpe (estimated time experience), SUS (system usability scale), IMI (intrinsic motivation inventory), QÉP (presence in virtual environments), QPI (immersive tendencies), SAM (self-assessment manikin), HR (heart rate), RPE (rated perceived exertion).

The relationship between presence in virtual environments and immersive tendencies, the usability of the system, and intrinsic motivation were investigated using Pearson product-moment correlation coefficient (Table 2).

Table 2. Correlation coefficients between presence in virtual environments, immersive tendencies, the usability of the system, and intrinsic motivation inventory.

Variables	1.	2.	3.	4.
1.QÉP	-	.400 (*p* = .017)	.643 (*p* < .001)	.416 (*p* = .013)
2. QPI		-	.078 (*p* = .654)	- .076 (*p* = .066)
3. SUS			-	.359 (*p* = .034)
4. IMI				-

QÉP (presence in virtual environments), QPI (immersive tendencies), SUS (system usability scale), IMI (intrinsic motivation inventory)

A medium to large, positive correlation between presence in virtual environments with immersive tendencies, r = .40, $p = .017$, medium effect size; intrinsic motivation, r = .42, $p = .013$, medium effect size; and usability of the system, r = .64, $p < .001$, large effect size, were seen. High levels of presence were associated with higher scores of immersions, motivation, and usability.

Results from multiple regression analysis modelling, containing presence in virtual environments, immersive tendencies, the usability of the system, and intrinsic motivation, are presented in Table 3. The usability of the system, immersive tendencies, and intrinsic motivation all contributed significantly to variation in presence in virtual environments (beta =.52; $p < .001$; beta =.38, p =.003; and beta =.26, p =.045, respectively. Our regression model explained 59% of the total variance in the presence of virtual environments. The system's usability was the most significant predictor of presence in virtual environments.

Table 3. Multiple regression analysis between presence in virtual environments and usability of the system, intrinsic motivation inventory, and immersive tendencies.

Variables	B	Std. Error	Beta	t	*p*	95,0% Confidence Interval for B	
						Lower Bound	Upper Bound
(Constant)	-68.001	29.619		-2.296	0.029	-128.409	-7.593
SUS	22.682	5.379	0.521	4.217	<0.001	11.712	33.652
IMI	11.408	5.471	0.257	2.085	0.045	0.249	22.567
QPI	0.667	0.204	0.379	3.274	0.003	0.252	1.083

SUS (system usability scale), IMI (intrinsic motivation inventory), QPI (immersive tendencies)

Finally, the Wilcoxon Signed Rank Test was conducted to evaluate the impact of participation in a VR gaming session on participants' emotional responses (Table 4). There was a statistically significant increase in the SAM-pleasure scores from the beginning of the session (M = 3.97, SD = .62) to the end of the session (M = 4.37, SD = .69), $z = -2.84$, $p < .005$, with a medium effect size, r = .48. The mean increase in SAM -pleasure was .40, with a 95% confidence interval ranging from .147 to 653. No other significant differences were seen for SAM arousal or dominance.

Table 4. Findings on the self-assessment manikin score at pre- and post-experience.

Emotional response	Pre- experience Mean (SD)	Post- experience Mean (SD)	Δ	*p*	r
SAM- pleasure	3.97 (0.62)	4.37 (0.69)	0.40	0.005	0.48
SAM- arousal	3.09 (0.95)	3.31 (1.11)	0.22	0.238	0.20
SAM- dominance	3.86 (0.88)	3.74 (1.01)	-0.12	0.206	0.21

SAM (self-assessment manikin); r, effect size

4. Discussion

This study aimed to investigate the association between the presence and the usability of the system, motivation, and immersion in a virtual environment designed for musculoskeletal injury rehabilitation. Additionally, the impact of participation in a VR gaming session on participants' emotional responses was assessed. Overall, the results indicate a positive correlation between the presence in virtual environments and the system's usability, motivation, and immersive tendencies. On the other hand, concerning the emotional response domain, the SAM-pleasure component score significantly increased from the beginning to the end of the session.

According to the literature, increased levels of presence may lead users to adopt behaviors similar to those displayed while facing real word situations (Gonçalves et al., 2019; Slater, 2003). Moreover, previous research has reported that ratings for usability and user experience were correlated with presence in VR (Brade et al., 2017), which is consistent with the results of the present study. Although presence showed positive and strong correlations with immersion and motivation, the most significant relationship was observed with the system's usability. This finding was supported by multiple regression analysis, showing that the system's usability was the strongest predictor of the presence in this virtual environment (52%), followed by immersive tendencies (38%) and intrinsic motivation inventory (26%). The relationship between the presence and the usability of the virtual system seen in our study is aligned with previous research (Busch et al., 2014; Ntokas et al., 2015; Szczurowski & Smith, 2017). This supports the idea of the participants' feeling of "being there" (e.g., the sense of presence), which can improve the system's credibility and encourage them to behave as they would in real-world scenarios (Gonçalves et al., 2019). Indeed, usability and perceived realism are closely connected in virtual environments (Busch et al., 2014). A system with high usability contributes to a more immersive and engaging experience, enhancing the perceived realism. On the other hand, a poorly designed and difficult-to-use system can hinder immersion, making it challenging for users to perceive the virtual world as realistic. Thus, usability is an essential criterion for acceptance of a health-related VR system (Liljegren, 2006), and it concerns how people can use a product with efficacy, efficiency, and satisfaction (Bevan et al., 2015). In this study, the usability findings reflected the accessibility of the virtual system, more specifically, informing the degree of ease or difficulty perceived during the training session (Zhang et al., 2020). Perceptions of comfort during use indicate technology acceptance behavior, contributing to estimating future use of a product (Holden & Rada, 2011). Thus, as shown in a current systematic review study (Kiani et al., 2023), our usability results showed that the VR-based training protocol was attractive and motivating in providing a full rehabilitation designed for musculoskeletal injuries among a healthy adult population. Moreover, the finding is significant since rehabilitation sessions can be long and tedious (Kiani et al., 2023), making it difficult for patients to adhere to treatment.

The importance of usability as a critical criterion for accepting health-related virtual reality (VR) systems has been acknowledged in previous research (Liljegren, 2006). Usability refers to how people can effectively, efficiently, and satisfactorily use a product (Bevan et al., 2015). In this study, the usability findings focused on assessing the accessibility of the virtual system, particularly gauging the perceived level of ease or difficulty experienced during the training session (Zhang et al., 2020). The comfort levels reported during system usage indicate technology acceptance behavior, which, in turn, has implications for predicting the future adoption of the product (Holden & Rada, 2011).

As evidenced in a recent systematic review study (Kiani et al., 2023), our usability results demonstrate that the VR-based training protocol holds considerable appeal and is a motivating tool for delivering comprehensive rehabilitation designed for musculoskeletal injuries among a healthy adult population. This finding assumes significance, given that traditional rehabilitation sessions can often be lengthy and monotonous (Kiani et al., 2023), leading to challenges in patient adherence to treatment protocols.

Another subject worthy of highlighting in our study was the positive correlation between the presence and immersive tendencies found that support the idea that becoming immersed in a virtual environment will contribute to a greater sense of presence while interacting with the virtual environment (Ravaja et al., 2006; Wallach et al., 2010; Witmer & Kline, 1998). This supports the idea that presence is one of the main psychological traits in immersive virtual environments, which designers and developers of virtual gamification systems must assess. Indeed, having a high level of immersive tendencies has been associated with a more playful, spontaneously creative, and imaginative capacity (Newman, 2005; Webster & Martocchio, 1992) and, consequently, a higher likelihood of engagement and interest in new different VR activities. A review study highlighted the promising application of VR in rehabilitation due to its immersive characteristics, which can make the routine of a process lighter and more fun (Rose et al., 2018). A possible immersive advantage of our VR training protocol was the participants' interaction with the virtual environment through natural body movement. Indeed, solving the five VR custom games challenges required control of cognitive commands (i.e., attention, concentration, inhibitory control, visual and spatial planning) and activation of mechanisms underlying the psychomotor apparatus (i.e., strength, balance, coordination, flexibility, endurance). In turn, all this provided participants with new aesthetic experiences, strengthening the learning and correction of motor gestures (Levin et al., 2015; Sucar et al., 2013). In this way, playfulness, immersion, and presence together supported involvement in the VR rehabilitation section (Tao et al., 2021).

As anticipated, in line with the previous findings of the current study, a positive correlation was observed between intrinsic motivation and presence. This underscores the effectiveness of our multigame virtual rehabilitation system, specifically tailored to encompass key physical training aspects within an engaging soccer environment featuring soccer-related stimuli and gamification techniques. The system successfully fosters users' sustained interest and self-determined behavior. This aligns with the findings of Schrader's study (2013), where serious games were shown to elicit a heightened sense of virtual presence and significantly increase learners' motivation (Schrader, 2013). Similarly, in a study involving university students, Lin and Wang (2021) reported that VR technology can effectively enhance intrinsic motivation for learning (Lin & Wang, 2021).

Given the pivotal role of motivation in determining user engagement, the outcomes of this study underscore the importance of considering the sense of presence during the design of VR systems to ensure the creation of motivating environments.

Although the participants in this study performed only one training session, the gamification scenario created indicated significant levels of engagement, motivation, and pleasure. The finding is relevant, as it suggests that the aesthetic experience in the virtual environment has the future potential to awaken the patient's skills and autonomy during a rehabilitation session (Kern et al., 2019; Winter et al., 2021). In addition to being non-invasive, the procedure for simulating real motor realities in a virtual environment stimulated the interaction and satisfaction of the participants (Kern et al., 2019). In rehabilitation after an injury, the motivation to continue the treatment is essential for healing. However, it is fundamental that there is a will to do and that this motivation is intrinsic, therefore, attractive, pleasant, and self-determined (Ryan & Deci, 2000b).

On the other hand, when the stimulus for treatment comes from outside (extrinsic), this can generate the feeling of pressure to do something. In this case, the chances of triggering disinterest or a sense of inadequacy increase (Ryan & Deci, 2000a). Another interesting motivating element that may have been awakened during the gamified VR training session was the avatar personification effect (Latoschik et al., 2016). Studies have reported that, through identification processes associated with motor tasks, there is an increase in immersion in the virtual environment, which in turn stimulates involvement in the game, increasing motivation for the next challenges, which is followed by feelings of pleasure and satisfaction (Lugrin et al., 2015; Ratan & Sah, 2015).

Meantime, our regression model, composed of the usability of the system, immersive tendencies, and intrinsic motivation, explained a respectable amount of 59% of the total variance in the presence of this VR environment for rehabilitation after a musculoskeletal injury. The system's usability was the strongest predictor of VR presence among the personality traits analyzed. The positive relationship between usability, motivation, immersion, and presence in this specific-based VR environment for rehabilitation after a musculoskeletal injury is significant for the following research steps of implementing VR solutions in the musculoskeletal rehabilitation process. These results partly corroborate the idea that VR game participation enhances the player's experiences regarding emotional responses, appreciation, immersion, and presence (Peng et al., 2020). This is an important step for affirming this technological solution as an effective alternative rehabilitation method because it ensures that this system may be helpful for the physiotherapist and meaningful to the end-users. Also, these results bring an important message to game developers and designers that must focus on making the systems usable, engageable, and motivated to increase the feeling of presence.

This pilot study is subject to several limitations. First, for safety reasons at this stage of VR gaming development, we only conducted the study with healthy individuals recruited only from academic institutions. Therefore, we assume our results cannot be fully generalized to other populations, including high-performance athletes. Second, it should be considered that the choice of a therapeutic modality (i.e., VR gaming technology) needs to be aligned with the patient's subjectivities, type of musculoskeletal injury, and severity of the case, as each virtual technology has limitations (Tao et al., 2021). Despite the significant contributions of this study, which introduces an innovative approach in sports, particularly in soccer, through the integration of virtual reality technology to address specific challenges and fulfil distinct requirements in the context of soccer injury rehabilitation, our findings offer empirical support for the unique advantages and features of these VR systems. These include an immersive and engaging user experience and enhanced rehabilitation compliance facilitated by an augmented emotional response. These characteristics set these systems apart from conventional rehabilitation methods.

Furthermore, while prior research has explored the utilization of VR systems in soccer, the focus has predominantly revolved around decision-making and skills development (Shimi et al., 2021; Wood et al., 2021). In contrast, to the best of our knowledge, our investigation represents the first study dedicated to VR systems designed explicitly for injury rehabilitation in the context of soccer.

Another strong point of this study was the information about the potential of a protocol based on VR gaming for rehabilitation after musculoskeletal injuries that are recognized as one of the most common causes of physical disability and long-term pain (Lee et al., 2016). Finally, although our findings revealed satisfactory levels of usability, immersion, and intrinsic motivation for a VR gaming section, it is important to carry out experimental and longitudinal studies to expand and qualify the use of this methodology in the recovery of musculoskeletal injuries.

5. Conclusions

The results of our study validated the hypothesis that a correlation exists between the system's usability, motivation, and immersion and the sense of presence experienced within the VR environment for musculoskeletal injury rehabilitation. The implications of these results underscore the importance of considering the interplay between system usability, motivation, immersion, and presence when designing and implementing VR-based musculoskeletal injury rehabilitation programs. By prioritizing user engagement and experience (i.e., usability, motivation and immersion), VR technology can significantly enhance the effectiveness and acceptance of rehabilitation interventions.

The findings of this study also validated the hypothesis that engaging in virtual experience improves as there is an increase in pleasure from the beginning to the end of the session, in line with common psychological responses. This is an important conclusion because it means that this Virtual system could enhance user satisfaction and long-term engagement and positively impact learning, well-being, motivation, and user retention. Considering common psychological responses and factors that evoke pleasure can inform design decisions for more effective and enjoyable VR applications. Future research must conduct experimental and longitudinal studies to broaden and enhance the application of this methodology in musculoskeletal injury recovery.

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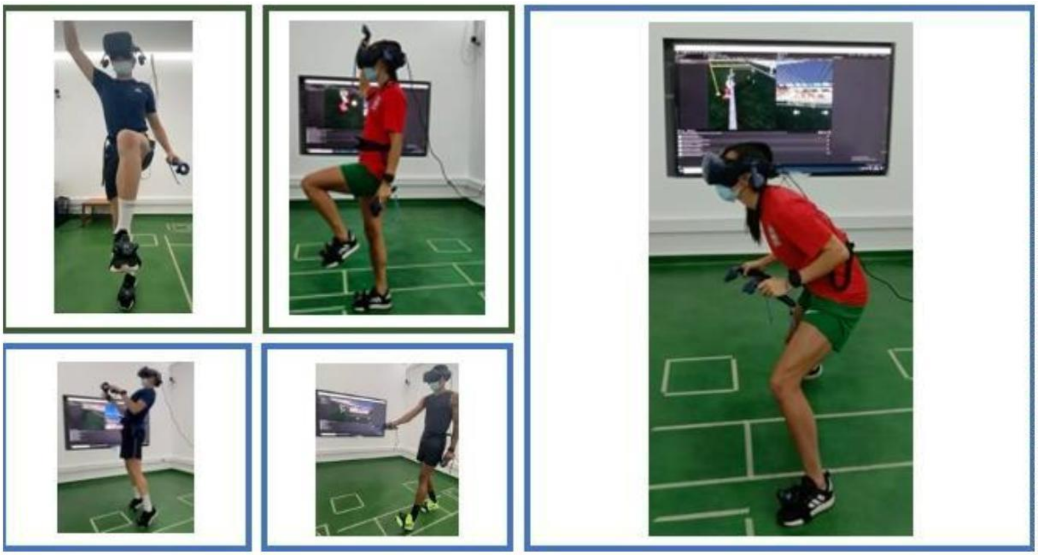

Figure 1. Customized VR games designed for musculoskeletal injury rehabilitation.