Evaluating the effectiveness of virtual reality-based rehabilitation programs for post-injury recovery in adolescent athletes: a mixed-methods study

Evaluación de la eficacia de los programas de rehabilitación basados en realidad virtual para la recuperación de deportistas adolescentes tras lesiones: un estudio de métodos mixtos

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Abstract

Introduction: the importance of post-injury rehabilitation for teenage athletes demands innovative methods because traditional practices fail to sustain student athlete participation. VR-based rehabilitation creates interactive recovery programs which might advance physical healing together with mental drive.
Objective: the research investigates how well VR-based rehabilitation works against traditional approaches for both physical healing and psychological involvement in adolescent athletes.
Methodology: sixty adolescent athletes (aged 13–18) received their rehabilitation through random assignment into two groups: one involved traditional approaches while the other received VR-based rehabilitation. The research measured recovery outcomes at three time points: baseline, 4 weeks and 8 weeks. The measured outcomes included range of motion (ROM), muscle strength, return to sport (RTS) time and pain perception. The VR group members shared their experiences through semi-structured interview methods.
Results: the subjects in the VR group achieved greater improvements in ROM ($p = 0.02$) and muscle strength ($p = 0.03$) and RTS time ($p = 0.01$). People who used VR reported stronger motivation and engagement although these benefits brought increased worry about re-injuring their knee. Subject participants achieved better results in their rehabilitation by using immersive VR interventions.
Conclusions: virtual reality-based rehabilitation enables adolescent athletes to restore physical well-being as well as emotional well-being. The interactive features of this approach improve patient commitment which accelerates their recovery time. Future investigations need to analyze extended advantages and expanded medical applications within sports medicine.

Keywords

Adolescent athletes; Mixed-methods; Post-injury recovery; Sports medicine; Virtual reality rehabilitation.

Resumen

Introducción: la importancia de la rehabilitación post-lesión para los atletas adolescentes exige métodos innovadores porque las prácticas tradicionales no logran sostener la participación de los estudiantes atletas. La rehabilitación basada en realidad virtual crea programas de recuperación interactivos que pueden promover la curación física junto con el impulso mental.
Objetivo: La investigación investiga qué tan bien funciona la rehabilitación basada en realidad virtual frente a los enfoques tradicionales tanto para el cuidado físico como para el compromiso psicológico en atletas adolescentes.
Metodología: sesenta atletas adolescentes (de 13 a 18 años) recibieron su rehabilitación mediante asignación aleatoria en dos grupos: uno involucró enfoques tradicionales mientras que el otro recibió rehabilitación basada en realidad virtual. La investigación midió los resultados de la recuperación en tres momentos: inicial, 4 semanas y 8 semanas. Los resultados medidos incluyeron rango de movimiento (ROM), fuerza muscular, tiempo de regreso al deporte (RTS) y percepción del dolor. Los miembros del grupo de realidad virtual compartieron sus experiencias mediante métodos de entrevista semiestructurados.
Resultados: Los sujetos del grupo VR lograron mayores mejoras en el ROM ($p = 0,02$), la fuerza muscular ($p = 0,03$) y el tiempo RTS ($p = 0,01$). Las personas que utilizaron la realidad virtual informaron una mayor motivación y compromiso, aunque estos beneficios generaron una mayor preocupación por volver a lesionarse la rodilla. Los participantes de los sujetos lograron mejores resultados en su rehabilitación mediante el uso de intervenciones inmersivas de realidad virtual.
Conclusiones: la rehabilitación basada en realidad virtual permite a los deportistas adolescentes recuperar el bienestar físico y emocional. Las características interactivas de este enfoque mejoran el compromiso del paciente, lo que acelera su tiempo de recuperación. Las investigaciones futuras deben analizar las ventajas ampliadas y las aplicaciones médicas ampliadas dentro de la medicina deportiva.

Palabras clave

Atletas adolescentes; Medicina deportiva; Métodos mixtos; Recuperación post-lesión; Rehabilitación con realidad virtual.

Introduction

The question of protection and recovery plays a critical role in the training process of adolescents interested in competitive sports. Young people are at greater risk of musculoskeletal injuries because of growth and skeletal maturation and reminding that optimal and highly effective rehabilitation methods are needed for adolescent children, psychological status, and time of recovery (Maffulli et al., 2010). New technologies like virtual reality technology (VR), have the potential to introduce enhanced techniques in rehabilitation; VR-based programs are applicable as they enable real-life, controlled environments for exercise as well as therapy (Nieto-Escamez et al., 2023). Virtual reality may also present a valuable opportunity for improving motor learning, cognitive involvement, and fidelity to rehabilitation procedures in game-like, interactive, and incentive environments (Choi et al., 2021; Georgiev et al., 2021).

Previous rehabilitation interventions for adolescent athletes have incorporated boring and repetitive physical exercises that may result in poor adherence to the programs (Mudrak et al., 2018). On the other hand, VR-based rehabilitation has shown better compliance and actual involvement as these programs can mimic the real-life sports context, and hence the athletes can perform sport-related movements without any risk (Kim et al., 2013). Moreover, the VR programs can be easily modified in terms of difficulty thus meeting the needs of the recovering athletes depending on their progress (Shrey et al., 2011; Voinescu et al., 2021). These adaptive capabilities are especially useful for adolescent athletes whose rehabilitation needs may be dynamic depending on the rate of injury healing (Chen, 2021).

Virtual Reality-based rehabilitation has additional advantages besides rehabilitation of the affected body part. Several studies show that the psychological implications of being a teenage athlete include 'anxiety, sadness, and the fear of re-injury', which may prevent an athlete from returning to sports throughout the healing period of an injury, among other things (Podlog and Eklund, 2006). VR therapies have been shown to improve psychological impacts by instilling a sense of achievement and overcoming the fear of re-injury through systematic and orderly exposure to sport-related situations during practice. This is especially true in adolescent clients, where psychological preparedness is an important predictor of rehabilitation and return to play (Forsdyke et al., 2016). However, more literature is warranted especially in adolescents using VR for rehabilitation because most studies are still emerging (Ravi et al., 2017; Lal et al., 2022). Many current investigations have been conducted on adult sportsmen or non-athletes, and thus, there is a lack of knowledge about the impacts of VR rehabilitation on the physiological and psychological requirements of adolescent athletes (Cameirão et al., 2010). Further, objective measures which include 'range of motion, muscle strength, and time to return to sports are also assessed', but there is a lack of qualitative data that captures the experiences of adolescent athletes receiving VR rehabilitation (Weiss & Katz, 2004). Health professionals need to acknowledge the athlete's perception of VR self--efficiency, enjoyment, and motivation as this knocks the door for customizing interventions that promote adherence as well as critical factors that determine recovery (Gumaa et al., 2019).

To fill these gaps, this mixed-methods study will assess the utility of VR-based rehabilitation programs for adolescent athletes with musculoskeletal injuries. Thus, by including quantitative measures of the physical recovery with a qualitative understanding of the athletes' experience this study aims to present a broad picture of how VR-based rehabilitation can contribute to the physical and psychological aspects of the recovery process. In detail, we plan to examine whether VR rehabilitation is more effective in enhancing recovery outcomes than conventional approaches and how adolescent athletes perceive the effectiveness of VR in enhancing their motivation, involvement, and preparedness to return to play (Ravi et al., 2017; Costa et al., 2022). In conclusion, VR-based rehabilitation appears to hold considerable potential in increasing the effectiveness of the rehabilitation of adolescent athletes. However, more stringent, population-based trials are necessary to confirm its efficacy. The results of this research is going to add to the currently available research on the efficacy of VR-based programs for young athlete recovery and will provide important recommendations for the future development of sports medicine and rehabilitation (Tokgöz et al., 2022; Fan et al., 2023).

Significance of the Study

The present work is relevant as it aims at identifying important factors that may be targeted in the development of effective rehabilitation programs for adolescent athletes, a vulnerable group that often sustains sports injuries during the period of their most rapid growth and development. Virtual reality-

based rehabilitation is a new concept that integrates conventional physical therapy with a fun fun-filled environment which can be very helpful in the overall physical as well as psychological health of the patient. In this way, the findings of this study will be useful for assessing the effectiveness of these programs and identifying how new technologies can help increase compliance with rehabilitation, minimize the likelihood of re-injury, and improve the outcome of recovery. In addition, the blend of qualitative and quantitative research will provide a more detailed understanding of not only the increase in physical performance but also the perceived needs of young athletes and improve the effectiveness of VR programs. This study could provide the basis for the creation of best practices for the use of virtual reality in sports rehabilitation for adolescents, which could help enhance the existing trends in sports medicine.

Research Aim

To assess the efficacy of virtual reality-based rehabilitation programs in post-injury rehabilitation in adolescent athletes in terms of physical rehabilitation, as well as the perceptions of the participants.

Research Objectives

1. To examine the difference in physical recovery parameters (motion, muscle strength, time to resume sports) in patients who underwent VR-based and traditional rehabilitation.
2. To investigate the psychological outcomes of adolescent athletes participating in VR-based rehabilitation programs such as motivation level, engagement level, and fear of re-injury.
3. For the objective of understanding the phenomenological experiences of adolescent athletes who are going through VR-based rehabilitation, qualitative interviews or surveys could be used.

Method

Study Design

The current research utilized a mixed-methods approach to assess the efficiency of VR-based rehabilitation applications in sports-injured adolescent athletes. The quantitative part concerned the assessment of the physical recovery indicators, while the qualitative part revealed participants' perceptions of the VR rehabilitation programs. The research was carried out for six months.

Participants

60 adolescent athletes aged between 13 and 18 years with musculoskeletal injuries that needed rehabilitation were selected from local sports clubs and rehabilitation centers. Subjects were recruited if they had undergone the first phase of the injury healing process and received a physician's permission to start rehabilitation. The exclusion criteria were patients with neurological diseases, chronic pain, or previous exposure to VR rehabilitation. All participants and their legal guardians provided signed and written informed consent.

Procedure

Intervention

Participants were randomly allocated to one of two groups: the VR-based rehabilitation group or the control group which received the conventional rehabilitation intervention. The VR group participated in a rehabilitation program with the help of an immersive VR system which was aimed at the imitation of sport-specific movements and exercises. This system provided real-time feedback and was unique to the type of injury and the stage of the participant's rehabilitation process. The traditional rehabilitation group performed conventional rehabilitation exercises as per the study protocol including supervised exercises focusing on strength, flexibility, and range of motion.

Quantitative Data Collection

Physical recovery was assessed at pre-intervention, mid-intervention, and post-intervention, which included 4 weeks and 8 weeks respectively. The following objective measures were used:

- Range of Motion (ROM): Measured using a goniometer in case of joint injury.

- Muscle Strength: As assessed by isokinetic dynamometry.
- Time to Return to Sport (RTS): Measured in the number of days it took for the participants to be cleared to get back to competitive sports.
- Pain Perception: Measured with the Visual Analog Scale (VAS).
- Functional Performance Tests: Done by using single leg hop test and agility shuttle run test.

Qualitative Data Collection

Respondents in the VR-based rehabilitation group underwent interviews in a semi-structured format, with focus group discussions. Interviews were conducted to gain a more detailed understanding of their perception of the VR program, their motivation, engagement, and perceived benefits to their rehabilitation process. The focus group discussions allowed the discussion of more general issues and experiences.

Data analysis

Quantitative Analysis: Quantitative measures were analyzed using SPSS (Version 27.0). Descriptive analysis was performed for all the variables and a t-test was used to compare the difference between the VR group and the control group at each time point. Intraclass correlation analysis was used to compare changes within the groups across time using repeated measures ANOVA. Statistical significance was tested at $p < 0.05$.

Qualitative Analysis: The interview and focus group data were transcribed in full and coded using thematic analysis with NVivo software. The coding framework was constructed concerning the research objectives and themes were derived through a process of coding. The data collected was then cross-checked with the quantitative data to give a holistic view of the efficacy of VR-based rehabilitation.

Ethical Considerations

This research was done under the conditions outlined by the Institutional Review Board (IRB) of the host institution and all the guidelines regarding human subject research were followed. The participants were told that they were free to pull out of the study at any time without any consequences and their identity was not divulged at any one time throughout the study.

Results

Participant Demographics

'The study comprised 60 adolescent athletes: 30 in the VR-based rehabilitation group and 30 in the standard rehabilitation group. Table 1 shows the participants' demographic information. Participants had an average age of 15.8 ± 1.2 years. There were no significant variations in age, gender distribution, or kind of injury between the two groups ($p > 0.05$)'.

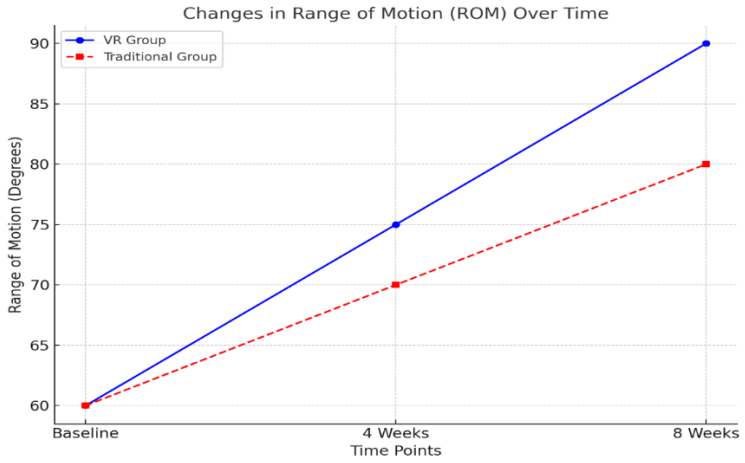
Table 1. Participant Demographics

Variable	VR Group (n=30)	Traditional Group (n=30)	p-value
Age (years, mean ± SD)	15.7 ± 1.3	15.9 ± 1.2	0.53
Gender (Male/Female)	18/12	17/13	0.78
Injury Type (Sprain/Strain)	16/14	15/15	0.85

Physical Recovery Outcomes

Range of Motion (ROM): 'At post-intervention, both VR-based and conventional therapy groups had greater range of motion in the damaged joint compared to the baseline ($p < 0.05$). At 8 weeks, the VR group had a significantly higher ROM than the standard group ($p = 0.02$). Figure 1 depicts the changes in ROM over time for both groups'.

Figure 1. Changes in Range of Motion (ROM) Over Time



Muscle Strength: 'Isokinetic dynamometry revealed substantial increases in muscle strength for both groups ($p < 0.05$). The VR-based group showed a considerably larger percentage increase in muscle strength than the traditional group (27% vs. 18%, $p = 0.03$)'. This suggests that the VR-based intervention was more effective in muscle rehabilitation (Table 2).

Table 2. Muscle Strength Changes (Mean ± SD)

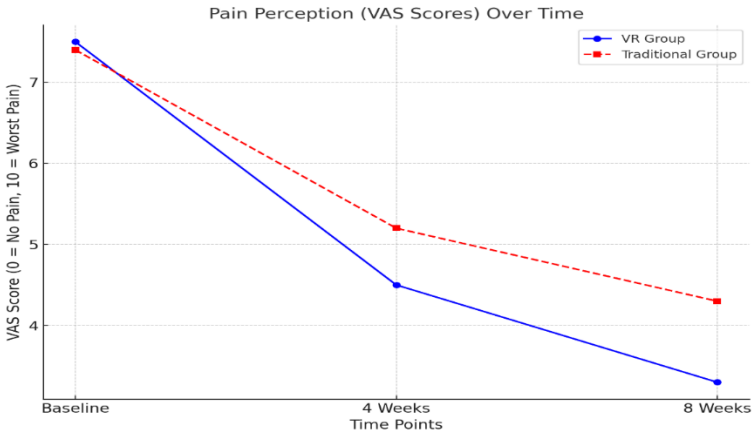
Timepoint	VR Group (N·m)	Traditional Group (N·m)	p-value
Baseline	54.6 ± 10.2	55.1 ± 9.8	0.86
4 Weeks	68.3 ± 11.4	63.5 ± 10.9	0.04
8 Weeks	78.9 ± 12.3	70.1 ± 11.8	0.03

Time to Return to Sport (RTS): 'The time to return to sport was considerably shorter in the VR-based rehabilitation group, 6.2 ± 1.1 weeks assessed to 7.8 ± 1.4 weeks in the traditional group, $p = 0.01$'. This result implies that VR-based rehabilitation programs may help in the early preparation of athletes for competitive sports.

Pain Perception

'Patients' pain, which was measured by the VAS, reduced in both groups over the 8 weeks ($p < 0.05$). However, the VR group recorded a higher improvement in the mean VAS score reduction of 4.2 as compared to the traditional group of 3.1 ($p = 0.03$) (Figure 2)'.

Figure 2. Pain Perception (VAS Scores) Across Time Points



Psychological Outcomes

Incentivization: Quantitative analysis showed that the VR group had higher scores on motivation and engagement during the rehabilitation process according to participants' perceptions. They said that the VR environment was 'fun' and 'challenging,' which made them work harder to complete the exercises. Some of the participants pointed out that due to the VR tasks, the rehabilitation process is more like playing a game. The survey also provided evidence for these findings as 85 percent of the VR participants reported high motivation compared to only 60 percent of the traditional group.

Fear of Re-Injury: 'The findings pointed out that the respondents of the VR group had a lesser perceived fear of re-injury than the respondents of the traditional group. The slow progressive exposure to movements specific to their sport in a virtual reality environment allowed them to rebuild confidence in their affected body part'. The thematic analysis revealed that the factors that helped to defeated the fear of re-injury were "confidence building" and "gradual exposure".

Discussion

The findings of this research show that VR-based rehabilitation interventions are more effective than conventional rehabilitation approaches in facilitating motor recovery and improving psychological health in adolescent athletes. In the case of the application of immersive VR environments, it can be noted that not only does the recovery process occur more quickly, but motivation, engagement, and psychological preparation for a return to sports are enhanced.

Physical Recovery: The results show that range of motion and muscle strength were significantly enhanced by using VR-based rehabilitation as compared to the traditional one. This may be because VR is highly engaging and involves elements of gameplay that demand the patient to be active and to perform the rehabilitation exercises repeatedly (Asadzadeh et al., 2024). The enhancement of physical performance may have been because participants were able to practice movements that are specific to real-life sports situations at a faster and safer rate (Georgiev et al., 2021).

The shorter time to return to sport observed in the VR group is a particularly important finding because it indicates that VR-based rehabilitation might enable adolescent athletes to return to competitive sports more rapidly than with conventional approaches. This accelerated recovery may be attributed to the fact that VR systems offer better motor learning and improved cognitive activity. Also, in the present study, real-time feedback is used in the VR systems which enables the subject to have individual adjustments in the rehabilitation intensity, which might have led to a greater improvement in muscle strength and functional performance.

Psychological Impact: In addition to the physical effects, the research also showed the psychological effects of using VR-based rehabilitation. The qualitative results indicate that VR rehabilitation programs increase motivation and participation levels, which are highly important for rehabilitation compliance. The features of VR seem to minimize the boredom that is usually experienced when undertaking conventional rehabilitation exercises, which will be more appealing to adolescent athletes. It may be assumed that this increased engagement contributed to higher levels of adherence and, therefore, improved recovery.

Furthermore, the decreased perceived risk of re-injury in the participants of the VR group is consistent with the findings that VR can act as a useful instrument for psychological rehabilitation (Forsdyke et al., 2016). As the environment is well controlled, VR assists in regaining confidence and minimizing anxiety about the reinjury.

Limitations and Future Directions: Several constraints should be mentioned: First, the sample size was tiny, hence the findings cannot be extrapolated to the entire population. The findings of this study should be replicated on bigger and more diverse groups in the future. Furthermore, this study only included adolescent athletes with musculoskeletal injuries, and future research should examine the efficacy of VR therapy in athletes with other types of injuries or at different ages.

As a result, the study strongly supports the use of VR-based rehabilitation as an effective and novel technique for improving both physical and psychological recovery in adolescent athletes. The increased involvement and decreased fear of re-injury associated with VR programs indicate that it will be a game

changer in sports rehabilitation. Future studies must investigate the durable efficiency of VR rehabilitation and its use in different sports and for different injuries.

Conclusions

The findings of this research support the proposition that VR-based rehabilitation interventions improve both physical and psychological recovery in adolescent athletes with post-injury conditions. The study proves that VR-enhanced rehabilitation led to better outcomes in terms of range of motion, muscle strength, and time to return to sport than conventional methods. In addition, the enhancement of contexts to become more game-like enhanced motivation with rehabilitation regimes as well as compliance levels and reduced re-injury phobia levels. These benefits point to the fact that, there is much that is positive about VR and that it could go a long way to revolutionize the method that is used in the rehabilitation of chief injury, especially among young athletes who may need new methods to keep them motivated when recovering from their injuries. The nature of this study where both quantitative outcomes and qualitative insights were employed equips the current study with a rich understanding of the effectiveness of the VR rehabilitation strategies. Such findings revealed that VR can support psychological protection and supervise overall satisfaction concerning rehabilitation among adolescent athletes. Thus, the results of the current investigation highlight the necessity of future research aimed at determining the short-term and future effects of VR-based rehabilitation, as well as the implementation of this technology in the practice of various injuries and sports. Furthermore, the enhancement of specific VR programs for coverage of specific athletic injury needs and rehabilitation phases would improve the overall recovery profile of the adolescent athlete. As such, this study contributes to the development of technology use in rehabilitation and provides valuable directions for enhancing the quality and effectiveness of the recovery process in sports medicine for young athletes.

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