BRAIN. Broad Research in Artificial Intelligence and Neuroscience

e-ISSN: 2067-3957 | p-ISSN: 2068-0473

Covered in: Web of Science (ESCI); EBSCO; JERIH PLUS (hkdir.no); IndexCopernicus; Google Scholar; SHERPA/RoMEO; ArticleReach Direct; WorldCat; CrossRef; Peeref; Bridge of Knowledge (mostwiedzy.pl); abcdindex.com; Editage; Ingenta Connect Publication; OALib; scite.ai; Scholar9; Scientific and Technical Information Portal; FID Move; ADVANCED SCIENCES INDEX (European Science Evaluation Center, neredataltics.org); ivySCI; exaly.com; Journal Selector Tool (letpub.com); Citefactor.org; fatcat!; ZDB catalogue; Catalogue SUDOC (abes.fr); OpenAlex; Wikidata; The ISSN Portal; Socolar; KVK-Volltitel (kit.edu)

2024, Volume 15, Issue 3, pages: 141-152.

Submitted: August 25th, 2024| *Accepted for publication:* September 26th, 2024

Utilizing Virtual Reality in the Treatment of Subacromial Impingement Syndrome: Enhancing Efficacy Through Integration with the Simple Shoulder Test and Pain Arch Test

Daniel Madalin Coja [1]
Ilie Onu [2]
Ana Onu [3]
Daniel Andrei Iordan [4]
Virgil Ene-Voiculescu [5]
Laurentiu-Gabriel Talaghir [6]

[1] Department of Individual Sports and Physiotherapy, Faculty of Physical Education and Sport, "Dunarea de Jos" University of Galati, 800008 Galati, Romania. Center of Physical Therapy and Rehabilitation, "Dunarea de Jos" University of Galati, 800008 Galati, Romania, daniel.coja@ugal.ro, https://orcid.org/0009-0007-9953-393X

[2] University of Medicine and Pharmacy "Grigore T. Popa" Faculty of Medical Bioengineering, Iasi, 700454 Iasi, Romania. Department of Physiotherapy, Elipetro Med Clinic, 610119 Piatra Neamt, Romania. Center of Physical Therapy and Rehabilitation, "Dunarea de Jos" University of Galati, 800008 Galati, Romania, ilie.onu@umfiasi.ro, https://orcid.org/0000-0002-1003-0719

[3] Department of Physiotherapy, Elipetro Med Clinic, 610119 Piatra Neamt, Romania, onu.ana80@gmail.com

[4] Department of Individual Sports and Physiotherapy, Faculty of Physical Education and Sport, "Dunarea de Jos" University of Galati, 800008 Galati, Romania. Center of Physical Therapy and Rehabilitation, "Dunarea de Jos" University of Galati, 800008 Galati, Romania, daniel.iordan@ugal.ro, https://orcid.org/0000-0001-6422-2030

[5] Naval Academy "Mircea cel Bătrîn", Fulgerului street no.1, 900218, Constanța, Romania, virgil.ene@anmb.ro, https://orcid.org/0000-0002-1451-207X

[6] Department of Individual Sports and Physiotherapy, Faculty of Physical Education and Sport, "Dunarea de Jos" University of Galati, 800008 Galati, Romania. Center of Physical Therapy and Rehabilitation, "Dunarea de Jos" University of Galati, 800008 Galati, Romania, gabriel.talaghir@ugal.ro, https://orcid.org/0000-0002-3133-9192

*Correspondence: ilie.onu@umfiasi.ro

Abstract: *Subacromial impingement syndrome (SIS) is a prevalent cause of shoulder pain and dysfunction. This study investigates the impact of virtual reality (VR) therapy on shoulder function, joint dysfunction, and pain in SIS patients, comparing its effectiveness to traditional rehabilitation methods. Materials and Methods: Over 50 weeks, 288 participants with SIS were recruited and divided into two groups: an experimental group (EG) receiving VR-augmented therapy and a control group (CG) undergoing conventional rehabilitation. Recovery was assessed using the Painful Arch Test and Simple Shoulder Test (SST) at key intervals (T0, T1, T2, and T3). Statistical analysis was conducted to evaluate recovery times and functional improvements. Results: The EG showed significantly faster recovery with a mean duration of 6.04 weeks compared to 7.01 weeks for the CG ($p = 0.0041$), as determined by the Welch Two Sample t-test. The 95% confidence interval (0.3137 to 1.6330) confirmed the reliability of these findings. The VR group demonstrated sustained functional improvements, as evidenced by narrower interquartile ranges and more stable SST scores over time, particularly by Session 18, indicating reduced variability and faster recovery compared to the CG. Conclusion: VR therapy significantly accelerates recovery in SIS patients, offering faster and more consistent outcomes compared to conventional rehabilitation. These findings highlight the potential of VR as a non-invasive and effective treatment for improving shoulder function in SIS. Further research is warranted to explore its long-term efficacy and potential for personalized rehabilitation programs.*

Keywords: *subacromial impingement syndrome; virtual reality; shoulder functionality; rehabilitation*

How to cite: Coja, D. M., Onu, I., Onu, A., Iordan, D. A., Ene-Voiculescu, V., & Talaghir, L.-G. (2024). Utilizing virtual reality in the treatment of subacromial impingement syndrome: Enhancing efficacy through integration with the Simple Shoulder Test and Pain Arch Test. *BRAIN: Broad Research in Artificial Intelligence and Neuroscience*, 15(3), 141-152. https://doi.org/10.70594/brain/15.3/10

1. Introduction

In an era marked by rapid technological advancement, virtual reality (VR) has earned its place in society, becoming a fascinating and highly relevant concept (Carvalho et al., 2010; North et. al., 2017). From the first concepts in the 1930s to the present day, the increased accessibility of this technology has led to a growing popularity among the general public, placing it at the forefront of technologies used in a variety of fields. VR is a combination of hardware and software that gives users an immersive experience in computer-generated artificial worlds, whether they simulate the real environment or create a completely different environment (Hoffman, 2004). This immersive experience is based on interaction and immersion, allowing users to feel completely absorbed in the virtual environment, interact with objects, and experience virtual events as if they were real (North & North, 2002). The dynamics of computer-generated 3D environments and immersive sounds complete this experience, allowing exploration in all directions and adding an immersive auditory dimension (Wiederhold & Wiederhold, 2005).

In the medical field, VR has become a powerful tool in the treatment and recovery processes (Jang et. al, 2002). By simulating stimulating environments, VR provides patients with immersive and interactive experiences, motivating them to a greater extent than traditional methods (Levac & Galvin, 2013; Bohil, Alicea & Biocca, 2011). VR can also modulate feelings of pain and anxiety associated with medical procedures. In physical recovery processes, the use of VR involves the creation of attractive and interactive digital environments where patients can perform specific movements to restore impaired body functions (Bohil, Alicea & Biocca, 2011).

Nam et al. in 2024 developed a VR application for shoulder rehabilitation using Meta Quest 2 technology, designed to assist patients after surgery by guiding them through personalized exercises at home. The app supports various surgical procedures, allowing patients to perform exercises while mimicking avatar movements in a 3D environment. Key benefits include increased patient engagement, reduced reliance on clinic visits, and reduced costs, along with improved rehabilitation experiences compared to traditional methods. Future improvements may involve the integration of mixed reality and IMU sensors for improved feedback on joint angles. Preliminary results indicate that VR rehabilitation can significantly enhance motivation and adherence to rehabilitation programs, promising better clinical outcomes (Nam et al., 2024).

Tokgöz et al. in 2022 in a literature review explores the use of VR in the rehabilitation of upper limb injuries and diseases. The review analyzed 11 studies and categorized VR technologies into high-end multisensory and game-based systems. Findings indicate that VR is comparable to traditional rehabilitation in promoting functional recovery, with additional benefits in terms of patient motivation and satisfaction. VR effectively facilitates training in activities of daily living, producing improvements in range of motion and pain reduction. The study emphasizes the need for evidence-based VR technologies and highlights their potential to improve rehabilitation practices through user-oriented design (Tokgöz et al., 2022).

Lohre et al. in 2020 explores the emerging role of VR in shoulder and elbow surgery, focusing on its applications in preoperative planning, intraoperative support, and surgical education. Despite its increasing prevalence, the integration of VR in orthopaedics remains limited compared to other surgical fields, with the existing literature presenting a spectrum of levels of evidence that complicates the assessment of its effectiveness. A significant challenge is the ambiguous terminology surrounding immersive VR (iVR), which hinders clear communication and standardization between studies. Furthermore, while VR training tools, particularly arthroscopic simulators, show promise, there is a notable lack of evidence to support their transfer validity in real-life operating room scenarios (Lohre et al., 202).

Park et al 2021 evaluated the efficacy of a rehabilitation program incorporating a wearable glove device in conjunction with a game-based VR system on upper limb function, activities of daily living, and rehabilitation participation among acute stroke patients. A total of 44 participants were randomly assigned to either the experimental group, which received the VR-enhanced therapy,

or the control group, which underwent conventional physical therapy alone. Post-intervention assessments revealed that the experimental group demonstrated significantly greater improvements in hand strength, functional hand use, and daily living activities compared to the control group. These findings suggest that integrating wearable technology into rehabilitation can enhance patient engagement and outcomes, offering a valuable complement to traditional therapeutic approaches (Park, An & Lim, 2021).

Carnevale et al 2021 evaluate the accuracy of the Oculus Quest 2 in measuring translational and rotational displacements for shoulder rehabilitation. Using a setup designed for varying upper limb movements, the controller's measurements were compared to a Qualisys optical capture system. Results indicated a mean absolute error of 13.52 ± 6.57 mm for translational displacements at a distance of 500 mm, and a maximum error of 1.11 ± 0.37° for rotational displacements at 40° around the z-axis. These findings suggest that the Oculus Quest 2 is a viable alternative to traditional motion analysis systems due to its inside-out tracking capabilities and cost-effectiveness. Overall, the device shows promise for enhancing the monitoring of upper limb movements during rehabilitation for patients with shoulder musculoskeletal conditions (Carnevale et al., 2021).

Subacromial impingement syndrome (SIS), a common shoulder condition, can be effectively treated by integrating virtual reality into the recovery process (Krijn et al., 2004). In this context, the Simple Shoulder Test (SIS) is a valuable tool used to assess shoulder function and mobility in people with shoulder problems (Fu et al., 1991). The test involves performing a series of movements and tasks that mimic normal daily activities, and a positive result indicates difficulty or discomfort in performing these movements, suggestive of impaired shoulder function (Kirkley, Griffin & Dainty, 2003).

In addition, the Pain Arch Test is another crucial tool used in the evaluation of shoulder conditions. It consists of assessing shoulder pain and tenderness and providing essential information for diagnosis and management (Harvie et al., 2005).

By integrating these tests into personalized virtual environments tailored to individual patient needs, VR can be used to monitor progress and adjust treatment accordingly (Angst et al., 2011; Naghdi et al., 2019). This approach not only improves the effectiveness of treatment but also increases patient satisfaction, helping to advance the field of medical recovery in the modern technological age.

2. Materials and Methods

2.1. Trial Procedure

Our methodology involved the careful selection of adult participants, aged between 18 and 65 years, with no previous experience in VR rehabilitation therapy. Recruitment was done from clinics and medical centers through direct referrals to the study, ensuring a representative demographic base. The study was carried out between October 1, 2022, and October 14, 2023, the treatment was made in the Galati rehabilitation center. The study received approval from the ethics committee of the Elipetro Med Centre, with no.12 / August 25, 2022, and adheres to the principles outlined in the Helsinki Declaration. Patients provided informal consent and willingly agreed to participate in the study.

The duration of the study was 50 weeks with a working capacity of 18 participants for both the experimental and control groups, resulting in a maximum combined employment of 36 participants at any one time, with a time of average recovery estimated based on specialized literature predominantly between 5-8 weeks. To maximize sample size and fully utilize available resources, the study was designed to continuously recruit new participants. Once a participant (from either group) reaches the established recovery criteria, they exit the study. Simultaneously, a new participant is recruited, ensuring that the laboratory is operating at its optimal capacity, the criterion used is the interpretation of three consecutive scores of zero on the Painful Arch Test as an indicator of the participant's recovery. This criterion was rooted in the clinical understanding that the

consistent absence of pain during arch motion is a robust surrogate for the restoration of shoulder function.

2.2. Virtual reality devices in research

The Oculus Rift S is a technology product created by Lenovo in partnership with Facebook and is the second generation in its series of glasses with enhanced features and performance, created by the aforementioned company, the first being the Oculus Rift. (Oculus Rift S Features | Oculus, n.d).

The headset that comes right at the eyes covers the entire visual perimeter and prevents light from entering which could blur the transposition of images. Thanks to the redesigned-for-speed halo headband, the Rift S can be placed firmly and comfortably in place with a quick twist of the headband's thumbwheel, so the headset can take over or amplify your fastest reactions. (Setup | Oculus, n.d, Oculus Rift Software Install Patch | Oculus, n.d) The next-generation lenses and sharper display deliver a brighter, more vivid color and reduced distortion (the "screen-door effect").

The advanced hardware works seamlessly with Oculus software innovations to deliver an enjoyable user experience on a wide range of PCs. The Oculus Insight system translates your movements into VR, no matter which direction you're looking in, and gives you a room-scaling tracking experience without the use of external sensors. Built into the headset are two specially designed speakers, which create a three-dimensional sound effect while allowing the user to hear everything going on around them. (Oculus Rift S: Full Specification - VRcompare, n.d)

This type of device also comes with two joysticks to control application settings. Using the Oculus Touch controllers, you can translate your hands and gestures into the game. Hits, throws, and catches appear in VR with intuitive, realistic precision. (14 Amazing Oculus VR Headset For 2023 | Robots.net, n.d)

2.3. Study Design

The research used a randomized controlled trial (RCT) design. This choice ensured that confounding variables are minimized and the effects of VR-augmented therapy can be directly compared to traditional rehabilitation methods, despite the methodology being differentiated by the very nature of the therapeutic intervention structure.

Control group (CG): Participants followed traditional methods of rehabilitation for SIS, with sessions three times per week, following best practice standards. Each session lasted 60 minutes, including short intermittent breaks and adjustments which is approximately 40 minutes per week. Half of the participants engaged in a Monday-Wednesday-Friday schedule, while the remainder followed a Tuesday-Thursday Saturday training schedule. This division ensured optimal use of the unit, allowing for optimized use of training resources, unobstructed monitoring, and avoiding overcrowding. Consequently, their cumulative weekly exposure to training was approximately 180 minutes, of which a total of 140 minutes was actual work.

Experimental group (EG): Participants will be immersed in a VR-augmented rehabilitation program with daily sessions to match the cumulative training duration of the CG. Each session lasted approximately 30 minutes logistically, with a pre-session protocol of 10 minutes, consisting mainly of the induction of the participant and the comfortable attachment of the VR device – the working protocol also involves checking its compliant positioning, the same every session, followed by a concentrated 20-minute VR training regimen, which is the actual work.

EG participated daily, culminating in a total weekly training time of 140 minutes. This structure allowed the evaluation of the cumulative effects of the VR sessions, especially given their uninterrupted frequency and the absence of significant breaks. In total, the EG had about 140 minutes of actual work.

Our study used a computerized random number generator to randomly assign subsets to either CG or GE, ensuring an unbiased allocation process. Stratified randomization was applied based on key factors such as age, sex, and lesion severity to maintain balance between groups. Allocation concealment prevented study coordinators and physiotherapists from knowing future allocations, minimizing selection bias. Although subjects could not be blinded because of the nature of the interventions, assessors evaluating outcomes were blinded to group assignments to avoid measurement bias. At baseline, complete demographic and clinical data, including age, sex, lesion severity, and medical history, were collected. Statistical tests confirmed no significant differences between groups at baseline, ensuring comparability. Standardization of treatment protocols and blinding of assessors helped to address potential performance errors. Thorough process documentation increased transparency and replicability, strengthening the internal validity of the study.

2.4. Patient Evaluation

To evaluate the effectiveness of the therapy, we adopted a rigorous experimental design, using a Randomized Controlled Trial (RCT) with two distinct groups: a CG and an EG. Assessment protocols included the "Pain Arch Test" and the "Simple Shoulder Test" (SST) to assess shoulder pain and function (Schor et al., 2022).

These critical time points were carefully selected to harmonize the different session frequencies between the two groups while ensuring that each assessment point would be predictive of significant recovery milestones. This harmonization was essential to mitigate any discrepancies arising from differential training durations and to ensure a valid comparison: T0 (baseline): performed at the start of the study to capture the baseline condition of all participants. T1 (2 weeks or 6 sessions for the CG): scheduled after two weeks for the EG and after the completion of six sessions for the CG. This intermediate checkpoint was designed to track early recovery and adaptability to the respective training modalities. T2 (4 weeks or 12 sessions for the CG): Positioned in the middle, this point was considered critical to document any significant plateaus or progressions in recovery. T3 (6 weeks or 18 sessions for the CG): Positioned towards the second half of the anticipated recovery period, the intention here was to capture the data at a stage where a substantial proportion of participants, particularly in the EG, it was postulated to show a marked recovery (Niculescu et al., 2020; Faur & Niculescu, 2017).

In the CG, standard rehabilitation protocols were followed based on international guidelines for SIS. The recovery process was divided into three phases: an initial phase focused on pain reduction, an intermediate phase aimed at restoring the upper limb range of motion (ROM), and an advanced phase focused on shoulder muscle strengthening and readiness for daily activities. Passive and active mobilizations were used to restore ROM, while strength training targeted the rotator cuff and scapular stabilizing muscles. Functional integration involved plyometric exercises to improve neuromuscular coordination, along with postural education to promote correct scapular positioning and posture to prevent syndrome recurrence.

In contrast, the EG underwent VR therapy using a high-resolution platform with an intuitive graphical interface. Participants engaged in large rhythmic movements and directional hitting techniques within the VR environment, targeting joint mobility and rotator cuff engagement. The immersive nature of the VR environment provided a distraction from pain and increased participant engagement in the recovery process. This approach facilitated the mind-body connection and positively impacted the psychological component of recovery.

Comparing these approaches, the CG followed conventional rehabilitation protocols, while the EG engaged in VR therapy with an emphasis on interactive and engaging exercises tailored to shoulder function improvement.

3. Results

The study was initially planned for 50 weeks, with a maximum capacity of 18 patients for both the EG and CG, totaling 36 participants. Estimated recovery time ranged from 5 to 8 weeks based on literature findings. Continuous recruitment was implemented to maximize the sample size and resource utilization. When a patient met recovery criteria, they were replaced by a new participant to maintain a consistent participant pool throughout the study duration.

To ensure uniformity between the groups, a system of socio-demographic quotas was applied, according to the criteria established in the specialized literature.

In the end, the study was able to successfully recruit male 288 participants over one year, 144 in each group, using maximum resources over 50 weeks.

Assessment times were defined as T0 (baseline/start of study), T1 (2 weeks), T2 (4 weeks) and T3 (6 weeks). Interpretation of recovery by the painful arc test consisted of performing three consecutive tests, obtaining a score of 0, indicating good shoulder function. Data were compared from T0 to T3, marking the end of the recovery period for each patient.

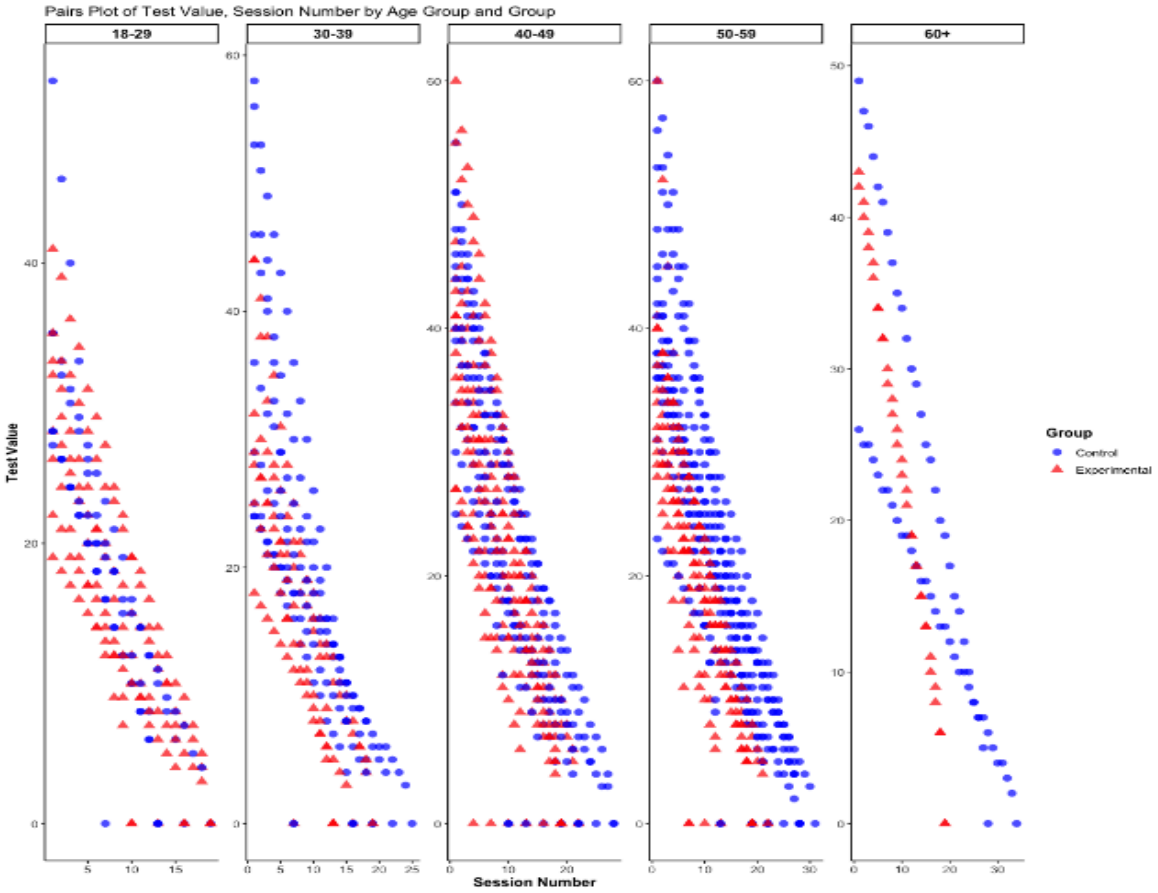

Figure 1. Subject sampling

In Figure 1, three lines are observed, each representing a different total sample size (10, 20, and 30 participants). As the effect size increases, the power of the test increases for all sample sizes. Over one year, the study was able to successfully recruit 288 participants (144 in each group) and resources were used to capacity over the 50 weeks.

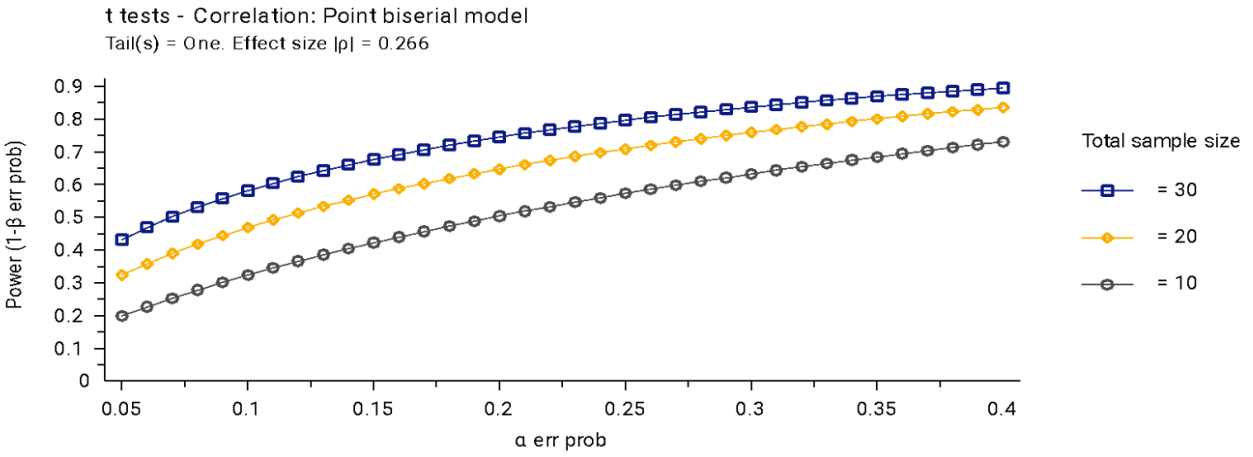

Figure 2. Variation of compression scores by measure of recovery

The recovery trajectories of the EG and CG (figure 2) were rigorously evaluated, revealing significant differences in recovery times and progression slopes as evidenced by a comprehensive statistical analysis. Using the Welch Two Sample t-test, a robust method for comparing means between two independent groups with unequal variances, patterns of differential recovery were quantitatively elucidated.

The EG showed a mean recovery time of 6.04 weeks, as opposed to the CG of 7.01 weeks, with a t-value of 2.9172, degrees of freedom equal to 140.36, and a p-value of 0,004114. These results were not only statistically significant but also indicated a practical implication in the context of patient recovery times. The 95% confidence interval, ranging from 0.3136895 to 1.6329772, further emphasized the reliability and significance of these findings, highlighting a pronounced reduction in recovery time associated with the VR intervention.

Figure 3 shows the SST score distribution for a CG and an EG during Session 1. The center line in each box represents the median score, and this appears to be slightly higher in the CG than in the EG. The box indicates the interquartile range (IQR), showing where the middle 50% of scores fall and appear comparable in size between the two groups. However, the CG has a wider range of scores, suggesting greater variability in shoulder strength, observable in longer whiskers. No outliers are seen in any of the groups, indicating that all scores are within a relatively expected range. Although the median scores are similar between the two groups, the variability is greater in the CG. Longitudinal assessment at Session 18 shows persistent improvement in shoulder function for the EG, evidenced by lower median scores compared to the CG. In the SST boxplot, higher mean scores are seen for the EG, indicating superior shoulder functional capacity. The proximity of the upper quartiles and the distribution of the data points suggest a comparable range of function in both groups, but the EG tends toward greater function.

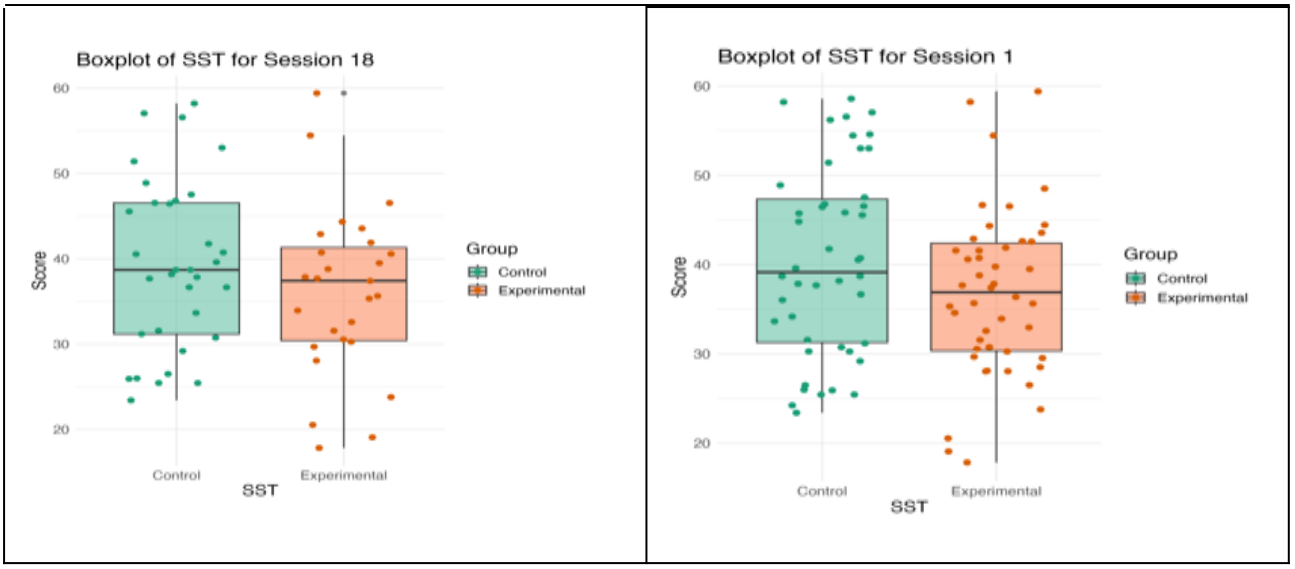

Figure 3. SST Session 1-18

4. Discussion

This study employs statistical and mathematical modeling to analyze Pain Arc Test trends in participants recovering from subacromial decompression. Time series analysis organizes test results chronologically, capturing symptom evolution over multiple sessions. The rate of change in test scores is determined using first-order differencing, providing insights into recovery dynamics. Simple linear regression is used to explore the relationship between time and test scores, with the slope indicating the rate of improvement.

Average slopes for both the CG and EG are calculated to create an improvement indicator. Statistical comparisons between these indicators are conducted using t-tests or Mann-Whitney U-tests, depending on data distribution. Cluster analysis groups participants by similar recovery patterns, highlighting subgroups with distinct trajectories. This approach ensures observed differences in recovery rates are not due to uncontrolled sociodemographic variables. The modeling framework aims to provide a comprehensive understanding of VR therapy's effectiveness in rehabilitation.

VR therapy is increasingly showing promise in various medical applications, including rehabilitation. SIS is a common shoulder condition characterized by pain and limited function due to compression of structures within the shoulder joint. VR therapy can help improve shoulder function in SIS, which could offer a non-invasive and potentially effective treatment option for patients (Plăstoi & Buțu, 2019). Participants who received VR therapy showed significant and persistent improvement compared to those in the CG (Plăstoi & Buțu, 2019). These findings suggest that VR may provide additional benefits compared to traditional therapy. It is essential to continue research to fully evaluate the potential and long-term efficacy of VR in SIS recovery and to develop personalized therapy programs that optimize treatment outcomes (Pekyavas & Ergun, 2017; Bağcıer & Çüçen Batıbay, 2021; Gumaa & Rehan Youssef, 2019; Brady et al., 2023; Carnevale et al., 2022; Hakim & Ross, 2020).

Analyzing the results of the Shapiro-Wilk test for the age variable and the initial test values, we observed that these variables did not show a normal distribution in any of the groups. Given these findings, we considered it necessary to use non-parametric statistical tests for further analyses, thus ensuring the correctness and reliability of the results. Discussions in this perspective focused on assessing the normality of the data and how these findings affect subsequent statistical analyses. The results of the Shapiro-Wilk test indicated that both age-related and baseline test data did not follow a normal distribution in either group. By fully analyzing the recovery times and progress of the EG and CG, we concluded that the VR intervention had a significant impact on accelerating the

recovery of patients with SIS (Hakim & Ross, 2020; Dejaco et al., 2024; Marin et al., 2014; Stanescu, 2014; Stanescu, 2018; Voicu, Stănescu, & Voicu, 2021).

The results of the Welch Two Sample test confirm that the EG had a significantly shorter average recovery time (6.04 weeks) compared to the CG (7.01 weeks). This significant difference underscores the effectiveness of VR intervention in accelerating the recovery process for patients with SIS.

Combining neurofeedback training with VR rehabilitation holds promise for enhancing patient outcomes across various medical conditions. By integrating neurofeedback techniques into VR programs, patients can improve both physical and cognitive abilities. Patients engage in VR activities requiring focused attention, while neurofeedback aids in concentration development (Carvalho et al., 2010; Stanescu, 2018). VR environments also help manage stress, complemented by neurofeedback stress-response regulation. Simulated scenarios in VR enhance reaction time and decision-making, further refined with neurofeedback. Customized rehabilitation programs tailored to individual needs are facilitated by neurofeedback monitoring. The immersive nature of VR enhances patient motivation and engagement, augmented by real-time feedback from neurofeedback. Overall, this integrated approach offers holistic patient care, addressing the physical and cognitive aspects of rehabilitation. Continued research promises innovative strategies for enhancing patient outcomes and quality of life (Stanescu, 2018; Voicu, 2021).

The study on VR-augmented therapy for SIS faces several limitations. The relatively small sample size of 36 participants (18 per group) may limit generalizability. Recruitment through direct referrals from clinics could introduce selection bias. The 50-week study duration may not capture long-term outcomes or potential relapses adequately. Concerns arise regarding the use of informal consent procedures despite ethical approval. Measurement tools like the Painful Arch Test and SST may vary in reliability for assessing VR therapy outcomes. Variability in individual responses to traditional therapy in the control group could confound comparisons. Dependence on a specific VR technology (Oculus Rift S) may restrict applicability to other VR platforms. Non-normal data distributions necessitating non-parametric tests may impact statistical robustness. Resource constraints and participant turnover could affect treatment adherence and study continuity. Publication bias towards studies with positive outcomes may skew perceptions of VR therapy efficacy in SIS treatment. Addressing these limitations in future research can enhance the validity and broader applicability of findings in clinical settings.

An important driver for choosing this theme is the increasing popularity of VR technology, which has led to a decrease in the price of products and associated content, making them affordable and increasingly used. This technology can be used in a variety of medical settings, both in specialized centers and in the user's home, making it very accessible for treating SIS. All costs associated with the study have been borne by self-funding, without requiring patients to pay for VR testing and treatments or traditional physiotherapy. This approach not only facilitates access to innovative treatments but also helps to reduce the financial barrier for patients, thus supporting the widespread adoption of technology-assisted rehabilitation therapies.

5. Conclusions

This study demonstrates the significant potential of VR as an innovative tool in the rehabilitation of patients with SIS. The findings reveal that patients who participated in VR-augmented therapy exhibited a faster and more pronounced recovery compared to those who underwent traditional rehabilitation methods. The EG not only showed a reduced average recovery time but also demonstrated greater improvements in shoulder function, as evidenced by the Pain Arch Test and SST scores.

The integration of immersive VR environments into rehabilitation routines provided patients with engaging and interactive experiences that likely contributed to these enhanced outcomes. The ability of VR to distract from pain and enhance the psychological aspects of recovery suggests that this technology can offer significant advantages over conventional therapies. Moreover, the use of

VR in physical therapy opens new avenues for creating personalized and adaptive treatment plans tailored to individual patient needs, thereby improving overall treatment efficacy and patient satisfaction.

The study's results underscore the importance of continuing research into VR-based therapies to explore their full potential in medical rehabilitation. Future studies could expand on these findings by exploring long-term outcomes, optimizing VR protocols, and integrating complementary technologies like neurofeedback to further enhance rehabilitation outcomes. Ultimately, the adoption of VR in rehabilitation represents a promising step forward in modernizing patient care and improving recovery processes in the digital age.

Funding: This research received no external funding.
Informed Consent Statement: The study was conducted by the principles set out in the Declaration of Helsinki. All patients were properly informed, agreed with their participation in the study, and signed a consent form.
Data Availability Statement: Data are contained within the main text of the article.
Acknowledgments: The authors thank the staff and the participants of the study for their valuable contributions.
Conflicts of Interest: The authors declare no conflict of interest.

References

Angst, F., Schwyzer, H. K., Aeschlimann, A., Simmen, B. R., & Goldhahn, J. (2011) Measures of adult shoulder function: disabilities of the arm, shoulder, and hand questionnaire (DASH) and its short version (QuickDASH), shoulder pain and disability index (SPADI), American Shoulder and Elbow Surgeons (ASES) Society standardized shoulder assessment form, constant (Murley) score (CS), simple shoulder test (SST), Oxford shoulder score (OSS), shoulder disability questionnaire (SDQ), and Western Ontario shoulder instability index (WOSI). *Arthritis care & research*. 63, S11, S174-S188.

Bağcıer, F., & Çüçen Batıbay, S. (2021) The effects of virtual reality exergaming on pain, functionality and acromiohumeral distance in shoulder impingement syndrome patients: A randomized controlled study. Turkiye Klinikleri J Health Sci. 2021, 6, 1:55-61, https://doi.org/10.5336/healthsci.2020-74413

Bohil, C. J., Alicea, B., & Biocca, F. A. (2011) Virtual reality in neuroscience research and therapy. Nature reviews neuroscience. 2011, 12, 2, 752-762.

Brady, N., Dejaco, B., Lewis, J., McCreesh, K., and McVeigh, J. G. (2023) Physiotherapist beliefs and perspectives on virtual reality supported rehabilitation for the management of musculoskeletal shoulder pain: A focus group study. *PLoS One*. 18, 4, e0284445, https://doi.org/10.1371/journal.pone.0284445

Carnevale, A., Mannocchi, I., Sassi, M. S. H., Carli, M., De Luca, G., Longo, U. G., et al. (2022) Virtual reality for shoulder rehabilitation: Accuracy evaluation of oculus quest 2. *Sensors*, 22, 15, 5511.

Carnevale A, Mannocchi I, Sassi MSH, Carli M, De Luca G, Longo UG, Denaro V, Schena E.(2022) Virtual Reality for Shoulder Rehabilitation: Accuracy Evaluation of Oculus Quest 2. Sensors (Basel) ;22(15):5511. https://doi.org/10.3390/s22155511

Carvalho, M. R. D., Freire, R. C., & Nardi, A. E. (2010) Virtual reality as a mechanism for exposure therapy. *The World Journal of Biological Psychiatry*. 11(2-2), 220-230.

Dejaco, B., Brady, N., Tankink, A., Lewis, J., van Goor, H., Staal, J. B., & Stolwijk, N. (2024) Experiences of physiotherapists considering virtual reality for shoulder rehabilitation: A focus group study. Digital Health, 10.

Faur, C., Niculescu, B. (2017) Comparative biomechanical analysis of three implants used in bicondylar tibial fractures. Wiener Medizinische Wochenschrift. https://doi.org/10.1007/s10354-017-0551-9

Fu, F. H., HARNER, C. D., & KLEIN, A. H. (1991) Shoulder impingement syndrome: a critical review. *Clinical Orthopaedics and Related Research®*, 269, 162-173.

Gumaa, M., & Rehan Youssef, A. (2019) Is virtual reality effective in orthopedic rehabilitation? A systematic review and meta-analysis. *Physical therapy*. 99,10, 1304-1325, https://doi.org/10.1093/ptj/pzz093

Hakim, R. M., & Ross, M. (2020) Emerging perspectives of virtual reality techniques. Virtual Reality in Health and Rehabilitation. 231-256.

Harvie, P., Pollard, T. C. B., Chennagiri, R. J., & Carr, A. J. (2005) The use of outcome scores in surgery of the shoulder. *The Journal of Bone & Joint Surgery British Volume*, 87, 2, 151-154.

Hoffman, H. G. (2004) Virtual-reality therapy. *Scientific American*. 291, 2, 58-65.

Jang, D. P., Ku, J. H., Choi, Y. H., Wiederhold, B. K., Nam, S. W., Kim, I. Y., & Kim, S. I. (2002) The development of virtual reality therapy (VRT) system for the treatment of acrophobia and therapeutic case. *IEEE Transactions on Information Technology in Biomedicine*. 6, (3), 213-217.

Kirkley, A., Griffin, S., & Dainty, K. (2003) Scoring systems for the functional assessment of the shoulder. Arthroscopy: *The Journal of Arthroscopic & Related Surgery*. 19, 0, 1109-1120.

Krijn, M., Emmelkamp, P. M., Olafsson, R. P., & Biemond, R. (2004) Virtual reality exposure therapy of anxiety disorders: A review. *Clinical psychology review*, 24, 3, 259-281.

Levac, D. E., & Galvin, J. (2013) When is virtual reality "therapy"? *Archives of physical medicine and rehabilitation*. 94, 4, 795-798.

Lohre R, Warner JJP, Athwal GS, Goel DP. (2020) The evolution of virtual reality in shoulder and elbow surgery. *JSES Int*. 4(2):215-223. https://doi.org/10.1016/j.jseint.2020.02.005

Marin, M. I.; Robert, S.; Sakizlian, R. E.; Rusu, L.; Rusu, R. M. A (2014) Biomechanical Evaluation of the Upper Limb Kinematic Parameters of the Throwing Action in Handball: A Case Study. *Appl. Sci*. 14, 667. https://doi.org/10.3390/app14020667

Naghdi, S., Nakhostin Ansari, N., Rustaie, N., Akbari, M., Ebadi, S., Senobari, M., & Hasson, S. Simple shoulder test and Oxford Shoulder Score: Persian translation and cross-cultural validation. *Archives of orthopaedic and trauma surgery*, 135, 1707-1718.

Nam J, Koh YG, Chung S, Kim PS, Jang J, Park JH, Kang KT. (2024) The Application of Virtual Reality in Shoulder Surgery Rehabilitation. *Cureus*. 16(4):e58280. https://doi.org/10.7759/cureus.58280

Niculescu, B., Faur, C. I., Tataru, T. Diaconu, B. M., and Cruceru, M. (2020) Investigation of Biomechanical Characteristics of Orthopedic Implants for Tibial Plateau Fractures by Means of Deep Learning and Support Vector Machine Classification. *Applied Sciences*. 10, 14: 4697. https://doi.org/10.3390/app10144697

North, M. M., & North, S. M. (2002). Virtual reality therapy. In M. Hersen & W. Sledge (Eds.), *Encyclopedia of psychotherapy* (Vol. 2, pp. 785-793). Elsevier Science.

North, M. M., North, S. M. (2017) Virtual reality therapy for treatment of psychological disorders. *Career Paths in Telemental Health*, 263-268.

Park YS, An CS, Lim CG. (2021) Effects of a Rehabilitation Program Using a Wearable Device on the Upper Limb Function, Performance of Activities of Daily Living, and Rehabilitation Participation in Patients with Acute Stroke. *Int J Environ Res Public Health*;18(11):5524. https://doi.org/10.3390/ijerph18115524

Pekyavas, N. O., Ergun, N. (2017) Comparison of virtual reality exergaming and home exercise programs in patients with subacromial impingement syndrome and scapular dyskinesis: Short term effect. *Acta orthopaedica et traumatologica turcica*, 51, 3, 238-242.

Plăstoi C. D., Buțu I. (2019) Sports education and its impact on the health and integration into society. *EDU World 2018-8th International Conference*, ISSN: 1844-6272, WoS: Book

Series: European Proceedings of Social and Behavioural Sciences, Volume: 67, eISSN: 2357-1330.

Schor D., Schor V., Geambaşu A., Ferrario B., Savu C., Plăstoi C. D. (2022) The Highlighting of the Relationships between Biomechanical Parameters of Musculoskeletal System of the Spine Measured with Backfix Technology and its Statokinetic Functional State. *RREM,* 14, 4, Sup.1, ISSN: 2066-7329

Stanescu, R. (2014) Mental training assisted by neurofeedback - as a method to improve technical level in tennis. *The International Scientific Conference eLearning and Software for Education*; Bucharest, 2014, ISSN: 2066 - 8821 online

Stanescu, R. (2018) The new on-court tennis software – perspectives in training. The International Scientific *Conference eLearning and Software for Education*; Bucharest. 3, 341-345. https://doi.org/10.12753/2066-026X-18-192

Tokgöz P, Stampa S, Wähnert D, Vordemvenne T, Dockweiler C. (2022) Virtual Reality in the Rehabilitation of Patients with Injuries and Diseases of Upper Extremities. *Healthcare (Basel)*.;10(6):1124. PMID: 35742176 https://doi.org/10.3390/healthcare10061124

Voicu, A.V.; Stănescu, R.; Voicu, B.I. (2021) Professional responsibility of coaches. *Discobolul – Physical Education, Sport and Kinetotherapy Journal*, 60, 3, 307-327. https://doi.org/10.35189/dpeskj.2021.60.3.9

Wiederhold, B. K., Wiederhold, M. D. (2005) Virtual reality therapy for anxiety disorders: Advances in evaluation and treatment. *American Psychological Association*. https://doi.org/10.1037/10858-000