BRAIN. Broad Research in Artificial Intelligence and Neuroscience
e-ISSN: 2067-3957 | p-ISSN: 2068-0473
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2024, Volume 15, Issue 4, pages: 11-26.

Submitted: August 21st, 2024 | *Accepted for publication:* October 28th, 2024

The Use of Virtual Reality-Assisted Therapy to Improve Shoulder Function in Subacromial Impingement Syndrome: a Randomised Controlled Trial

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Abstract: *Subacromial impingement syndrome (SIS) is a common problem in clinical practice that affects the functionality of the shoulder. This study investigates the effectiveness of virtual reality (VR) assisted therapy in treating this syndrome, focusing on assessment using the Constant-Murley shoulder score. Materials and Methods: A group of 288 participants was randomly divided into two categories: an experimental group that received VR therapy and a control group that underwent conventional therapy. The Constant-Murley shoulder score assessed patients' progress, measuring shoulder function, joint mobility, and associated pain. Results: The participants underwent therapeutic interventions for 50 weeks, and the results were compared between the two groups. The experimental group that benefited from VR therapy showed significant improvements in Constant-Murley scores, indicating an increase in shoulder functionality, joint mobility, and pain reduction compared to the control group. Conclusion: VR therapy has proven effective in improving shoulder functionality in patients with SIS according to the Constant-Murley score. These results support the use of VR as an innovative and promising therapeutic option in treating this musculoskeletal condition.*

Keywords: *subacromial impingement syndrome; virtual reality; Constant-Murley Shoulder Score; shoulder functionality; rehabilitation.*

How to cite: Coja, D. M., Onu, I., Onu, A., Iordan, D. A., Gheorghiu, G., Ene-Voiculescu, V., & Talaghir, L.-G. (2024). The use of virtual reality-assisted therapy to improve shoulder function in subacromial impingement syndrome: A randomised controlled trial. *BRAIN. Broad Research in Artificial Intelligence and Neuroscience*, *15*(4), 11-26. https://doi.org/10.70594/brain/15.4/2

1. Introduction

In recent years, the intersection of advanced technologies and medical rehabilitation has seen a renaissance, particularly with the introduction and maturation of virtual reality (VR) systems. (Elor and Kurniawan, 2020) present a comprehensive analysis of immersive VR applications in physical rehabilitation, highlighting the technology's potential to enhance patient engagement and outcomes. Their findings support the argument for integrating VR into clinical settings, as immersive environments can provide motivation and a more enjoyable rehabilitation experience. Additionally, VR allows for tailored therapeutic exercises that can be monitored and adjusted in real-time, improving adherence and effectiveness in rehabilitation protocols. By emphasising the benefits of VR in fostering a more interactive and personalised rehabilitation experience, their work reinforces the viability of VR as a valuable tool in clinical practice (Elor & Kurniawan, 2020).

Subacromial impingement syndrome (SIS), a relatively common orthopedic condition characterised by pain and restricted movement of the shoulder, not only hinders daily activities but also drastically affects the quality of life of those affected, their ability to work and concentration in activities that require physical effort (Koester, George, & Kuhn, 2005; Chang, 2004). Traditional rehabilitation approaches, while effective, can often be tiring, requiring prolonged periods before noticeable improvement is seen. Furthermore, maintaining consistent patient engagement and motivation during these interventions can be challenging, partly because the experience of working in the treatment of subacromial impingement is painful, and therefore unpleasant, partly because the pain itself not only demotivates but misinforms the patient that the rehabilitation must be stopped. It frustrates and causes the patient to give up, even temporarily, on his healing effort.

VR provides a dynamic, engaging, and interactive environment, transforming mundane rehabilitation exercises into engaging, motivating activities that will make you forget the pain during your workout (Alghamdi et al., 2020; Hoffman, 2004). In the context of subacromial impingement syndrome, VR can facilitate exercises and movements that specifically target the affected area, providing real-time feedback and adjustments based on individual progress. Gamification of exercise in VR serves a dual purpose: increasing motivation through rewarding experiences and ensuring consistent adherence to correct postures and movements, continuously adjusting movements to fit individual characteristics, and removing the factoring of inter-individual variability into inherent impediments to exercise rehabilitation physically monitored, but also the inherent ability of VR to monitor movement and signal in real time the need for its rehabilitation, are advantages likely to demonstrate its impact in the improved rehabilitation of patients working for VR-assisted decompression (North & North, 2002; Gamito et al., 2009). In addition, the adaptability of VR environments ensures that patients, regardless of their initial fitness level or symptom severity, can begin rehabilitation at a pace tailored to their needs, as their capabilities progress, the intensity and complexity of exercises can be adjusted, providing an ever-evolving rehabilitation journey (Jang et al., 2002). Vibhuti, Kumar, & Kataria (2023) present a comprehensive review of VR-based neuromotor rehabilitation, highlighting the diverse applications of virtual reality in physiotherapy. Their analysis emphasises how VR technology can enhance patient engagement, improve therapeutic outcomes, and provide tailored rehabilitation experiences. By examining various studies and case applications, they illustrate the effectiveness of VR in addressing motor deficits and promoting functional recovery. The review also discusses the challenges and limitations of implementing VR in clinical settings, including accessibility and cost factors. Overall, Kumar and Kataria's work strengthens the argument for incorporating VR into physiotherapy, showcasing its potential to revolutionise rehabilitation practices (Vibhuti, Kumar, & Kataria, 2023).

The Constant Murley Score (CMS), often referred to simply as the Constant Score, is a renowned objective assessment tool designed to assess functional performance and pain levels in individuals with various shoulder pathologies (Vrotsou et al., 2018; Hirschmann et al., 2010). Conceived by Constant and Murley in 1987, the CMS combines both patient-reported outcomes and

clinician-based objective assessments, thereby providing a holistic view of shoulder function. Its comprehensive approach has solidified its position as the gold standard in the assessment of shoulder conditions in both clinical practice and research paradigms (Boehm et al., 2004; Holmgren et al., 2014; Fialka et al., 2005).

• Pain (Maximum 15 points): This domain is entirely subjective, assessing the patient's perception of pain via a visual analog scale or categorical options. Absence of pain brings the 15 points to the final score. We are interested in this dimension because it is an important component in the rehabilitation process, but due to its subjective nature, it is not a component that can be compared between individuals, but only at the level of repeated scores of each participant.

• Activities of daily living Function (maximum 20 points): This subjective domain assesses difficulties felt in daily activities such as sleep, work, or recreational activities.

• Range of Motion (Maximum 40 points): This objective domain assesses the active range of motion of the shoulder in different planes: flexion, extension, abduction, and external and internal rotation. Each plane's maximum achievable movement is given specific points, and the actual movement is proportional accordingly. This component is similar to the painful arc test.

• Strength (Maximum 25 points): In this objective domain, the assessor measures the strength of abduction in the affected shoulder using a dynamometer or weights. The maximum achievable score is given for a given weight lifted against gravity through the full range of motion (ROM) of abduction.

Summing the scores in these domains gives the overall CMS, a potential maximum of 100 points.

The multifaceted nature of the CMS gives it several uses (Roy, MacDermid, & Woodhouse, 2010; Constant, 1997):

• Comprehensive assessment: amalgamating subjective pain and functional assessments with objective measures of ROM and strength provides a comprehensive view of shoulder status.

• Standardization: CMS provides a standardised protocol for assessment, allowing for consistent assessments across time frames, assessors, or institutions.

• Research Applicability: CMS, given its rigor and complexity, serves as the preferred metric in clinical trials, comparative studies, and longitudinal evaluations related to shoulder interventions or pathologies.

• Progress Tracking: Its quantitative nature allows tracking of visible changes in scores, making it suitable for monitoring post-surgical or therapeutic progress.

Although the CMS is robust and widely recognised, it is not without its limitations:

• Evaluator Expertise: Objective components, particularly strength, and ROM, require a certain level of expertise and consistency on the part of the evaluator for accurate measurements.

• Equipment dependence: Accurate measurements of strength may require specific equipment, such as calibrated dynamometers, which may preclude its use in all clinical settings.

• Ceiling and floor effects: Certain groups of patients may achieve high or low scores, limiting the ability to detect subtle or extreme changes in these populations. We combat this aspect with the weight of the other tests in the analysis of the variance of the obtained scores.

Constant Murley, with its multidimensional approach to shoulder assessment, is an essential tool in orthopedics and rehabilitation sciences due to its ability to juxtapose subjective experiences with objective clinical assessments, thereby providing a nuanced understanding of the functional status of the shoulder (North & North, 2002).

2. Materials and Methods

The study was conducted from October 1, 2022, to October 14, 2023, at the Galați Rehabilitation Center, in partnership with Elipetro Med Clinic, where the evaluation and treatment protocols were implemented. Approval was granted by the ethics committee of the Elipetro Med Centre (approval no. 12, August 25, 2022), and the study adhered to the ethical principles outlined in the Helsinki Declaration. All participants provided informed consent before their involvement.

2.1 Participant Recruitment and Selection

A total of 288 participants, aged 18 to 65 years, were recruited over 50 weeks through direct referrals from clinics and medical centers. Participants had no prior experience with VR therapy. Continuous recruitment was employed throughout the study to maintain a steady participant pool of 36 individuals at any given time (18 in the experimental group and 18 in the control group). Participants were replaced upon meeting the rehabilitation exit criteria: three consecutive zero scores on the Painful Arc Test, a validated indicator of shoulder function restoration.

To ensure demographic variability, the participants represented a wide range of ages and a nearly even gender distribution, with 55% male and 45% female participants. General health was screened during recruitment to exclude severe comorbidities that could interfere with the rehabilitation process (e.g., neurological disorders, advanced arthritis). This ensured a consistent baseline of health status across the cohort, apart from Subacromial Impingement Syndrome (SIS).

2.2 Study Design

The study employed a randomised controlled trial (RCT) design to evaluate the effectiveness of VR-assisted therapy versus traditional rehabilitation methods for SIS. The control group followed conventional rehabilitation methods, while the experimental group underwent VR-assisted rehabilitation.

Participants in the Control Group (CG) adhered to standard rehabilitation protocols, attending sessions three times per week. Each session lasted 60 minutes, including breaks and adjustments, resulting in a cumulative weekly training duration of 180 minutes (140 minutes of active work). Participants were divided into two training schedules (Monday-Wednesday-Friday or Tuesday-Thursday-Saturday) to optimise resource use and prevent overcrowding.

Participants in the Experimental Group (EG) participated in daily VR-assisted rehabilitation sessions. Each session lasted 30 minutes, with a 10-minute pre-session protocol that included an introduction and setup of the VR equipment, followed by 20 minutes of focused VR-based training. The cumulative weekly training time for the EG was 140 minutes of active work, matching the CG's training duration.

Participants were randomly assigned to either the CG or the EG using a computerised random number generator. Stratified randomization was applied based on age, gender, and lesion severity to ensure balance between groups. Blinding was applied where possible: while participants could not be blinded due to the nature of the interventions, outcome assessors remained blinded to the group allocations.

2.3 Recruitment and Standardization Protocols

In this study, a continuous recruitment model was used to facilitate the timely incorporation of new participants, thereby replacing those who met established recovery criteria. Each participant underwent an initial assessment that included the painful arch test and SST. This protocol ensured that all participants, regardless of when they were recruited, were enrolled with a well-documented baseline condition.

To mitigate potential familiarity bias, a standardised induction protocol was implemented for all participants. This protocol included an orientation session designed to familiarise participants with the experimental environment and the VR system used in the study. As a result, later recruits

did not have a familiarity advantage over earlier participants. In addition, study staff received comprehensive training to adhere to strict and consistent procedures throughout the study for both experimental setup and therapy delivery. Statistical analysis demonstrated no significant differences between early and later recruited participants, confirming that familiarity did not affect study outcomes.

The randomization procedure was carefully structured to minimise bias and to ensure a balanced allocation of participants between the CG and the EG. A computerised random number generator was used for randomization, which was stratified based on key variables including age, gender, and lesion severity. This stratification ensured equivalence between groups, preventing the overrepresentation of any demographic subgroup.

To further reduce allocation bias, allocation concealment was implemented during the recruitment phase. Neither the study coordinators nor the physiotherapists were aware of the participant's group allocation at enrollment. Although blinding participants was not feasible due to perceptible differences in interventions, the evaluators assessing outcomes remained blinded to group assignments, thereby reducing the risk of measurement error.

2.4 Evaluation Time Points

To assess the effectiveness of this treatment, we adopted a rigorous RCT experimental design with two different groups: a control group and an experimental group. The assessment protocol includes the Pain Arch Test and SST to assess shoulder pain and function.

These key time points were carefully selected to coordinate the different training frequencies between the two groups while ensuring that each assessment point was predictive of key rehabilitation milestones. This coordination is crucial to reduce any differences due to different training durations and ensure valid comparisons:

- T0 (Baseline) initial assessment of participants' conditions.
- T1 (2 weeks or 6 sessions for CG): Assessment after two weeks for the EG, and after six sessions for the CG.
- T2 (4 weeks or 12 sessions for CG): Midpoint evaluation to capture significant recovery progress or plateaus.
- T3 (6 weeks or 18 sessions for CG): Final assessment to evaluate substantial recovery across both groups.

These time points were carefully selected to harmonise the different session frequencies between the CG and EG, ensuring a valid comparison of recovery trajectories.

2.5 Rehabilitation Procedures

For CG rehabilitation followed international guidelines for SIS. The process was divided into three phases: (1) pain reduction, (2) restoration of ROM, and (3) strengthening of the shoulder muscles. Passive and active mobilizations were used to improve ROM, and strength training focused on the rotator cuff and scapular stabilisers. Functional exercises aimed to improve neuromuscular coordination and posture, preventing syndrome recurrence. Balneotherapy, utilising mineral-rich water treatments and combined with techniques like electrotherapy, has shown notable success in alleviating pain and enhancing mobility in musculoskeletal conditions, including shoulder disorders. Such therapies leverage natural and mechanical stimuli to promote recovery through improved circulation and neuromuscular activation. These principles align with the goals of virtual reality-assisted therapy, which can further enhance patient outcomes by providing immersive, engaging, and controlled rehabilitation environments, offering a modern complement to traditional methods (Gurau et al., 2023).

VR-assisted therapy for EG involved immersive environments designed to engage participants with large, rhythmic movements and directional hitting techniques. These exercises

targeted joint mobility and rotator cuff activation, with the immersive VR environment distracting participants from pain and improving their psychological engagement in rehabilitation.

2.6 Oculus Rift-Virtual Reality Headset

For this study, we utilised the Oculus Rift S, a VR headset developed by Lenovo in partnership with Facebook, optimised for PC use, delivering enhanced functionality compared to the original Rift. It offers a resolution of 1,280 by 1,440 pixels per eye and an 80 Hz refresh rate, leveraging the PC's processing power to support advanced graphics that standalone headsets may struggle with. The headset is designed to cover the entire visual field, effectively blocking external light to enhance immersion. It features a redesigned halo headband for a secure and comfortable fit, adjustable with a thumbwheel for quick customization.

The Rift S incorporates next-generation lenses and a sharper display, providing brighter colors and minimising distortion, often referred to as the "screen-door effect." Its advanced hardware integrates seamlessly with Oculus software, ensuring a smooth user experience across various PC configurations. The Oculus Insight system enables room-scale tracking without external sensors, translating user movements in any direction. Additionally, the headset includes integrated speakers that produce three-dimensional audio, allowing users to remain aware of their surroundings (Oculus Rift S: Full Specification - VRcompare, n.d). The Oculus Touch controllers facilitate natural interactions by translating hand movements and gestures into the virtual environment, allowing for intuitive actions such as throwing and catching (14 Amazing Oculus VR Headset For 2023 | Robots.net, n.d)

2.7 Working method in vr for the experimental group

The VR environment was developed on a high-resolution immersive platform for therapeutic applications. Its graphical interface prioritised clarity, allowing participants to easily discern movement cues. Haptic feedback enriched the experience, providing tangible sensations corresponding to virtual interactions. The platform integrates bodily movement dynamics with feedback from hand sensors, creating a virtual context perceived as real, where participants' movements yield desirable outcomes.

To facilitate multifaceted recovery of shoulder function, participants engaged in rhythmic movement sequences structured in natural progressions that promote fluidity in rehabilitation exercises. Initial levels focused on establishing a basic rhythm, and training participants to synchronise their movements with VR cues. As they demonstrated competence, they progressed to advanced sequences, interweaving multidirectional strikes and evasive maneuvers to cultivate proprioception and dynamic shoulder stability. This progression is characterised by the increase in the patient's total working capacity in VR, rather than complexity alone.

Directional strikes provided specific benefits: anterior-posterior oscillations targeted the deltoids, enhancing shoulder flexion and extension while promoting joint lubrication. Lateral movements engage the medial deltoid, essential for tasks like reaching overhead without subacromial compression. Diagonal movements improved circulation by combining flexion-extension and abduction-adduction.

Strategic intercalation of overhead arm movements with mid-level and low-level movements ensured complete engagement of the rotator cuff, emphasising scapulohumeral rhythm for pain-free arm elevation. The immersive VR experience also fostered psychological resilience through tangible achievement markers and distraction from discomfort, leading to improved therapeutic outcomes. Sessions were supervised by rehabilitation experts to ensure adherence to therapeutic norms, maximising benefits and minimising the risk of incorrect movement patterns.

2.8 Detailed presentation of traditional rehabilitation for the control group for subacromial impingement syndrome

The traditional rehabilitation approach was meticulously designed, and based on evidence-based practices. It represents the pinnacle of current best practices in physiotherapy for addressing SIS, focusing on pain alleviation, mobility improvement, and strength restoration.

The initial phase emphasised pain alleviation through progressive mobilizations and modalities like cold compresses or ultrasound. With pain reduction, the intermediate phase shifted focus to restoring ROM and introducing strengthening exercises. In the advanced phase, exercises targeted the scapular girdle muscles, restoring functional movement patterns and preparing patients for returning to regular activities.

Restoration of ROM included passive exercises using external forces for mobility, active-assisted exercises utilising the unaffected arm for support, and active exercises relying solely on the affected shoulder. Strength restoration exercises were calibrated to address the complex musculature of the shoulder, strengthening the rotator cuff and scapular stabilisers. Exercises ensured improved scapular anchoring for optimal biomechanics. After mastering isolated exercises, participants progressed to complex and functional movements, incorporating plyometric exercises to stimulate shoulder stability and dynamic strength, along with proprioceptive training to improve neuromuscular coordination and refine movement precision.

Participants received education on optimal scapular positioning to prevent unnecessary subacromial compression and ergonomic practices to modify daily activities and prevent the recurrence of SIS.

3. Results

The study was planned for 50 weeks, with a maximum capacity of 18 patients for the experimental group and 18 for the control group, totaling 36 participants. Estimated rehabilitation time varies between 5 and 8 weeks, according to the literature. Recruitment was designed to be continuous to maximise sample size and fully utilise available resources. As a patient met established rehabilitation criteria, they were replaced by a new participant.

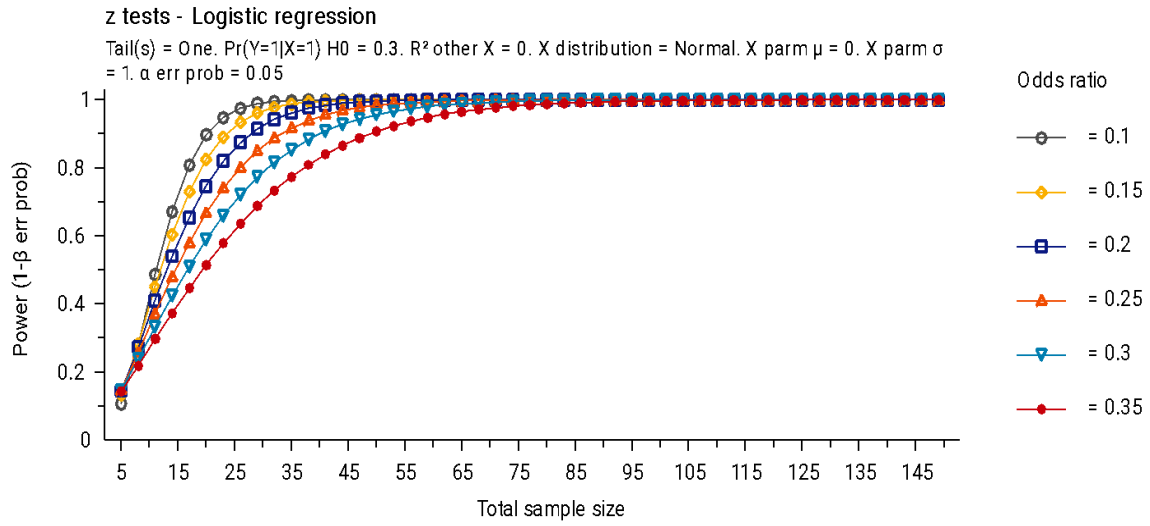

Figure 1. Logistic regression model

To ensure uniformity between the groups, a system of socio-demographic quotas was applied, according to the criteria established in the specialised literature. In the end, the study was able to successfully recruit 288 participants over one year, 144 in each group, using maximum resources over the 50 weeks. Assessment times were defined as T0 (baseline/start of study), T1 (2 weeks), T2 (4 weeks) and T3 (6 weeks). Interpretation of rehabilitation by the Constant-Murley shoulder score consisted of assessing shoulder function, joint mobility, and pain level, and data were compared from T0 to T3, marking the end of the rehabilitation period for each patient.

In the graph above, we observe how the power of the test increases with sample size and is higher for higher odds. For an odds ratio of 1.870871, a sample size of 144 participants per group is shown to achieve a power of approximately 0.95, indicating a 95% probability of detecting an effect of this size if it exists. This is a strong level of power, suggesting that, for 144 participants in each group (control and experimental), the study is well-powered to detect the specified effect, which, in the context of survival analysis, would translate into a difference in survival times between the two groups.

In context, the logistic regression model is often used as an approximation for survival analysis when the outcome is binary (event occurred or not) and time to event is not explicitly modeled. However, in the survival analysis, the event is the time to an occurrence (in our case, achieving three consecutive 0 compression tests in the painful spring test.). The assumption here is that the odds ratio in logistic regression can approximate the hazard ratio in survival analysis. Given the high power achieved with 144 participants per group, we argue that this sample size is sufficient to detect clinically meaningful differences in survival outcomes between our study's control and experimental groups.

3.1 Testing in T0

In the three histograms representing the CMS distribution from Session 1 for the experimental group, control group, and all participants combined, we can see how similar participants scored for CMS in Session 1. In the first histogram, the distribution for the experimental group is centered around a CMS score of 70, with frequency decreasing as scores move away from this central value. This suggests that most participants in the experimental group had scores around this median, with fewer individuals reporting higher or lower scores. The second histogram for the control group shows a more even distribution of CMS scores, with frequencies being relatively similar in the range from 60 to 100. There is no clear central peak as seen in the experimental group, which could imply a response more varied to whatever is measured or controlled within this group. However, such differences are natural and considered when referring to CMS scores. The third histogram combines data from both the experimental and control groups, showing the overall distribution of CMS scores for all participants. This distribution takes a more normal shape with a clear central peak around 70-80 CMS, suggesting that when both groups are combined there is a trend towards average scores in this range. In essence, we can infer that in terms of CMS testing, the participants of the two groups are close to being part of the same larger group of participants, which means that they have homogeneously isomorphic dispersions of the CMS test result.

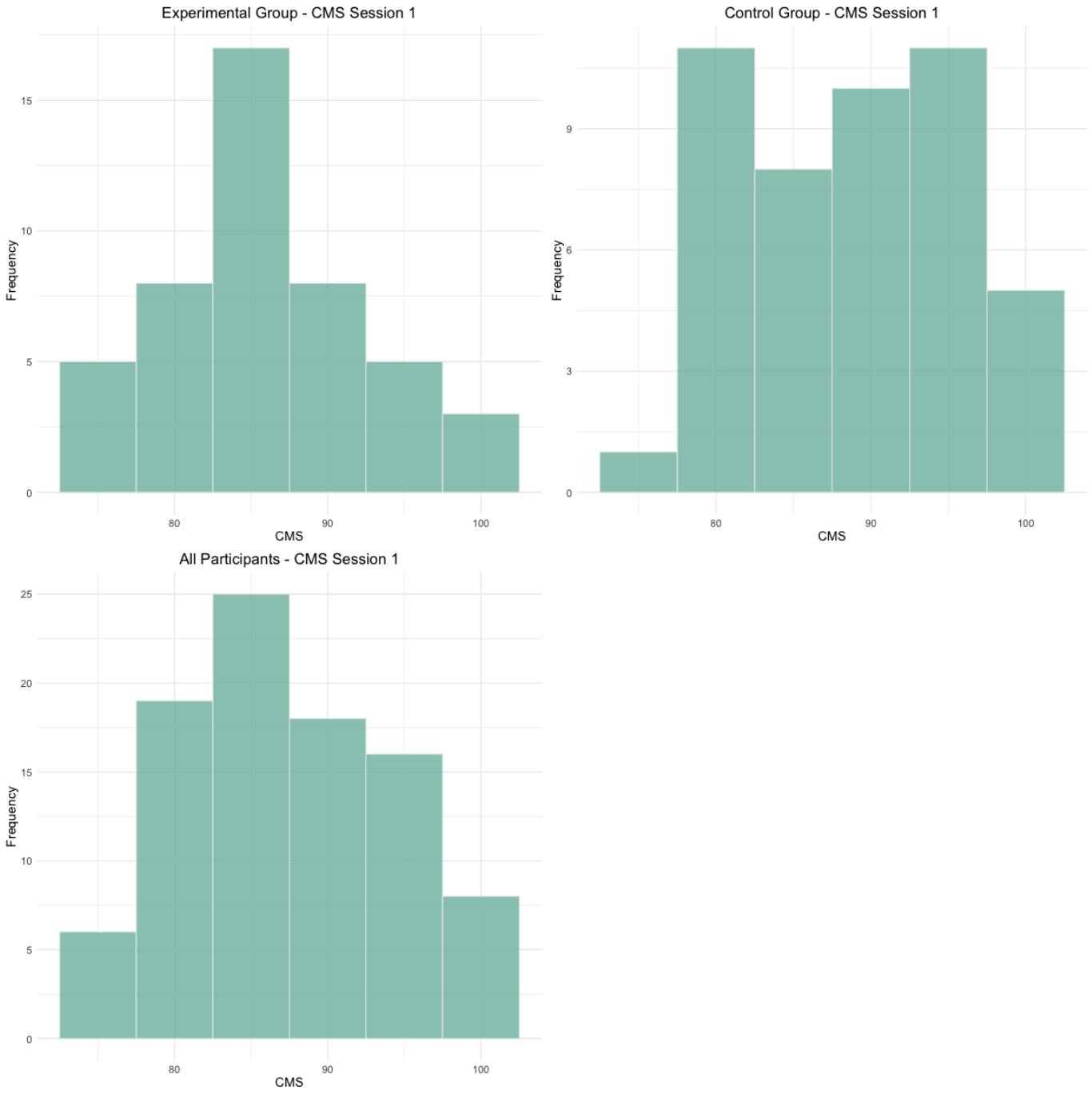

Figure 2. CMS Histogram in T0, on groups collected

3.2 Testing in T3

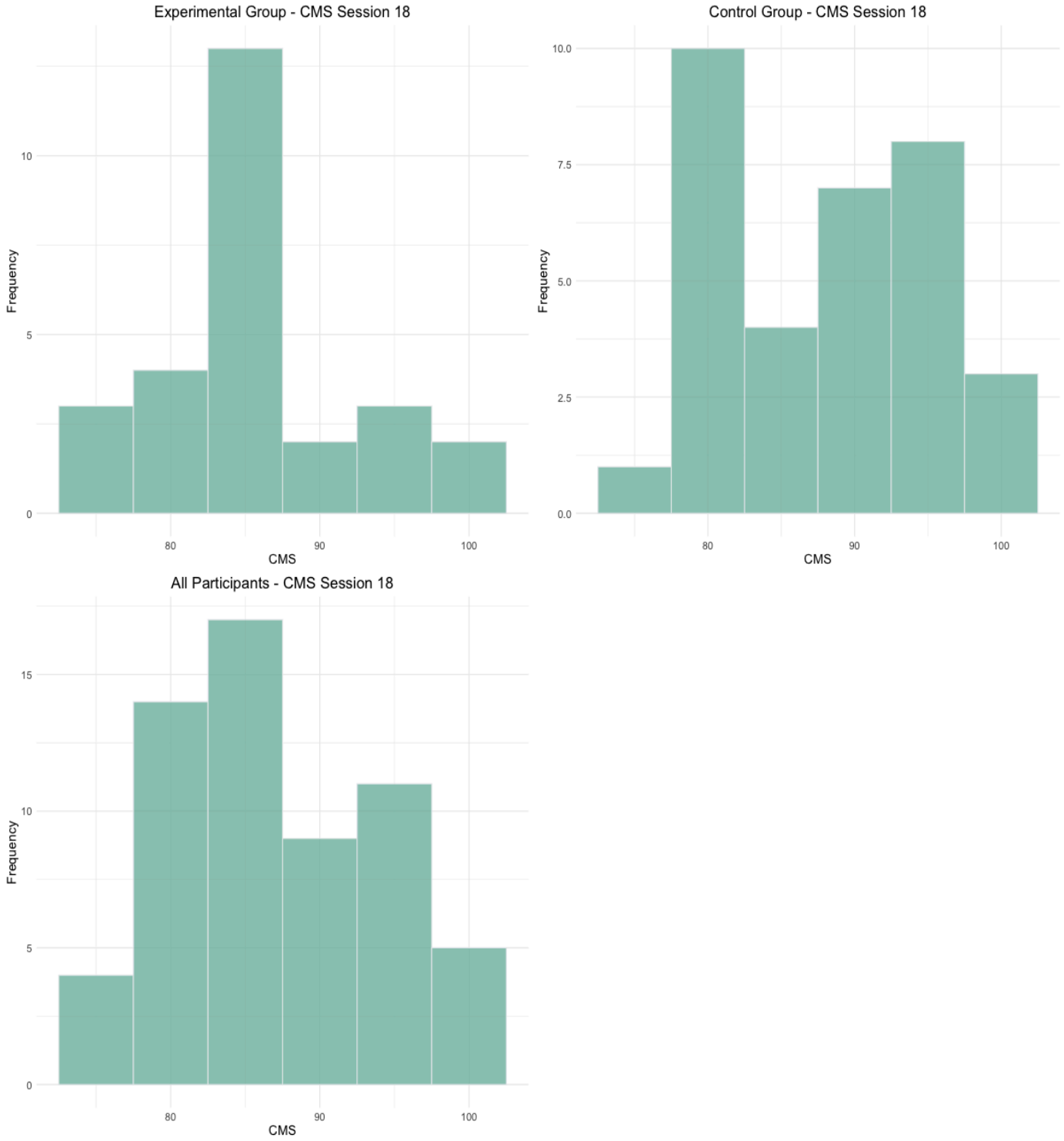

Figure 3. CMS - Histogram in T3

In session T3 (session 18) of our study, we examined the results of Constant-Murley score (CMS) testing to assess the progress of participants in the experimental group and the control group. We observed a significant evolution among participants in the experimental group compared to those in the control group.

During testing in T3, we found that the distribution of CMS scores for the experimental group was concentrated around a higher level, indicating a significant improvement in shoulder functionality in this group. Most participants in the experimental group scored higher, suggesting more efficient rehabilitation and improved shoulder functionality.

In contrast, in the control group, the distribution of CMS scores was more varied, with no obvious central peak. This suggests that progress in shoulder function was less consistent in this group, with some participants reporting significant improvements, while others experienced less progress or stagnation.

Analysing the combined data from both groups, we observe that the distribution of CMS scores takes on a more normal shape. This indicates that when considering the entire cohort of participants, there is a trend towards improved shoulder function overall.

In conclusion, the results of testing with the Constant-Murley score in the T3 session indicate that the experimental group performed much better compared to the control group. This suggests that the therapy applied in the experimental group had a significant positive impact on shoulder functionality, offering promising perspectives for the treatment of subacromial impingement syndrome.

3.3 Trend analysis on the main tests T0 – T3

Trend analysis delineates the trajectory of rehabilitation as measured by the Constant-Murley Score (CMS) from baseline assessment (T0) to the third assessment point (T3) across sequential treatment sessions, identified by numbers along the x-axis.

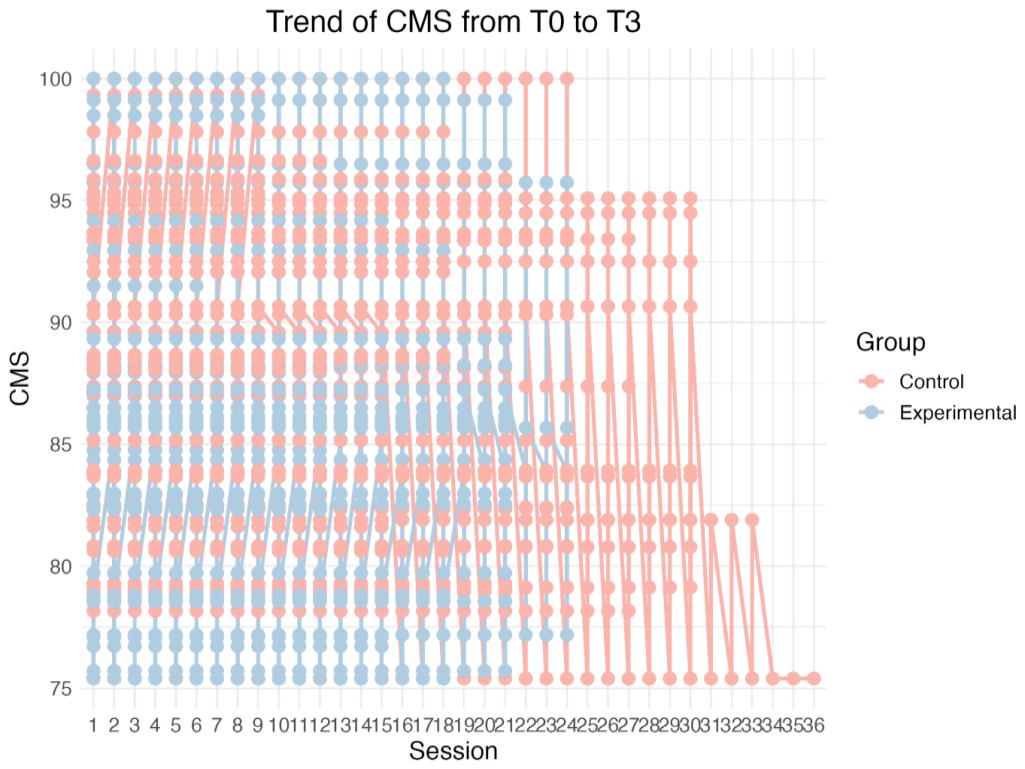

Figure 4. The trend of CMS from T0 to T3

CMS, a composite measure of shoulder function that encompasses pain, range of motion, strength, and ability to perform activities of daily living, provides a quantifiable index of rehabilitation from subacromial impingement syndrome.

The two-color scatter of the data points—red for the control group and blue for the experimental group—reveals a dichotomy in rehabilitation patterns. The red data points (values for the control group), while covering the full range of the score spectrum, display a gradual rise across sessions. This suggests a progressive improvement in shoulder function within the control group, but with a notable range of recorded values, as evidenced by the vertical spread of points across sessions.

In contrast, the blue data points, representative of the EG, show a steeper trajectory toward higher CMS values in fewer sessions. This accelerated improvement implies a more pronounced response to the administered treatment, with individuals in this cohort achieving scores indicating superior shoulder function in a condensed time frame. In conclusion, the presented trends confirm the premise that the rehabilitation of the EG, as measured by CMS, is accelerated relative to the control group.

This suggests a possible superiority of the treatment applied to the experimental cohort, a conclusion that could have significant implications for clinical practice, should further statistical analysis confirm its validity. The graphical representation serves not only as a visual summary of the data but also as a diagnostic tool to interrogate the nuances of rehabilitation patterns in the studied cohorts.

4. Discussion

De Amorim et al. in 2018 showed that VR therapy has potential clinical applications for balance rehabilitation in the elderly, though there is no consensus on its efficacy. This review aimed to summarise the effects of VRT interventions on balance recovery in older adults. A systematic search across PubMed, SciELO, LILACS, and PEDro identified clinical trials from 2010 onward involving VRT, with methodological quality assessed via the PEDro scale. A random effects meta-analysis was conducted on studies using the Berg Balance Scale and the Timed Up and Go (TUG) test. Ten articles met the inclusion criteria, revealing variability in intervention types (70%) and outcomes analysed (60%). The average duration of interventions was 13.90 weeks, with approximately two sessions per week. Positive results indicated improvements in dynamic and static balance (70%), mobility (80%), flexibility (30%), gait (20%), and fall prevention (20%). The meta-analysis significantly affected the Berg scale (SMD: -0.848) and the TUG test (SMD: 0.894). While VRT demonstrated beneficial effects on static balance, mobility, and fall self-efficacy, there were no significant improvements in dynamic balance or fall reduction. Further research is needed to validate these findings, and caution is advised in clinical decision-making due to the variability in methodologies and outcomes (de Amorim et al., 2018).

The results of this study represent a significant step in understanding the effectiveness of VR-assisted therapy in treating SIS (Gromala et al., 2015; Chang, 2004). By analysing the progress of the patients during the treatment sessions, it was observed that VR therapy had a positive impact on the functionality of the shoulder, as assessed by the Constant-Murley Score (CMS).

Our data demonstrate that participants who underwent VR therapy experienced significant improvements in CMS scores compared to those in the control group who underwent conventional therapy. These findings support the hypothesis that virtual reality-assisted therapy may be an effective and promising therapeutic option in the management of SIS (Bankes & Emery, 1997; Krijn et al., 2004).

A notable observation of this study is the difference in the trajectory of rehabilitation between the experimental group and the control group (Bush, 2008). While the control group showed a gradual increase in CMS scores, the experimental group showed an accelerated improvement, indicating a more pronounced response to VR therapy. This significant discrepancy

in rehabilitation patterns underscores the therapeutic potential of VR in accelerating the rehabilitation process and improving shoulder functionality (Bush, 2008).

In addition to the obvious benefits in terms of shoulder functionality, VR therapy may offer other clinical and practical advantages (Amorim et al., 2019; Vibhuti, Kumar, & Kataria, 2023). For example, the use of VR can improve patient compliance and engagement in the rehabilitation process, providing a more engaging and fun experience compared to conventional therapies (Fernández-Álvarez et al., 2019; Chen et al., 2009; Carvalho, Freire, & Nardi, 2010).

However, it is important to also acknowledge some limitations of the study. Firstly, the sample size, while adequate for initial findings, may not fully represent the diverse population affected by SIS, potentially limiting the generalizability of the results. Additionally, the relatively short duration of the study restricts the ability to assess the long-term effects and sustainability of the improvements observed. Variability in individual responses to VR therapy could also influence outcomes, as not all participants may have engaged equally with the technology. Furthermore, the lack of blinding in the study design might introduce bias in reporting outcomes, as participants were aware of the treatment they received. The reliance on self-reported measures for pain and functionality may also lead to subjective variations in the data. Lastly, external factors such as participants' motivation and compliance during the rehabilitation process could have affected the results, highlighting the need for further research in this area.

The results of this research suggest that VR-assisted therapy may represent a promising therapeutic approach to treating subacromial impingement syndrome. However, further studies are needed to confirm and extend our findings, as well as to assess the long-term benefits of this innovative intervention. These findings may have significant implications for clinical practice and improving the quality of life of patients with SIS.

While the findings of this study provide valuable insight into the efficacy of VR-assisted therapy in treating SIS, several limitations must be recognised. Although the study successfully recruited 288 participants, the sample was limited to a specific demographic range (18-65 years) and geographic area. This may restrict the generalizability of results to wider populations, including older adults or those from different regions. The effectiveness of VR-assisted therapy could be influenced by the technical quality of the VR system, including aspects such as latency, resolution, or user comfort. Any limitations of the VR technology could have an impact on participants' experience and, consequently, on outcomes. The primary assessment tools used, the Pain Arc test and the CMS, although validated, cannot capture all aspects of shoulder function or the psychological components of pain management. Additional or alternative assessment methods could provide a more comprehensive assessment of treatment impact.

To address the clinical significance of the findings, it’s important to contextualise the changes in CMS with daily activities. Specific improvements in scores correspond to enhanced abilities in tasks such as reaching overhead, carrying objects, or performing activities of daily living (ADLs) like dressing. Citing studies that establish minimal clinically important differences (MCIDs) for the CMS can provide benchmarks for interpreting the meaningfulness of score changes observed in the study. Additionally, including qualitative data or testimonials from participants about their experiences and how their daily activities changed as a result of the therapy can offer a personal perspective on the clinical significance of the findings. Discussing the implications for quality of life is also essential; improvements in shoulder function through VR therapy may lead to better quality of life, reduced pain levels, and decreased reliance on medications or further interventions, potentially reducing healthcare costs associated with improved functional outcomes.

Regarding the long-term effects of VR therapy, it’s crucial to acknowledge the need for follow-up studies to evaluate the durability of the improvements observed in CMS scores. Discussing the possibility that significant short-term improvements may not be sustained can highlight the importance of ongoing rehabilitation or maintenance programs. Recommendations for

future research should include designing studies with long-term follow-ups (e.g., 6 months, 1 year post-intervention) to assess the lasting effects of VR therapy, helping to determine whether the benefits seen at T3 are maintained or if further interventions are necessary. Comparing the long-term effects of VR therapy with other rehabilitation modalities could also provide insights into whether it offers sustained benefits over conventional therapies or if a combination of therapies would be more effective. Integrating these discussions into a dedicated section under the Discussion heading would enhance the depth of the analysis and strengthen the practical implications of the findings, making them more relevant to clinicians and researchers in the field.

5. Conclusions

This study highlights the significant impact of VR therapy on shoulder functionality for patients with SIS. Participants in the EG demonstrated substantial improvements in the CMS compared to those in the CG, who received conventional therapy. The accelerated rehabilitation observed in the EG suggests that VR therapy is not only effective but also has the potential to enhance patient engagement and compliance during the rehabilitation process.

The results underline the therapeutic advantages of VR in treating SIS, indicating a faster recovery trajectory and improved shoulder functionality. However, it is essential to acknowledge certain limitations, such as variability in individual treatment responses and the relatively short study duration, which may affect the generalizability of the findings.

In conclusion, VR-assisted therapy emerges as a promising and innovative treatment option for patients with SIS, offering significant implications for clinical practice. Future research is warranted to validate these findings further, explore the long-term benefits of VR therapy, and determine its effectiveness in broader populations.

Acknowledgements: This scientific work was carried out with the Internal Grant of the 2024 Department of Individual Sports and Kinetotherapy of "Dunarea de Jos" University in Galati and the Research Centre for Physical Therapy and Rehabilitation, “Dunărea de Jos” University of Galati, Romania.

Institutional Review Board Statement: The study was approved by the Ethics of Elipetro Med Centre, with no.12 from August 25, 2022.

Informed Consent Statement: The study was conducted by the principles set out in the Declaration of Helsinki.

Funding: This research received no external funding.

Data Availability Statement: Data are contained within the main text of the article.

Conflicts of Interest: The authors declare no conflict of interest and have no other relationships or activities that could appear to have influenced the submitted work.

References

Alghamdi, N., Meyer, W J., Atzori, B., Alhalabi, W., Seibel, C C., Ullman, D G., & Hoffman, H G. (2020). Virtual reality analgesia with interactive eye tracking during brief thermal pain stimuli: A randomized controlled trial (crossover design). *Frontiers in Human Neuroscience. 13*, 467. https://doi.org/10.3389/fnhum.2019.00467

Amorim, J. S. C. D., Leite, R. C., Brizola, R., & Yonamine, C. Y. (2019). Virtual reality therapy for rehabilitation of balance in the elderly: a systematic review and META-analysis. *Advances in rheumatology*, 58. https://doi.org/10.1186/s42358-018-0013-0

Bankes, M. J., & Emery, R. J. (1997). An evaluation of the Constant-Murley shoulder assessment. *The Journal of bone and joint surgery. British volume*, *79*(4), 696.

Boehm, D., Wollmerstedt, N., Doesch, M., Handwerker, M., Mehling, E., & Gohlke, F. (2004). Entwicklung eines Fragebogens basierend auf dem Constant-Murely-Score zur Selbstevaluation der Schulterfunktion durch den Patienten [Development of a questionnaire based on the Constant-Murley-Score for self-evaluation of shoulder function by patients]. *Der Unfallchirurg*, *107*(5), 397–402. https://doi.org/10.1007/s00113-004-0757-3

Bush, J. (2008). Viability of virtual reality exposure therapy as a treatment alternative. *Computers in Human Behavior*, *24*(3), 1032-1040. https://doi.org/10.1016/j.chb.2007.03.006

de Carvalho, M. R., Freire, R. C., & Nardi, A. E. (2010). Virtual reality as a mechanism for exposure therapy. *The world journal of biological psychiatry : the official journal of the World Federation of Societies of Biological Psychiatry*, *11*(2 Pt 2), 220–230. https://doi.org/10.3109/15622970802575985

Chang W. K. (2004). Shoulder impingement syndrome. *Physical medicine and rehabilitation clinics of North America*, *15*(2), 493–510. https://doi.org/10.1016/j.pmr.2003.12.006

Chen, C. H., Jeng, M. C., Fung, C. P., Doong, J. L., & Chuang, T. Y. (2009). Psychological benefits of virtual reality for patients in rehabilitation therapy. *Journal of Sport Rehabilitation*, *18*(2). https://doi.org/10.1123/jsr.18.2.258

Constant, C. R. (1997). An evaluation of the Constant-Murley shoulder assessment. *The Journal of Bone & Joint Surgery British Volume*, 79(4), 695-696. https://doi.org/10.1302/0301-620X.79B4.0790695c

de Amorim, J. S. C., Leite, R. C., Brizola, R., & Yonamine, C. Y. (2018). Virtual reality therapy for rehabilitation of balance in the elderly: A systematic review and meta-analysis. *Advances in Rheumatology, 58*(1), 18. https://doi.org/10.1186/s42358-018-0013-0

Elor, A., & Kurniawan, S. (2020). The Ultimate Display for Physical Rehabilitation: A Bridging Review on Immersive Virtual Reality. *Sec. Virtual Reality and Human Behaviour Volume 1*. https://doi.org/10.3389/frvir.2020.585993

Fernández-Álvarez, J., Rozental, A., Carlbring, P., Colombo, D., Riva, G., Anderson, P. L., Banos, R. M., Benbow, A. A., Bouchard, S., Breton-Lopez, J. M., Cardenas, G., Difede, J., Emmelkamp, P., Garcia-Palacios, A., Guillen, V., Hoffman, H., Kampann, I., Moldovan, R., Muhlberger, A., North, M., Pauli, P., Penate Castro, W., Quero, S., Tortella-Feliu, M., Wyka, K., & Botella, C. (2019). Deterioration rates in Virtual Reality Therapy: An individual patient data level meta-analysis. *Journal of Anxiety Disorders, 61*, 3–17. https://doi.org/10.1016/j.janxdis.2018.06.005

Fialka, C., Oberleitner, G., Stampfl, P., Brannath, W., Hexel, M., & Vécsei, V. (2005). Modification of the Constant-Murley shoulder score-introduction of the individual relative Constant score Individual shoulder assessment. *Injury*, *36*(10), 1159–1165. https://doi.org/10.1016/j.injury.2004.12.023

Gamito, P., Oliveira, J., Morais, D., Oliveira, S., Duarte, N., Saraiva, T., & Mendes, A. (2009). Virtual reality therapy controlled study. In *Annual Review of Cybertherapy and Telemedicine: Advanced Technologies in the Behavioral, Social, and Neurosciences* (Vol. 144, pp. 269–270).

Gurau, T. V., Musat, C. L., Voinescu, D. C., Anghel, L., Gurau, G., Postelnicu, M. G., Stefanescu, C. A., Onu, I., Corciova, C., & Iordan, D. A. (2023). Incidence and prevalence of injuries in some sports – review. *Balneo and PRM Research Journal, 14*(4), 617. https://doi.org/10.12680/balneo.2023.617

Gromala, D., Tong, X., Choo, A., Karamnejad, M., & Shaw, C. D. (2015, April). The virtual meditative walk: Virtual reality therapy for chronic pain management. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (pp. 521–524). https://doi.org/10.1145/2702123.2702344

Hirschmann, M. T., Wind, B., Amsler, F., & Gross, T. (2010). Reliability of shoulder abduction strength measure for the Constant-Murley score. *Clinical orthopaedics and related research*, *468*(6), 1565–1571. https://doi.org/10.1007/s11999-009-1007-3

Hoffman H. G. (2004). Virtual-reality therapy. *Scientific American*, *291*(2), 58–65. https://doi.org/10.1038/scientificamerican0804-58

Holmgren, T., Oberg, B., Adolfsson, L., Björnsson Hallgren, H., & Johansson, K. (2014). Minimal important changes in the Constant-Murley score in patients with subacromial pain. *Journal of shoulder and elbow surgery*, *23*(8), 1083–1090. https://doi.org/10.1016/j.jse.2014.01.014

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 : a publication of the IEEE Engineering in Medicine and Biology Society*, *6*(3), 213–217. https://doi.org/10.1109/titb.2002.802374

Koester, M. C., George, M. S., & Kuhn, J. E. (2005). Shoulder impingement syndrome. *The American journal of medicine*, *118*(5), 452–455. https://doi.org/10.1016/j.amjmed.2005.01.040

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. https://doi.org/10.1016/j.cpr.2004.04.001

North, M. M., & North, S. M. (2002). Virtual reality therapy. In *Encyclopedia of Psychotherapy* (Vol. 1). Elsevier.

Roy, J. S., MacDermid, J. C., & Woodhouse, L. J. (2010). A systematic review of the psychometric properties of the Constant-Murley score. *Journal of shoulder and elbow surgery*, *19*(1), 157–164. https://doi.org/10.1016/j.jse.2009.04.008

Vrotsou, K., Ávila, M., Machón, M., Mateo-Abad, M., Pardo, Y., Garin, O., Zaror, C., González, N., Escobar, A., & Cuéllar, R. (2018). Constant-Murley Score: systematic review and standardized evaluation in different shoulder pathologies. *Quality of life research : an international journal of quality of life aspects of treatment, care and rehabilitation*, *27*(9), 2217–2226. https://doi.org/10.1007/s11136-018-1875-7

Vibhuti, Kumar, N., & Kataria, C. (2023). Efficacy assessment of virtual reality therapy for neuromotor rehabilitation in home environment: a systematic review. *Disability and rehabilitation. Assistive technology*, *18*(7), 1200–1220. https://doi.org/10.1080/17483107.2021.1998674