

The Relationship between DASH, SST and CMS Scores in Assessing Shoulder Function: A Comparative Study between VR and Traditional Treatment

Daniel Mădălin COJA¹
Teodora Mihaela ICONOMESCU^{2,*}
Adelina Elena PANAET³
Mihaela ANGHEL⁴
Laurențiu Gabriel TALAGHIR^{5,*}
Sebastian Ion ENACHE⁶

¹ “Dunărea de Jos” University of Galati, Domnească, 47, 800008, Romania, Daniel.Coja@ugal.ro

² “Dunărea de Jos” University of Galati, Domnească, 47, 800008, Romania, ticonomescu@ugal.ro

³ “Vasile Alecsandri” University of Bacau, Calea Mărășești 157, 600115, Romania, panaet.adelina@ub.ro

⁴ “Vasile Alecsandri” University of Bacau, Calea Mărășești 157, 600115, Romania, anghel.mihaela@ub.ro

⁵ “Dunărea de Jos” University of Galati, Domnească, 47, 800008, Romania, gtalalghir@ugal.ro

⁶ University Center of Pitesti, Pitesti, Romania, enachecesti@yahoo.com

* Correspondence: ticonomescu@ugal.ro, ITM and gtalalghir@ugal.ro, TLG

Abstract: *Subacromial impingement syndrome is a common condition in clinical practice, characterized by shoulder pain and functional limitations. This study aims to compare the effectiveness of virtual reality-based therapy (VR) and traditional therapy in improving functional outcomes, while also analyzing correlations between key assessment tools: the Disabilities of the Arm, Shoulder, and Hand Score (DASH), the Simple Shoulder Test (SST), and the Constant-Murley Score (CMS). Patients were divided into two groups (VR therapy vs. traditional therapy), and their progress was assessed using these tools. The results revealed significant improvements in functional scores for both groups, with the VR group demonstrating slightly superior outcomes. VR has not only revolutionized individual patient care but also provided scalable solutions in physiotherapy clinics, aligning with modern healthcare management principles. A correlation analysis indicated strong positive relationships between DASH, SST, and CMS scores, highlighting their consistency in evaluating shoulder function. Additionally, significant negative correlations were observed between functional scores and pain ratings, emphasizing the critical role of pain management in treatment success. These findings suggest that VR therapy is an effective complement to traditional methods, providing enhanced engagement and measurable improvements in shoulder function. The study underscores the importance of integrating innovative approaches like VR into rehabilitation strategies, paving the way for personalized and multidimensional care in subacromial impingement syndrome. This study highlights how VR-based interventions align with international trends in digital health innovation, particularly in East European rehabilitation centers that have successfully integrated VR-based therapies.*

Keywords: *Subacromial Impingement Syndrome, Virtual Therapy (VR), Constant-Murley Score (CMS), Disabilities of the Arm, Shoulder and Hand (DASH) Score, Simple Shoulder Test (SST), Pain Assessment, Recovery, Approach multidimensional.*

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Introduction

In recent years, the intersection of advanced technologies and medical rehabilitation has experienced a renaissance, particularly with the introduction and maturation of virtual reality (VR) systems (Burdea, 2003; Sveistrup, 2004). The potential of VR to be a transformative agent in medical rehabilitation is hard to underestimate, and its adoption in the clinical field is still in its infancy, offering an unprecedented number of research opportunities (Wang et al., 2023; O'Neil et al., 2018). Subacromial impingement syndrome, a relatively common orthopaedic condition characterised by pain and restricted shoulder movement, 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 (Pirovano, 2016; Van Straaten et al., 2017). Traditional rehabilitation approaches, although effective, can often be tiring, requiring prolonged periods before noticeable improvement is seen (Pilutti & Hicks, 2013). Furthermore, maintaining consistent patient engagement and motivation during these interventions can be challenging, in part because the experience of working in the treatment of subacromial impingement is painful and, therefore, unpleasant, in part because pain itself not only demotivates but misinforms the patient. The fact that the recovery must be stopped frustrates and causes the patient to give up, even temporarily, his healing effort (Dong et al., 2015). VR provides a dynamic, immersive and interactive environment, transforming mundane rehabilitation exercises into engaging, motivating activities that will make you forget the pain during your workout. 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 (Gumaa & Rehan Youssef, 2019; Wiederhold et al., 2014; Baldominos et al., 2015). 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 recovery physically monitored, but also the inherent ability of VR to monitor movement and signal in real time the need for its recovery, are advantages likely to demonstrate its impact in the improved recovery of patients working for VR-assisted decompression (Dewil et al., 2023; Rose et al., 2018). 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 (Pirovano et al., 2016).

Of course, this factor can also be tracked in modern, non-technological recovery approaches via virtual reality. Still, the adjustments cannot track the instant, immediate character, adapted in microseconds and millimeters to the patient's individual characteristics (Elor & Kurniawan, 2020; Ku & Kang, 2018).

From a psychological point of view, VR can also play an essential role in the patient's recovery (Vigliani et al., 2019; Riva, 2009). The immersive nature of VR can distract from pain or discomfort during exercise, potentially allowing patients to push their limits and achieve more than they could in a traditional setting (Dascal et al., 2017; Spiegel, 2018). Treatments have already been written regarding pain and its impact on recovery, thousands of articles and studies have been conducted, and hundreds of tools have been developed to assess pain and quantify it (Sunda et al., 2022; Emedoli et al., 2024). Still, there is no consensus about it - naturally, considering that pain, a fundamental physiological experience for living beings, is nevertheless also a deeply subjective experience – which is why we do not evaluate pain in our research but only consider the impact of the painful experience to the progress in recovery: quantitative and objective measures, appropriate for the present endeavour scientific (He et al., 2023; Krueger & Stone, 2014; Del Sordo et al., 2020). The potential economic implications are also worth noting. With VR systems becoming more affordable, integrating them into rehabilitation programs could translate into fewer in-person therapy sessions, reducing the overall cost of treatment, both in time and effort (Del Sordo et al., 2020). Moreover, as patients can use VR systems from the comfort of their homes, this may also lead to more consistent adherence to rehabilitation exercises, reducing the likelihood of failures or prolonged recovery periods: we, therefore, theories that the impact of VR systems on subacromial impingement recovery may ultimately be cost-effective, in addition to its recognized benefits in pain reduction and exercise motivation (Hoffman et al., 2020; Hoffman, et al., 2001; Wiederhold et al., 2014).

Materials and methods

The VR working method of the experimental group

The VR environment utilized in the study was based on an existing rhythm-based game, adapted to meet the specific therapeutic requirements for shoulder rehabilitation in patients with subacromial impingement

syndrome (SIS). The system ran on the Oculus Quest 2, using motion-tracking sensors to capture real-time body movements. The game's immersive platform, originally designed for entertainment, was adapted to simulate functional, real-life movements that align with the goals of shoulder rehabilitation, mimicking the motions and postures typically required in traditional physical therapy exercises.

The game used a combination of visual and sensory feedback to guide and engage participants. It involved tasks that simulated therapeutic exercises targeting the shoulder joint. The system's adaptive difficulty levels and real-time feedback helped reinforce proper motion patterns, ensuring that participants maintained the correct postures and movement speeds necessary for recovery. Haptic feedback further enhanced the experience, providing tactile sensations that reinforced virtual interactions, making the process more immersive.

By leveraging an existing, widely available application, the study was able to tailor the game to match the specific movement patterns and functional exercises needed for shoulder rehabilitation, allowing participants to engage in a more motivating and dynamic therapy experience while still adhering to the principles of traditional physical recovery techniques.

The traditional working method of the control group

The traditional approach to rehabilitation was implemented following evidence-based practices, representing the current standard in physical therapy for subacromial impingement syndrome (SIS). The treatment focused on a structured integration of three core components: pain relief, improved mobility, and restored strength.

Pain relief was addressed through a combination of manual therapy techniques, such as soft tissue mobilization and joint manipulation, alongside adjunct modalities like ultrasound therapy and cryotherapy. Mobility was enhanced through a progressive range of motion exercises, starting with passive movements and advancing to active-assisted and active techniques tailored to the patient's recovery stage. Strength restoration was achieved through resistance training, incorporating isometric and isotonic exercises, progressively adjusted to the patient's functional capacity.

These components were applied in a phased manner, emphasizing pain relief in the initial stages, followed by mobility exercises, and culminating in strength training to ensure a comprehensive recovery. Each session was individualized, with frequency and intensity adjusted based on ongoing assessments of patient progress and tolerance.

Methodology

The research was carried out during the year 2023 with the following methodology: study duration 50 weeks, the choice of recovery session durations – 20 minutes daily for the experimental group and 60 minutes three times a week for the control group this was guided by the pedagogical paradigms of each recovery session. While the addictive nature of VR in the experimental group required shorter but frequent exposures, the traditional methods used for the control group, often being intensive, required longer durations but reduced frequency to prevent overtraining.

Participants

A maximum of 18 participants for both the experimental and control groups resulted in a maximum combined occupancy of 36 participants at any one time, with an average literature-estimated recovery time predominantly between 5-8 weeks. By using the continuous recruitment model coupled with the sociodemographic proportion system, over the course of one year, the study successfully recruited a total of 288 participants, with 144 in each group. Consequently, laboratory resources were used efficiently throughout the 50-week study, logistically supporting research resource limitations. Given the expected recovery time frame, we hypothesised that many participants would complete their recovery before the 12-week laboratory occupancy limit. The study was designed to continuously recruit new participants to maximise sample size and fully utilise available resources.

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 operates at its optimal capacity.

Our approach aligns practical laboratory capacity constraints with research objectives, maximising the study sample by increasing the number of subjects participating in the research, thus ensuring a robust sample size without compromising study quality and validity. Participants were primarily recruited through physical therapy clinics and community health centres. At the beginning of the research, the participants were subjected to a detailed physical evaluation by qualified physiotherapists, and a socio-demographic questionnaire was administered to ensure adherence to the study quota system. The results were recorded as "admitted/rejected" to participate in the study. A total of only four candidates were rejected because they appeared more than the predetermined quotas. Still, the continuous, multi-

night research method allowed the acceptance of participants who would not have been available in a standard study design.

Signing informed consent

Participants who wanted to participate in the study after discussion were asked to sign the informed consent form. This form, in accordance with the Declaration of Helsinki, emphasised their voluntary participation, their right to withdraw at any time without consequences, and their consent to the use of data, ensuring anonymity.

The FEFS Ethics Committee (UDJG) reviewed and approved the study protocol, including the informed consent process. Regular audits were conducted to ensure adherence to ethical standards and protocols. Following the informed consent process, the participants were officially enrolled in the study and randomly assigned to either the control or experimental groups, ensuring socio-demographic balance through the quota system.

Instruments

Data collection employed a combination of validated self-assessment tools (DASH, SST, and CMS), real-time motion tracking, and physiotherapist evaluations.

Painful Arch Test for the Shoulder

The Painful Arch Test is a well-established clinical tool for assessing shoulder pathologies, particularly impingement syndromes or supraspinatus tendinitis. It was chosen for this study because of its specificity in identifying subacromial impingement, particularly in the range between 60° and 120° of abduction, where compression of the rotator cuff tendons—especially the supraspinatus tendon—is most pronounced. This test is highly practical, requiring minimal equipment and time, making it ideal for laboratory settings. A positive result in this test is indicated by pain experienced between 60° and 120° of abduction, which typically suggests subacromial impingement. Pain outside this range may indicate other shoulder pathologies. Although this test is highly specific for subacromial impingement, it only evaluates pain during abduction and does not assess other possible shoulder issues comprehensively. Due to its ease of application, we administered this test before and after each session, averaging the resulting values. As the experimental group follows a different progression of sessions compared to the control group, we pooled the values before and after the respective day's training. The results were then averaged to represent equivalent progression between groups: for the experimental group, we combined the values of two consecutive days

(previous day and current day) for comparison. This approach allowed for a detailed tracking of changes in both groups while minimizing the risk of errors due to differences in the schedule.

Disabilities of the Arm, Shoulder, and Hand (DASH) Score

The DASH score was included in this study because of its broad application in assessing physical function and symptoms in individuals with musculoskeletal disorders of the upper limb. Although not exclusive to SIS, the DASH is particularly relevant due to its focus on daily activities and arm-specific movements, which are commonly affected in SIS patients. This self-reported tool provides a comprehensive evaluation of how shoulder pathology impacts daily life, thus offering a broader perspective on recovery and quality of life. The DASH score is self-reported, and the higher the score, the more severe the disability. It covers a wide range of physical tasks and symptoms, making it a valuable tool for monitoring changes in function and quality of life. The data collected can also be compared with other studies to benchmark our findings.

Simple Shoulder Test (SST)

The SST was chosen for its conciseness and its strong presence in both clinical and research settings. This 12-item questionnaire assesses functional status and pain in shoulder disorders, making it an ideal complement to the DASH score. Its simplicity and direct relevance to tasks affected in SIS patients make it an efficient tool for monitoring changes in shoulder function. The SST score is based on patient-reported symptoms and functional challenges. A higher score indicates greater difficulty in performing shoulder-related tasks, which is directly correlated with the severity of the shoulder condition. This test allows us to assess improvements or deteriorations in function, complementing the other assessment tools used in this study.

Constant Murley Score (CMS)

The CMS, or Constant Score, was included because it is considered the gold standard for assessing shoulder function in clinical and research settings. It combines patient-reported outcomes with clinician-based objective assessments, providing a comprehensive view of shoulder function. This dual approach ensures that the CMS addresses both subjective and objective aspects of shoulder pathology, making it particularly valuable for evaluating conditions like SIS. The CMS includes both subjective measures (pain and function) and objective assessments (range of motion, strength), which provide a holistic view of shoulder performance. Higher scores indicate better shoulder function, with lower scores suggesting greater disability. While the test is considered the most comprehensive, it is less practical for frequent use in a laboratory setting due to

the need for specialized equipment and clinical expertise. Despite this limitation, it remains a crucial part of our study due to its detailed and validated approach to assessing shoulder conditions.

Statistical methods

Each participant's Arc of Pain test results from different sessions were arranged chronologically, forming a time series data set. This captures the evolution of their symptoms over time, particularly the evolution of subacromial decompression and participants' recovery. For each participant, the following were tested: Calculation of rate of change, Linear regression modelling, independent samples t-tests or Mann-Whitney U-tests, and Cluster analysis. Aggregating the results to construct an improvement indicator with the slopes (rate of improvement) from the individual regressions. The mean slope for each group (control and experimental) was calculated. The result was later used to determine the extent to which the improvement differed between the experimental and control groups by statistical tests, this result having practical applicability strictly within the experiment, being associated with tests and work procedures characteristic of the methodology of the current study.

Study Timeline

This study was conducted over a period of 50 weeks, with continuous recruitment of participants. Each participant's progress was evaluated using specific time points throughout the study, which were defined as follows:

- **T0:** Baseline assessment (the time point when the participant is first enrolled in the study).
- **T1:** First follow-up assessment (measured after the initial treatment period, typically after 2 weeks).
- **T2:** Second follow-up assessment (measured after another 4 weeks of treatment, typically at the 6-week mark).
- **T3:** Final assessment (measured after the full treatment protocol, at approximately 8 weeks for most participants).

These time points (T0, T1, T2, T3) correspond to key moments in the rehabilitation process, and data collected at each of these stages were used to assess the effectiveness of the treatments. The assessments included the Disabilities of the Arm, Shoulder, and Hand (DASH) score, the Simple Shoulder Test (SST), and the Constant-Murley Score (CMS), among other measures.

Each participant's recovery progress was tracked by measuring these indicators at the designated time points. In the case of the control group (traditional therapy), sessions were conducted three times per week, with 60-minute durations. For the experimental group (VR therapy), participants engaged in 20-minute daily VR sessions. These durations were chosen to align with the unique pedagogical paradigms and engagement patterns of each treatment modality.

By outlining the timing and procedural details for each measurement point, readers can now better interpret the longitudinal data provided in Section 3 and understand how the recovery progress was tracked and assessed over time.

Results

The study employed a combination of continuous and intermittent assessment tools to capture a detailed and comparable longitudinal perspective on participants' progress. The painful arc test, due to its brevity and noninvasive nature, was administered at each training session, allowing for high-resolution monitoring of symptom progression. In contrast, comprehensive assessments such as DASH, SST, and CMS were conducted at key milestones (T0, T1, T2, and T3), strategically selected to align with critical stages in therapeutic evolution.

Recovery trajectories were evaluated using CMS, a composite measure that assesses shoulder function based on pain levels, range of motion, strength, and daily activity performance. The analysis revealed distinct recovery patterns between the two groups. The control group exhibited a gradual but steady improvement in shoulder function over time, with significant individual variability. Conversely, the experimental group demonstrated a more rapid increase in CMS scores within a shorter period, suggesting a more pronounced response to the administered treatment and superior functional outcomes.

These findings indicate that recovery in the experimental group progresses at a significantly faster rate than in the control group. This trend suggests that the applied treatment may be more effective, potentially providing a more efficient approach to shoulder rehabilitation. However, further statistical validation is necessary to confirm these observations and assess their clinical implications.

A major advantage of this approach is its ability to capture individualized recovery profiles while identifying overall trends. Unlike aggregate scores that obscure individual variations, this method preserves the nuances of each participant's recovery journey. Such granularity is particularly valuable in

physical therapy research, where patient responses vary widely and can inform both treatment efficacy and the customization of interventions.

Additionally, this approach enables the identification of individuals whose recovery trajectories diverge from the expected pattern. These cases warrant further investigation to explore possible biological, behavioral, or other contributing factors that may influence recovery rates.

A comparable trend is observed in the SST values, reflecting recovery progression in both groups. Examining average progress across the control and experimental groups provides insights into the distinct effects of the interventions applied.

The evolution of scores over the course of 36 treatment sessions highlights notable differences in recovery patterns. Both groups experienced a decline in scores, but the rate of decline varied:

- The control group exhibited a steady decrease with a steeper slope, indicating a faster but less sustained recovery.
- The experimental group demonstrated a slower, more gradual decline, suggesting that the applied treatment possibly VR helped mitigate functional deterioration.

The observed mean trends, along with individual variability, emphasize the differences in recovery trajectories. The comparative analysis of decline rates suggests that the experimental treatment may have contributed to a more sustained recovery, reinforcing its potential effectiveness in rehabilitation compared to conventional approaches.

The analysis of correlations between various assessment metrics used in the study, including DASH, SST, CMS, their sub-metrics, and pain scores, reveals important patterns in functional impairments and pain dynamics in patients with subacromial impingement syndrome. Strong positive correlations are observed between DASH, SST, and CMS, indicating that individuals reporting higher disability scores on one test tend to exhibit similar impairments across the other assessments. For instance, patients with limited mobility reflected in high DASH scores often report comparable functional limitations in SST and CMS scores. This consistency reinforces the validity of these tools as complementary measures for evaluating shoulder function. Negative correlations emerge between functional scores (DASH, SST, CMS) and pain scores, confirming that increased pain is associated with reduced functional ability. This well-documented relationship highlights the significant impact of pain on movement, where higher pain levels restrict mobility and shoulder function.

Consequently, managing pain effectively plays a crucial role in improving recovery outcomes. While many correlations are significant, certain sub-metrics show weak or no meaningful relationships, suggesting that some aspects of shoulder function—such as stability or active movement—may not be directly linked to pain levels. This emphasizes the need for a multidimensional approach in patient assessment, as relying on a single measure may not fully capture the complexity of subacromial impingement syndrome. The relationships between these metrics are determined using Pearson or Spearman correlation coefficients, with statistical significance evaluated through p-values. Significant associations are clearly identified, providing transparency and ensuring that the observed trends are not due to random variation. Overall, the strong correlations between DASH, SST, and CMS underscore their reliability as complementary assessment tools, while the inverse relationship between pain and functionality highlights the crucial role of pain management in rehabilitation. The presence of weaker correlations among certain sub-components further supports the necessity of a comprehensive evaluation approach to fully understand the condition's complexity.

Discussion

The study performed a correlation matrix analysis to understand the relationships between the different tests and their components. Discussion of the main findings from this analysis, such as strong positive correlations between DASH, SST, and CMS scores, could provide insights into the multidimensional impact of subacromial impingement syndrome and the effectiveness of VR therapy. The study's analysis of the correlation matrix provides valuable insights into the relationships between the various tests and their components, focusing on the Constant Murley Score (CMS), the Disabilities of the Arm, Shoulder and Hand (DASH) score and the Simple Shoulder Test (SST). This analysis is essential in understanding the multifaceted impact of subacromial impingement syndrome and the effectiveness of VR therapy. The correlation matrix revealed strong positive correlations between DASH, SST, and CMS scores. This indicates that the others tend to follow suit as one measure gets worse or better. For example, a high DASH score (indicating more disability) correlates with lower CMS and SST scores, implying poorer shoulder function. Methodologically, we preferred to reverse the DASH score value for the matrix correlation analysis precisely because we wanted to emphasise the strong relationship between scores to illustrate some consistency between different measures, which strengthens the validity of these tests in reflecting the overall impact

of subacromial impingement syndrome on patients. A noteworthy finding is the strong negative correlations between functional scores and pain ratings. This suggests an inverse relationship, where higher pain scores (indicating more severe pain) are associated with lower functional scores, denoting a decrease in the patient's ability to perform certain activities, which is not surprising given the predictable relationship between function and pain (pain hinders function), which highlights the direct impact of pain on patient's functional abilities, emphasising the importance of pain management in treatment protocols. Since the quantification of pain, given the interindividual variability of pain perceptions, is particularly difficult, we did not focus the present research effort on any aspect directly related to the impact of pain on recovery. Still, the role of this factor remains important.

The correlations observed in the matrix suggest that VR therapy, potentially addressing multiple dimensions of shoulder function and pain, could broadly improve overall patient outcomes. In line with the previous discussion, the study analysis demonstrates that a multifaceted approach to treatment and assessment is necessary, as certain aspects of a patient's condition, such as pain level, may not always correlate with their functional capacity. Without rigorous tools for assessing pain and its impact, we consider that we have pursued any other aspects relevant to the topic addressed. Some components within the tests showed weak or nonsignificant correlations, indicating that certain aspects of the syndrome's impact on patients are unique and cannot be captured by a single test. This reinforces the need for a comprehensive approach in both treatment and assessment, which is why we pursued correlational analysis at a deeper level as well. It is important to state that in the methodology of our study, the participants were released as they recovered. Some of the values obtained in the correlation matrix were affected by this natural methodological process, which is why it is important to follow the results of the analysis correlative in tandem with the results of the recovery analysis (time to event – survival analysis). The study recognises consistent improvement in some measures (such as DASH and SST scores) while noting variation in others (such as CMS scores). This indicates the multifaceted nature of recovery, where improvements in one aspect of shoulder function do not necessarily correlate with others at a maximal level—the tests do, however, correlate strongly, positively, and statistically significantly ($p < .05$).

The study integrates a postmodern perspective by recognizing the subjective nature of pain perception and functional assessment. The findings support the argument that VR-based rehabilitation provides a more

personalized, patient-centered approach, which aligns with the broader postmodern critique of one-size-fits-all medical interventions.

The study by Laver et al. also found no significant effect of virtual reality on upper limb function compared to conventional therapy. In contrast, studies by Molina et al. suggest that virtual reality can effectively complement manual therapy for improving pain, kinematic function, and disability in patients with chronic neck pain (Laver et al., 2017; Molina-Espeja et al., 2014)

While evidence on the efficacy of virtual reality in upper limb rehabilitation after stroke is mixed, research supports its potential as a complementary intervention for other conditions such as chronic pain. The heterogeneity in findings underscores the need for further high-quality research to elucidate the specific applications and optimal implementation of virtual reality in rehabilitation (Sunda et al., 2022; Sveistrup, 2004; Vigliani et al., 2019). Although no significant differences were observed between VR therapy and traditional treatments, it is important to consider the possible reasons for this absence of difference. VR therapy, with its interactive environment and real-time feedback, was designed to enhance motivation and reduce the perception of pain. However, its effects may not have been pronounced enough to surpass the proven effectiveness of traditional rehabilitation methods. Both therapies target the same core goals of recovery, and traditional methods, being more familiar and widely accepted, might contribute to better patient adherence to treatment. Another important factor to consider is the variability among individual patients, which could influence their response to treatment. Additionally, the study's methodology, including continuous recruitment and participant withdrawal upon achieving recovery, may have influenced the results depending on the timing of when participants entered the study. While the assessment measures (DASH, SST, CMS) used in this research are valuable, they may not fully capture the psychological and motivational aspects that VR therapy is designed to address.

Thus, the lack of significant differences between the two treatments could be attributed to the similarities in the interventions, patient variability, and the limitations of the assessment tools employed. To further understand the impact of VR therapy on recovery, future research should delve deeper into its psychological and motivational effects, which may provide more insight into how this technology can complement or enhance traditional rehabilitation approaches.

Conclusions

In conclusion, the correlation matrix analysis from the study provides a nuanced understanding of the relationships between different measures of shoulder dysfunction and pain in patients with subacromial impingement syndrome. The findings highlight the interconnectedness of different aspects of the condition and validate the comprehensive nature of the tests used. Moreover, these insights could inform future research and clinical practice, particularly in evaluating the effectiveness of VR therapy in treating this condition. The study considers individual variability and long-term recovery trends, highlighting the research's thoroughness and relevance to personalised patient care. We note that the study meticulously addresses individual variability and long-term trends in recovery from subacromial impingement syndrome, which is crucial for understanding the personalised nature of patient care and recovery trajectories, particularly how sociodemographic may have a role in recovery.

The study demonstrates a keen awareness of individual variability in treatment response. This is exemplified in the diverse recovery patterns observed within and between the experimental and control groups. The implications of this study extend beyond the specific condition of subacromial impingement syndrome. The effectiveness of VR interventions in this context suggests potential applicability across a wider range of musculoskeletal disorders, encouraging further exploration and integration of VR technologies into various therapeutic scenarios, where we can formulate diverse dynamically adaptive therapy solutions to capture the benefits inherent in interindividual variability, to use them constructively and positively in recovery. We are referring, of course, to machine learning systems capable of incrementally tracking recovery progress, thus adjusting the very therapeutic intervention within VR.

This study provides empirical evidence supporting the efficacy of VR-based rehabilitation from both a clinical and managerial perspective. The findings suggest that integrating VR therapy into existing healthcare frameworks can lead to improved patient outcomes, increased engagement, and potentially lower long-term costs.

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