IOSUD – UNIVERSITY "DUNĂREA DE JOS" OF GALAȚI

Doctoral School of Social Sciences

THESIS

THE USE OF VIRTUAL REALITY IN THE TREATMENT OF SUBACROMIAL IMPINGEMENT SYNDROME

Candidate,

Daniel – Mădălin Coja

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Serial SSEF No. 6

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President	**Prof univ.dr.habil. Nicoleta Ifrim** University "Dunărea de Jos" of Galați
Scientific leader,	**Prof univ.dr.habil. Laureţiu Gabriel Talaghir** University "Dunărea de Jos" of Galați
Scientific references	**Prof univ.dr.habil. Beatrice Aurelia Abalaşei** University "Alexandru Ioan Cuza" of Iași **Prof univ.dr.habil. Virgil Ene-Voiculescu** Naval Academy „Mircea cel Bătrân" of Constanța **Prof univ.dr.habil. Claudiu Mereuţă** University "Dunărea de Jos" of Galați

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Table of Contents

INTRODUCTION

In a world of continuous technological evolution, virtual reality (VR) has become a fascinating and ubiquitous concept in society. This technology, which allows the creation of an artificial holographic world, has become increasingly accessible to the public in recent decades and has gained popularity in various fields such as medicine, entertainment, education and sports training. Virtual reality provides users with an immersive experience in a computer-generated environment, whether it simulates the real world or a completely different environment. Users are completely immersed in their environment, can interact with objects and experience virtual events as if they were real. This technology provides 3D computer-generated environments that allow exploration in all directions and immersive sounds that complete the experience.

Originally developed for military and scientific purposes, virtual reality has found applications in various fields and has become extremely popular among users. In medicine, virtual reality allows users to enter stimulating environments, offering immersive and interactive experiences that are more attractive and motivating compared to classical methods. It can be used in physical recovery processes to restore diminished or lost body functions. Currently, subacromial impingement syndrome is one of the most well-known conditions in the shoulder, which causes discomfort and painful sensations. The use of virtual reality in this condition accelerates the recovery process by creating personalized holographic environments that can adapt to the needs of each user. This provides a more engaging and fun user experience with clear goals to achieve and helps reduce the pain and anxiety associated with the recovery process. Virtual reality thus becomes a vital element in recovery processes and opens new horizons for research and development in this field.

ARGUMENTATION OF TOPIC CHOICE

Virtual reality users will experience a significant increase in shoulder range of motion in a shorter amount of time during the recovery process. The use of virtual reality will motivate more to perform the exercises compared to the classical therapeutic approach. Virtual reality can significantly reduce pain and discomfort in movement, measured subjectively or objectively, compared to conventional treatment. Virtual reality can also improve the quality of life, including the ability to perform daily activities without difficulty and the general well-being of treated patients. The data collected and analyzed following the research will validate or disprove these hypotheses, providing evidence regarding the effectiveness of using virtual reality in the treatment of subacromial impingement syndrome. The purpose of the research is to evaluate the effectiveness and impact of using virtual reality in the treatment of patients with subacromial impingement syndrome, to investigate whether this technology can really improve user outcomes, and to provide practical information to specialists in the field.

Research objectives:

• Theoretical foundation of virtual reality and understanding of its use in medical and other fields.

• Establishing clear lines in the theoretical approach to subacromial impingement syndrome in association with virtual reality.

• Implementation of solutions that associate virtual reality with recovery processes, especially in subacromial impingement syndrome.

• Development of a virtual reality implementation plan in subacromial impingement syndrome for the objective evaluation of research groups.

• Realization of an experiment that substantiates the working model in the delimitation between virtual reality and the classical approach.

• Elaboration of a working model for the distribution of study members, maintaining a homogeneity of the participant samples.

• Development of theoretical notions for more efficient implementation of virtual reality.

• Carrying out initial and final testing to evaluate the impact of virtual reality in the treatment of subacromial impingement syndrome, by applying test batteries.

• Clinical efficacy evaluation to determine the effectiveness of virtual reality in improving symptoms and joint function, monitoring short- and medium-term progress.

PART I

THEORETICAL SCIENTIFIC ASPECTS SPECIFIC TO THE RESEARCH APPROACH

CHAPTER I

VIRTUAL REALITY AND SUBACROMIAL IMPINGEMENT SYNDROME

Virtual reality is in full development and its history is very interesting and full of significant moments. One of the first important moments was the story "Pigmolion's Spectacles" written by Stanley G. Weinbaum in 1935, where the term virtual reality was used for the first time [5]. In the following years, various devices were made that contributed to the development of the technology, such as the "Sensorama" created by Morton Heilig in 1957 and the "Sword of Damocles" developed by Ivan E. Sutherland in 1968 [8].

Since the 1990s, consumer virtual reality products have been launched, and with the advancement of mobile technologies and powerful computers in the 2010s, it has become even more accessible [7]. In addition to virtual reality, other important concepts such as augmented reality and mixed reality have emerged. These historical milestones are just a few examples that underpin the continued evolution of this technology. Currently, virtual reality is defined as a technological product that creates 2D and 3D virtual environments and has great applicability in various fields [8].

The use of virtual reality is based on the human-computer connection and offers users the possibility to interact in a virtual world through visual, auditory, tactile or kinesthetic stimulation [10]. This technology can enable users to become active participants in the virtual environment and reduce unpleasant experiences by connecting the cognitive and emotional centers of the nervous system [3].

Subacromial impingement syndrome is a condition characterized by narrowing of the subacromial space and compression of the tissues in that area, causing pain and discomfort in the shoulder joint and affecting the mobility of the upper limb [1] [2] [6]. In the 20th century, physicians began to observe and document cases of pain associated with the subacromial space, paving the way for further research. Dr. Charles S. Neer II was one of the leading

researchers who described this syndrome in 1972, providing essential information for understanding the condition and for the medical field in general [10] [11].

Technological advances in medical imaging have allowed better diagnosis of impingement syndrome since the 1980s-1990s. In recent decades, significant advances have been made in the treatment of this condition, including physical therapy, lifestyle changes, minimally invasive surgical techniques, and anti-inflammatory drugs, which have improved patients' quality of life [9].

CHAPTER II
MODES OF ACTION OF VIRTUAL REALITY ON THE CENTRAL NERVOUS SYSTEM

Building on Melozach and Wall's Gate Control Theory, it has been suggested that the level of attention and emotions associated with pain play an important role in understanding it. McChaul and Mallot argue that the human being has a limited capacity to understand pain and that a painful stimulus is necessary to perceive it. Analgesia in virtual reality can be achieved by blocking or filtering pain signals to the brain. This technology can help treat chronic or post-operative pain by providing relaxing and fun environments to reduce painful sensations. Virtual reality can also distract from pain through engaging visual and auditory stimuli. Thus, gate control theory can be successfully applied in virtual reality for effective pain management.

PART II

CONSTATIVE RESEARCH

CHAPTER I
METHODOLOGY OF CONSTATIVE RESEARCH
I.1. PREMISES OF CONSTATIVE RESEARCH

We start from the idea that there is both reluctance towards new technologies or innovations, as well as enthusiasm and openness to adopt these new technologies, especially when the context of adoption is clear and the purpose of the technology is understood by users.

I.2. SUBSTANTIATING HYPOTHESES OF DECLARATIVE RESEARCH

Can the use of virtual reality in medicine, through games and enjoyable holographic environments, improve learning, facilitate medical recovery and improve medical services by reducing patients' fear and discomfort?

I.3. METHODOLOGICAL ASSUMPTIONS

The main methodological hypothesis is that the proposed operationalization can be confirmed by analyzing the data obtained by applying the research tools and the coherence of the operationalized model.

I.4. THE PURPOSE OF CONSTATIVE RESEARCH

The purpose of the constative research is to evaluate the impact of population openness to the use of virtual reality in physical therapy rehabilitation in acromial impingement syndrome. The aim is to identify positive or negative perceptions regarding physical therapy recovery through virtual reality, in accordance with the current level of development of this technology in the medical field and the degree of exposure of the population to the innovation of using virtual reality in medical procedures.

I.5. OBJECTIVES OF ASCERTAINMENT RESEARCH

• Identifying virtual reality knowledge regarding the technological product

• Identify the openness to this product

• Identify positive or negative perceptions about this product

• Identifying the implementation of virtual reality in medical recovery procedures

• Establish openness in the implementation and integration of virtual reality in medical rehabilitation physiotherapy.

I.6. QUANTITATIVE RESEARCH METHODOLOGY THROUGH THE CHOSEN MEASUREMENT TOOL

The tool used in this approach is a questionnaire with 26 answer items, of which 6 have the role of sociodemographic reference (gender, age, status of the respondent – patient/professional, professional experience, living environment and county of residence), and 20 are operationalized in order to achieve the objectives of the present research, with response options in the form of a simple Likert scale with 5 response options (not at all, a little, enough, a lot, very much).

CHAPTER II
ORGANISATION OF THE RESEARCH ACTIVITY

We selected 259 participants in a sampling: 64 patients and 195 physiotherapists. We tested the extent and conditions under which a student test is applicable to both subgroups. The selected sample is sufficient for such a test in both cases, as long as the other conditions of descriptive statistics are also met. Type I error is an incorrect rejection of the null hypothesis, while type II error is an erroneous failure to reject the null hypothesis. These tests are performed to determine whether the selected sample is large enough.

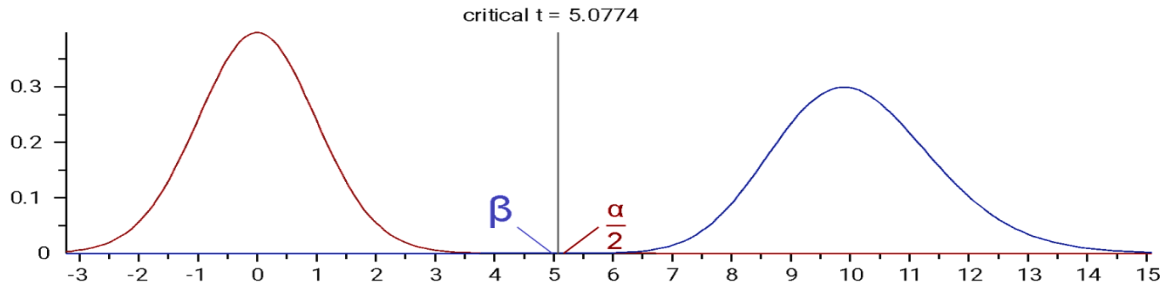


Figure 1 Distribution of type I and II error probabilities for a sample of 64 subjects

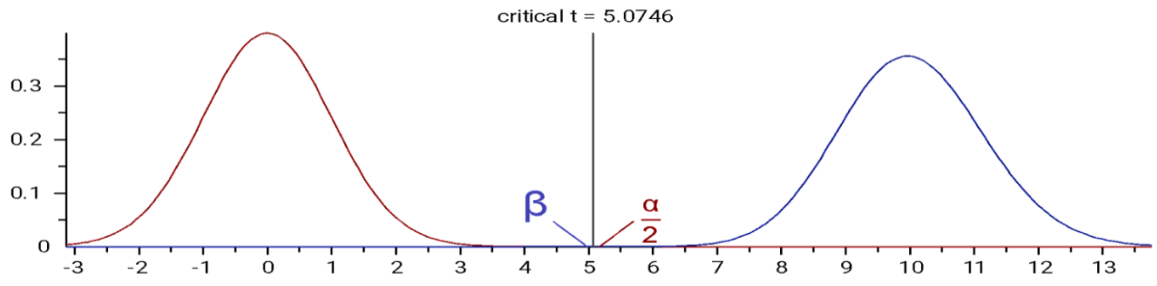


Figure 2 Distribution of type I and II error probabilities for a sample of 195 subjects

CHAPTER III

RESULTS

III.1. POST HOC ANALYSIS OF THE PROPOSED INSTRUMENT AND MODEL

In the methodological stage, the development of the measurement tool did not allow testing how it captures or measures realities and relationships in research. That's why we proposed formulating a test plan for the tool from the early stages of the research. Our goal is to determine whether the proposed factorization structure is optimal by analyzing the relationships between the primary variables. We want to see if the initial factorization of the variables is consistent with the results obtained.

We continue by using visual aids to explore and characterize the results obtained from 400 (20x20) Spearman correlation tests. These results will be grouped in a matrix that will contain information about each individual test, as well as the relative positioning of the values obtained according to the other values.

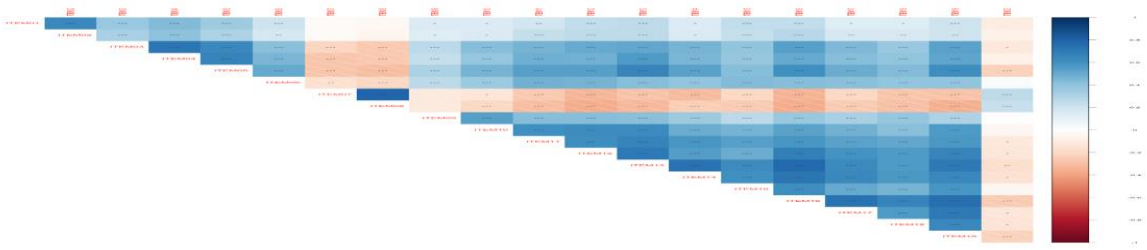


Figure 3 Matrix plot of correlation coefficients grouped in the order proposed by the working tool

In this sense, we follow the way in which the items form relationships with the help of some visual methods of tracking them: graphs that represent the matrix of correlation coefficients between the primary variables, and the way in which these relationships converge in aggregates that correspond to the initial factorization.

ITEM	MED	VAR	OBS	PV	HMD	df	t Stat	P(T<=t) one-tail	t Critical one-tail	P(T<=t) two-tail	t Critical two-tail
1. Ati auzit pana in prezent de acest tip de tehnologie?	2.866	1.412	194.000	1.434	0.000	257.000	2.446	0.008	1.651	0.015	1.969
vs. PAT	2.446	1.501	65.000								
ITEM	MED	VAR	OBS	PV	HMD	df	t Stat	P(T<=t) one-tail	t Critical one-tail	P(T<=t) two-tail	t Critical two-tail
2. Cunoasteti pe cineva care a utilizat aceasta tehnologie?	1.995	1.342	194.000	1.542	0.000	257.000	-2.190	0.015	1.651	0.029	1.969
vs. PAT	2.385	2.147	65.000								
ITEM	MED	VAR	OBS	PV	HMD	df	t Stat	P(T<=t) one-tail	t Critical one-tail	P(T<=t) two-tail	t Critical two-tail
5. Considerati realitatea virtuala ca fiind un produs bun de utilizat?	3.737	1.127	194.000	1.167	0.000	257.000	1.581	0.058	1.651	0.115	1.969
vs. PAT	3.492	1.285	65.000								

CHAPTER IV
CONCLUSION

The aim of the research was to evaluate the influence of VR technology on physical therapy recovery in acromial impingement syndrome. The study investigated the population's perceptions of VR and how these affect the use of VR in physical therapy. The degree of familiarity of the population with VR and its impact on perceptions was analyzed. The research also examined positive and negative perceptions of VR as a rehabilitation tool, including beliefs about its effectiveness, safety, and potential to enhance or disrupt traditional rehabilitation methods. Another objective was to assess the openness to the use of VR in physiotherapy, both on the part of medical professionals and patients.

The study methodology involved both quantitative and qualitative approaches to provide a complete picture of the subject. The results highlighted the diversity of attitudes towards VR, influenced by socio-demographic factors such as age, gender, professional status and geographical location. The study emphasized the importance of a cautious and progressive integration of VR into medical practices, but also identified barriers such as high costs and concerns about the effectiveness of the technology. Statistical analysis revealed relationships between socio-demographic factors and attitudes towards VR. The findings of the study provided essential knowledge for the development of future research and practice in the field of medical rehabilitation.

PART III EXPERIMENTAL RESEARCH

CHAPTER I
EXPERIMENTAL RESEARCH HYPOTHESES

The primary hypothesis

H1: Patients undergoing augmented VR rehabilitation will experience a significantly faster and more effective recovery compared to those receiving traditional rehabilitation methods.

Secondary hypotheses

H2: Recovery time will be shorter for the VR group compared to the traditional group. Rationale: Interactive VR can lead to more intense and regular engagement in the rehabilitation process, accelerating recovery.

H3: Patients in the VR group will show increased resistance to physical challenges, which may reduce the recurrence of the syndrome. They will perform the training without breaks. Rationale: VR therapy stimulates the development of neuromuscular strength and coordination, increasing resistance to physical stress.

CHAPTER II
OBJECTIVES OF EXPERIMENTAL RESEARCH

This research focuses on the effectiveness and advantages of virtual reality (VR) in the rehabilitation of subacromial impingement syndrome. The objectives were formulated to provide a comprehensive understanding of the subject, each objective contributing to the answer to the main question: Does VR accelerate and improve recovery compared to traditional methods?

CHAPTER III

DESCRIPTION OF THE EXPERIMENTAL RESEARCH

• Participant recruitment: Individuals diagnosed with subacromial impingement syndrome, aged 18 to 65 years, with no prior exposure to VR-based rehabilitation, will be recruited. Broad demographic representation, including men and women, will be ensured. Potential participants will be identified from orthopedic clinics, physiotherapy centers and through direct physician referrals. An initial screening will check that you meet our criteria.

• Experimental design: The research will use a randomized controlled trial (RCT) design to compare the effects of VR-augmented therapy with traditional rehabilitation methods. The control group will follow traditional rehabilitation methods, and the experimental group will receive VR-augmented treatment.

• Assessment protocols: Before the intervention, all participants will undergo a comprehensive assessment using various assessment tools. Assessments will be repeated weekly using tools such as the Pain Arch Test, DASH, Simple Shoulder Test and Constant Murley Score to monitor progress and identify differences between groups.

• Implementation of survival analysis for recovery: Survival analysis will be used to model the time required for participants to be considered fully recovered.

• Data collection and management: Patient data will be collected, stored and managed through a dedicated digital platform, ensuring data integrity and confidentiality.

• Data analysis: In addition to survival analysis, data will be subjected to descriptive and inferential statistical analyses. Comparisons between groups will use t-tests or Mann-Whitney U-tests, depending on the distribution of the data.

• Feedback Mechanism: Participant feedback will be collected to ensure the effectiveness of the research program.

• Ethical considerations: All participants will provide informed consent and the study will be subject to periodic reviews by an ethics committee to ensure integrity and appropriate care.

CHAPTER IV

ORGANIZATION OF EXPERIMENTAL RESEARCH

Introduction

Our study aims to evaluate the effectiveness of two different recovery methods for patients with subacromial impingement syndrome (SIS), a rare condition in the population and rarely occurring in the acute phase. Given these issues and the capacity limits of our research laboratory, we adopted a modified continuous recruitment design whereby participants can fill available slots as others are released from recovery, depending on the total available slots in the laboratory.

Objectives of the method

To detail and justify a methodologically sound approach that allows for maximum participant turnover, maintains laboratory capacity, and ensures sociodemographic similarity between control and experimental groups. To ensure an equivalent, coherent and cohesive

treatment of study participants, which does not in any way negatively affect their natural recovery.

Methodology

Initial setup: Study duration: 50 weeks. Laboratory: maximum 18 participants in each group (experimental and control), with a maximum total of 36 participants at the same time. The average estimated time for recovery, according to the specialized literature, is predominantly between 5-8 weeks.

Continuous recruitment model: Given the intended recovery time frame, we assumed that many participants would complete their recovery before the 12-week limit for laboratory occupancy. To maximize sample size and fully utilize available resources, the study was designed to continuously recruit new participants. When a participant (from either group) meets the established recovery criteria, they exit the study. At the same time, a new participant is recruited to ensure that the laboratory operates at full capacity.

The system of sociodemographic quotas: To ensure homogeneity and sociodemographic similarity between the two groups, a system of quotas based on sociodemographic criteria from the specialized literature was applied. New participants are only accepted if they fit the required socio-demographic profile, to guarantee balanced and comparable groups. This approach is important to maintain the internal validity of the study, given that participants fluctuate constantly.

Results: Using a continuous recruitment model and the sociodemographic proportion system, the study managed to recruit 288 participants in one year, 144 in each group. Thus, laboratory resources were efficiently used throughout the 50 weeks of the study, helping to overcome the logistical limitations of research resources.

Discussion: Our approach aligns practical laboratory constraints with research objectives, maximizing the number of subjects for a robust sample without compromising study quality and validity. The continuous recruitment model allows efficient use of resources, and the system of socio-demographic quotas ensures comparability between groups. We coordinate these aspects together with the method of cluster analysis, which highlights and compares groups and their differences to ensure that any differences in the experiment between the two groups are not due to chance or error.

CHAPTER V
REASONING FOR DIFFERENT DATA COLLECTION TIMES AND SESSION DURATIONS

Temporal alignment of assessments: To achieve rigorous and comparable participant progress, our study used both continuous and intermittent assessments. The painful arc test was administered continuously at each training session, providing a detailed record of symptom progression. Instead, tests such as DASH, SST, and CMS were reserved for critical time points, T0, T1, T2, and T3, according to the methodology.

Calibration of assessment times: These critical times were carefully selected to synchronize the different session frequencies between the two groups while ensuring that each assessment point was predictive of significant recovery milestones. This timing was essential to reduce discrepancies caused by different training durations and to ensure a valid comparison: T0 (baseline): performed at the beginning of the study to measure the baseline condition of all participants. T1 (2 weeks or 6 sessions for the control group): scheduled after

two weeks for the experimental group and after the completion of six sessions for the control group. This intermediate checkpoint was created to monitor early recovery and adaptability to the respective training methods. T2 (4 weeks or 12 sessions for the control group): This point, placed in the middle, was considered critical to record any significant plateaus or progress in recovery. T3 (6 weeks or 18 sessions for the control group): Placed in the second half of the anticipated recovery period, the intention here was to include data at a stage when a significant proportion of participants, particularly in the experimental group, were assumed to have a marked recovery.

Interpretation of recovery by the Painful Arc Test: An important decision in our method was to consider three consecutive scores of zero on the Painful Arc Test as a sign that the participant had recovered. This criterion is based on the clinical belief that the absence of constant pain during arch movement is a strong indicator of restoration of shoulder function. By aligning the testing times (T0 to T3) with this recovery criterion, we aimed to maximize the chances of assessing the majority of participants at these critical times so that we could perform a comprehensive analysis

Balancing session durations: The choice of session durations – 20 minutes daily for the experimental group versus 60 minutes three times per week for the control group – was guided by the pedagogical paradigms of each training modality. 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.

CHAPTER VI
INFORMATION ABOUT PARTICIPANTS, SELECTION AND INFORMED CONSENT

Participant Recruitment: Participants were recruited primarily through physical therapy clinics, community health centers, and advertisements in local newspapers and community bulletin boards. Online platforms and social media channels associated with SISA support groups were also used to promote the studies.

Initial Screening: Candidates were pre-screened through telephone interviews. This stage checked whether they met basic criteria, such as a confirmed diagnosis. Those who passed the initial assessment were invited to a full face-to-face assessment.

Personal assessment: At this stage, participants were physically assessed by qualified physical therapists and completed a socio-demographic questionnaire to enroll in the study. The results were recorded as "admitted/rejected" for participation in the study. Only 4 candidates were rejected due to exceeding the maximum number of participants, but the ongoing research method allowed the acceptance of participants who otherwise could not have been included in a standard study design.

Informed consent process: Participant information: Each potential participant was provided with a detailed information sheet about the study. This leaflet explained the purpose, procedures, risks, benefits, privacy and participant rights. Consent by discussion: After reviewing the information sheet, participants had an individual discussion with a member of the research team. This session allowed participants to ask questions, clarify doubts and be sure they understood the implications of the study. Signing informed consent: Participants who decided to participate in the study after the discussion were asked to sign an informed consent form. This form, according to the Declaration of Helsinki, emphasized the voluntary nature of

their participation, their right to withdraw at any time without consequences and consent to the use of data, ensuring anonymity.

Ethical approval: The study protocol, including the informed consent process, was reviewed and approved by the FEFS Ethics Committee. Regular audits were conducted to ensure adherence to ethical standards and protocols.

Selection and allocation of participants: Following the informed consent process, participants were formally enrolled in the study, and were randomly assigned to either the control group or the experimental group, ensuring socio-demographic balance through the quota system.

Privacy Measures: To protect the privacy of participants, all personal identifiers have been removed or obscured. Thus, participants' identities cannot be traced, and each participant was identified by a unique code for the duration of the study. This code is not associated with the participant's personal data and there is no access to this data after the code is assigned. The data has been stored in encrypted databases with restricted access and there is no direct link or access to the personal data, only the encoded data. Anonymity of the participants was ensured in any publication or presentation related to the study.

Post-Study Debriefing: At the end of participation, individuals were given a one-on-one debriefing session regarding the objectives of the study, the possible consequences of their participation, and were asked to revalidate their initial consent. All participants confirmed their consent.

CHAPTER VII
USE OF THE LABORATORY AND SESSION LOGISTICS FOR THE EXPERIMENTAL AND CONTROL GROUPS

• Work capacity: The subacromial impingement syndrome recovery research lab has 36 work slots, with optimally allocated resources for each participant. Allocation and booking of work slots was done equally for the two research groups.

• Streamlining training duration: Duration-differentiated training sessions are based on the assumption that the use of virtual reality technology can allow for shorter but more frequent sessions compared to traditional recovery sessions, while still having superior benefits.

• Experimental group: Each session lasted 30 minutes, including a 10-minute pre-session protocol to prepare the participant and the virtual reality (VR) device. This protocol included checking the correct positioning of the device. This was followed by a 20-minute period of focused VR training, which was the actual part of the session. The group participated daily, resulting in a total of 140 minutes of weekly training. This structure allowed the evaluation of the cumulative effects of the VR sessions, due to their constant frequency and the absence of long breaks. In total, the experimental group had about 140 minutes of actual work.

• Control group: Each session lasted 60 minutes, including short breaks and adjustments of about 40 minutes per week. Half of the participants trained on Monday, Wednesday and Friday, and the others chose Tuesday, Thursday and Saturday. This organization optimized the use of the training facility, resources and monitoring, avoiding overcrowding. In total, they had approximately 180 minutes of weekly training exposure, of which 140 minutes were actual.

• Comparative rationale: Although the experimental group had more frequent daily exposure, their total training time per week was approximately 140 minutes. In contrast, the control group,

training three times a week, accumulated about 180 minutes per week, but about 40 minutes were used for activities that were not actually training, such as pain breaks or preparing equipment . However, the difference was compensated by the intensity and immersion of the VR training, which had a pronounced therapeutic effect in a shorter time, even though the actual time worked was about the same.

• Logistics Overview: Laboratory participants organized to avoid overlapping sessions, ensure availability of resources, and optimize therapeutic outcomes. The experimental group used the laboratory resources in their daily routine, allowing immersive VR sessions without logistical problems. The control group had an alternate-day recovery structure, which was beneficial for intensive traditional rehabilitation sessions. This allowed alignment with established physiotherapy recommendations and justified recovery intervals.

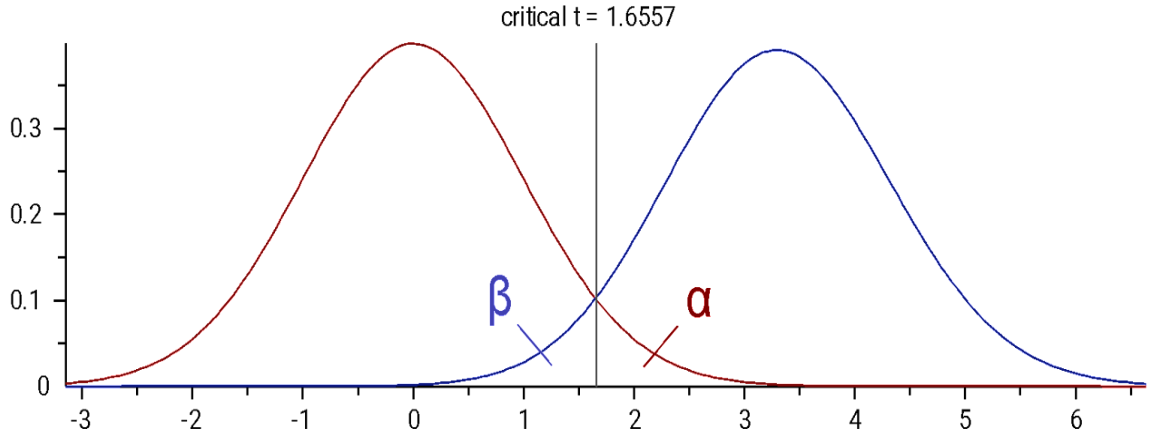
CHAPTER VII

SAMPLING OF SUBJECTS

Sampling is a critical component of any empirical research, ensuring that the results obtained are generalizable to a wider population. In this study, the precision and accuracy of our findings are supported by comprehensive sampling considerations.

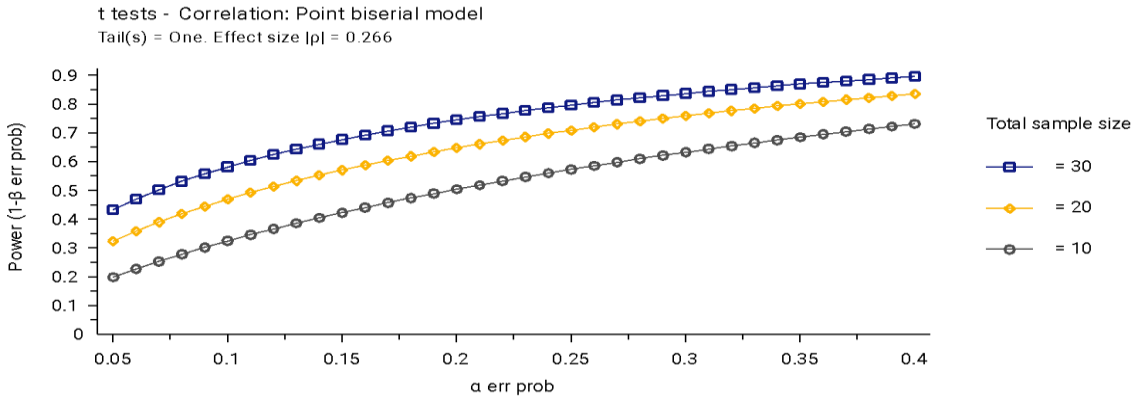
Determining the sample size for this study

While initial calculations, taking into account the anticipated effect size and acceptable error rates, indicated a sample size of 50 participants per group, the decision was made to increase this to 144 participants per group, and this increase, by nearly three times, was done deliberately to increase the statistical power of the study, ensure robustness against unanticipated variation, and have reservations against type I and type II errors, ensuring both the specificity and sensitivity of the findings.



The graph depicts a standard normal distribution curve, which is symmetric about the zero mean, and illustrates the probability density function for a normally distributed variable. The curve is divided into sections representing alpha (α) and beta (β) errors in the context of hypothesis testing. The critical value (t) is marked on the curve, demarcating the threshold beyond which the null hypothesis would be rejected at a given level of significance. The area under the curve to the right of the critical value represents the alpha error, the probability of a type I error in which a true null hypothesis is incorrectly rejected, and the area to the left of the curve and to the left of the mean (negative z-values) represents the beta error, the probability of an error of type II in which a false null hypothesis is not rejected. The power of the test, (1 -

), is not visualized directly on this diagram, but is conceptually represented by the complement of the β area.



Pictured is a power curve illustrating the relationship between the power of a statistical test and the effect size for three different total sample sizes in a biserial point model, which is used to measure the association between a binary variable and a continuous variable. The x-axis represents the effect size, while the y-axis indicates the power of the test, or the probability of correctly rejecting the null hypothesis when it is false.

CHAPTER VIII

WORKING METHOD IN VR OF THE EXPERIMENTAL GROUP

• System framework and interface: The VR environment was developed on an immersive platform adapted for therapeutic applications. The graphical interface has been optimized for clarity so that participants can easily perceive movement cues and react accordingly. Haptic feedback enriched the experience, providing tangible sensations consistent with virtual interactions. The platform used integrates body movements with hand sensor feedback, providing participants with a realistic virtual context in which their movements have a desired impact.

• Rhythmic movement dynamics: To facilitate shoulder recovery in a more complete manner, participants were encouraged to engage in rhythmic movement sequences. These sequences have been naturally structured, following movements that promote fluidity in recovery exercises. Fundamental sequences emphasized establishing a basic rhythm, training participants to time their movements in sync with the VR cues. This foundation was essential for the complex sequences that followed. Once participants demonstrated proficiency with fundamental movements, they progressed to advanced sequences, interweaving multi-directional strikes and dodges, cultivating a robust sense of proprioception and dynamic shoulder stability. It is important to emphasize that the separation between fundamental and advanced movements is based on their sequencing and not on a methodological separation. Progress in movement dynamics is characterized partly by complexity and entirely by increasing the patient's overall work capacity in VR.

• Directional kicks and their benefits: Anterior-posterior swings: These movements can improve shoulder flexion and extension, lubricate joints and reduce stiffness, especially in the fascia. Lateral movements: These promote shoulder abduction, essential to reach overhead without compressing the subacromial. Diagonal movements: Participants used diagonal trajectories to combine flexion-extension and abduction-adduction, improving movement at the joint.

• Modulation of vertical movement: Overhead arms with mid- and lower-level movements ensure full rotator cuff engagement. These movements contribute to the scapulohumeral rhythm necessary to raise the arm without pain. They involve the supraspinatus and upper trapezius muscles, aiming to restore overhead activities. Mid- and lower-level kicks focus on mid-shoulder movements, boosting rotator cuff endurance, especially during sustained activities.

• Engagement, mind-body connection and psychological component: Achievement stage: by unlocking levels or sequences, participants had tangible signs of progress, which motivated them more in the recovery process. Distraction from Discomfort: The immersive environment of VR helped participants focus less on temporary discomfort, allowing them to engage more and, as a result, achieve improved therapy. Expert supervision and guidance: While the VR platform works autonomously, the sessions were monitored by rehabilitation experts. This ensured that the participants' movements followed the therapeutic norms, maximizing the benefits and minimizing the risk of wrong movements or injuries that could lead to regression.

CHAPTER IX
DETAILED PRESENTATION OF TRADITIONAL CONTROL GROUP REHABILITATION FOR SUBACROMIAL IMPINGEMENT SYNDROME

• Fundamental principles: The traditional approach to rehabilitation for subacromial impingement syndrome has been meticulous and based on evidence-based practices. Although it is called "traditional", it represents the pinnacle of current physiotherapeutic practices for the treatment of this syndrome. This approach focuses on reducing pain, improving mobility and restoring strength.

• Staged progression: Initial phase: Progressive mobilizations, specific techniques for subacromial impingement syndrome, and modalities such as cold compresses or ultrasound are used to alleviate pain. Intermediate phase: Focuses on reducing pain, restoring range of motion (ROM) and introducing strengthening exercises. Advanced Phase: Exercises are performed to strengthen the shoulder girdle muscles, restore functional movement patterns, and prepare the patient for return to usual activities.

• Restoring the range of motion (ROM – Range of Motion): passive ROM: Through external forces (manual or with the help of tools), these exercises ensure joint mobility without involving muscle contraction. Active-assist ROM: Using the unaffected arm or external aids to facilitate movement of the affected shoulder. Active ROM: Relies only on the musculature of the affected shoulder to move through its full range of motion.

• Targeted Strength Training: Shoulder strength exercises have been precisely calibrated to strengthen the intricate musculature of the shoulder, including the rotator cuff and scapular stabilizers. Exercises such as scapular retractions and anterior serration grooves improved scapular anchorage, essential for optimal shoulder biomechanics.

• Functional integration and movement re-education: After isolated exercises, the regime moved on to more complex and functional movements, such as the medicine ball throw, to develop dynamic shoulder stability and strength. Proprioceptive training exercises such as balance boards were also added to improve shoulder neuromuscular coordination and movement precision.

• Postural education and ergonomics: Participants were instructed on the importance of posture in impingement syndromes, including proper scapular positioning to reduce undue

subacromial compression. They were also introduced to ergonomic practices and how they can modify daily activities to prevent SIS recurrence, such as workspace adaptation and lifting techniques.

CHAPTER X
RESULTS OF EXPERIMENTAL RESEARCH
Recovery time and progress slopes

The recovery trajectories of the experimental and control groups 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 (Ruxton, 2006), patterns of differential recovery were quantitatively elucidated.

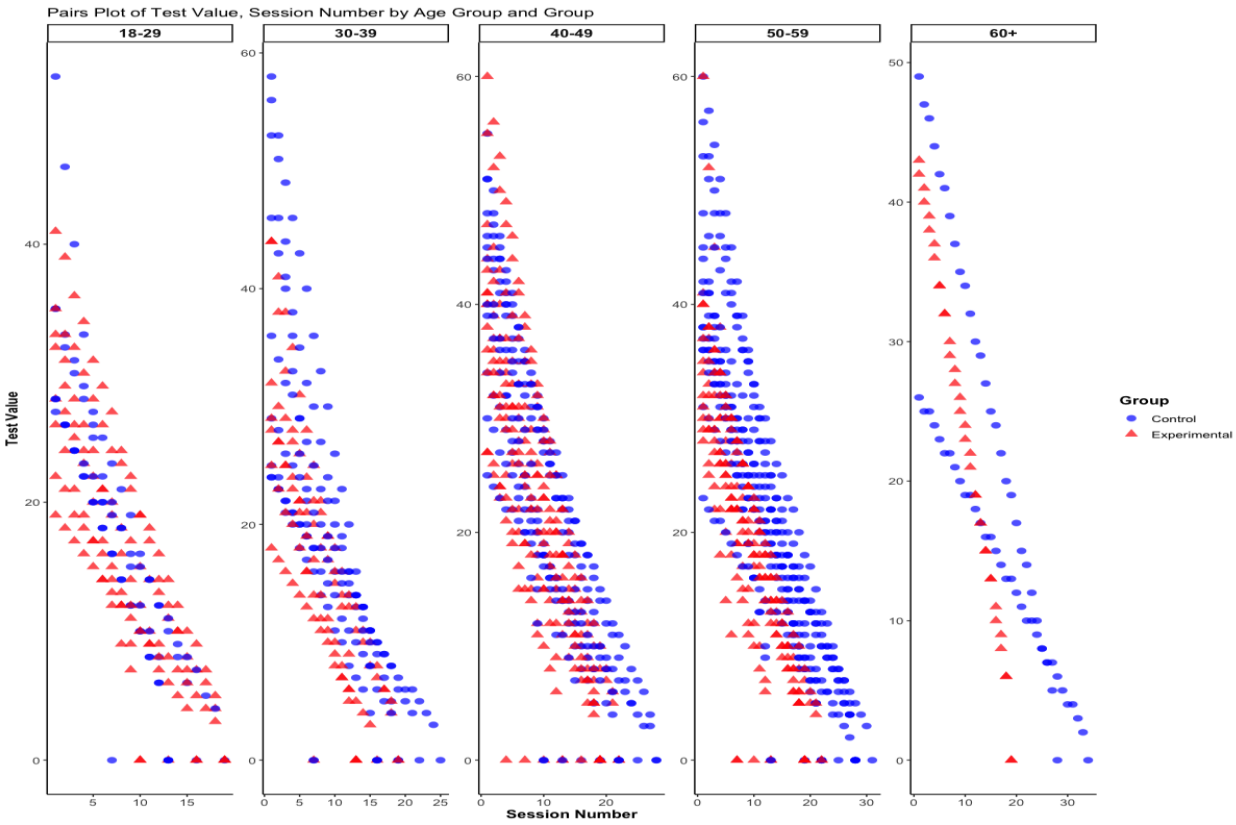


Figure 4 Variation in compression scores as a measure of recovery – decrease indicates healing

The experimental group showed a mean recovery time of 6.04 weeks, as opposed to the control group 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.

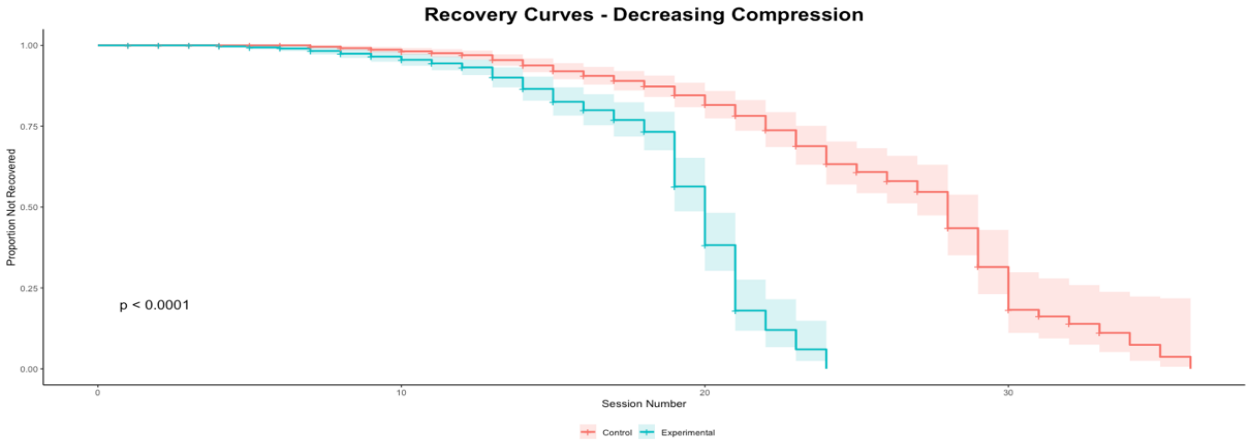


Figure 5 Mean recovery - comparison between groups

In tandem with the analysis of recovery times, the slopes of the linear progression of the test values were meticulously examined to obtain information on the rate of recovery. The experimental group showed a more pronounced negative slope of -2.73, compared to -2.59 of the control group. This steeper slope indicates a more rapid decline in test values, suggesting an accelerated recovery process for patients undergoing recovery with VR

Descriptive statistics results

Testing in T0

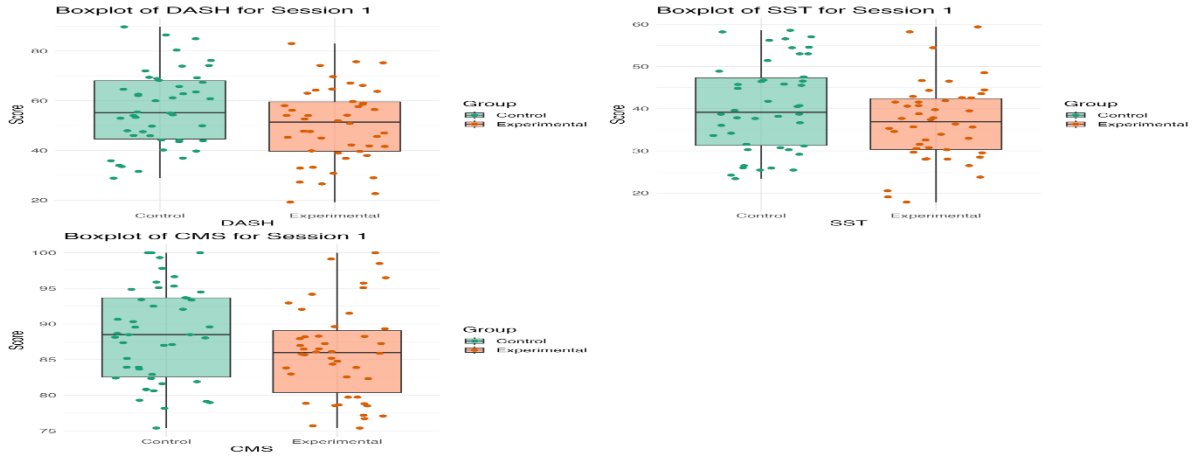


Figure 6 - Box plots for comparative analysis of extreme values - T0 - DASH, SST, CMS

DASH scores are represented by two boxplots, one for each group. The median is shown by the line in the box and appears to be similar for both groups. The interquartile range (IQR), which represents the middle 50% of scores, also overlaps significantly between the control and experimental groups, suggesting no substantial difference in the central distribution of scores at this baseline.

The median SST score for both groups appears to be almost identical, with a large degree of overlap in the IQR. The distribution of scores within the boxes, as well as the range indicated by the "whiskers", suggests an uniformity of shoulder function in both cohorts at the start of the study. The presence of outliers, indicated by points beyond the whiskers, appears similar in frequency and distribution for both groups.

CMS scores reveal a tight clustering around high scores for both groups.

Testing in T1

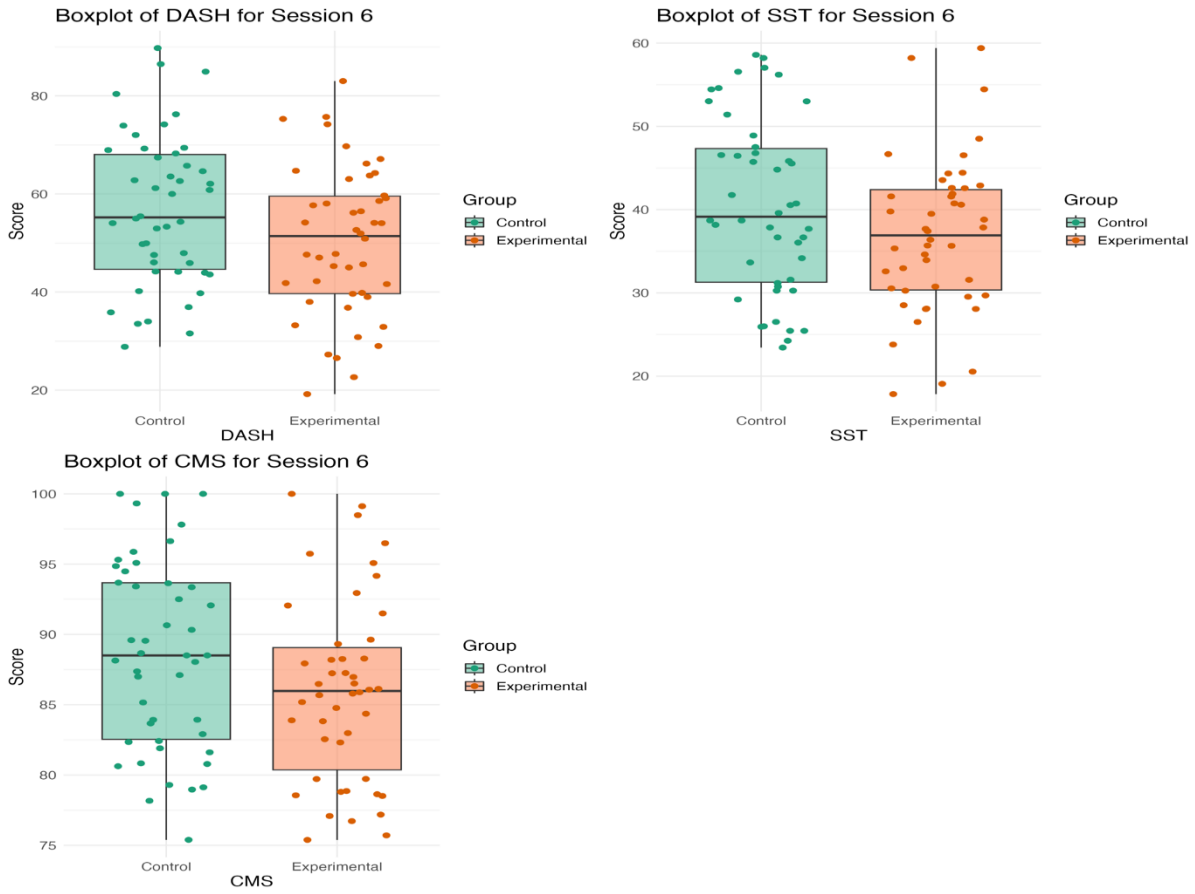


Figure 7 - Box plot graph for extreme value analysis

The boxplot indicates a slightly lower median for the experimental group compared to the control group, suggesting a trend toward improved functionality after the intervention. The interquartile range (IQR) of the experimental group is tighter, implying a more consistent response to treatment, while the control group shows a wider spread, indicating variable recovery outcomes. The accompanying histogram emphasizes this, with the experimental group showing a concentration of scores in the lower range.

SST scores show a higher mean in the box plot of the experimental group, which is desirable because higher scores reflect better function. The median of the control group is lower and its data points are more spread out, as evidenced by the wider IQR.

Testing in T2

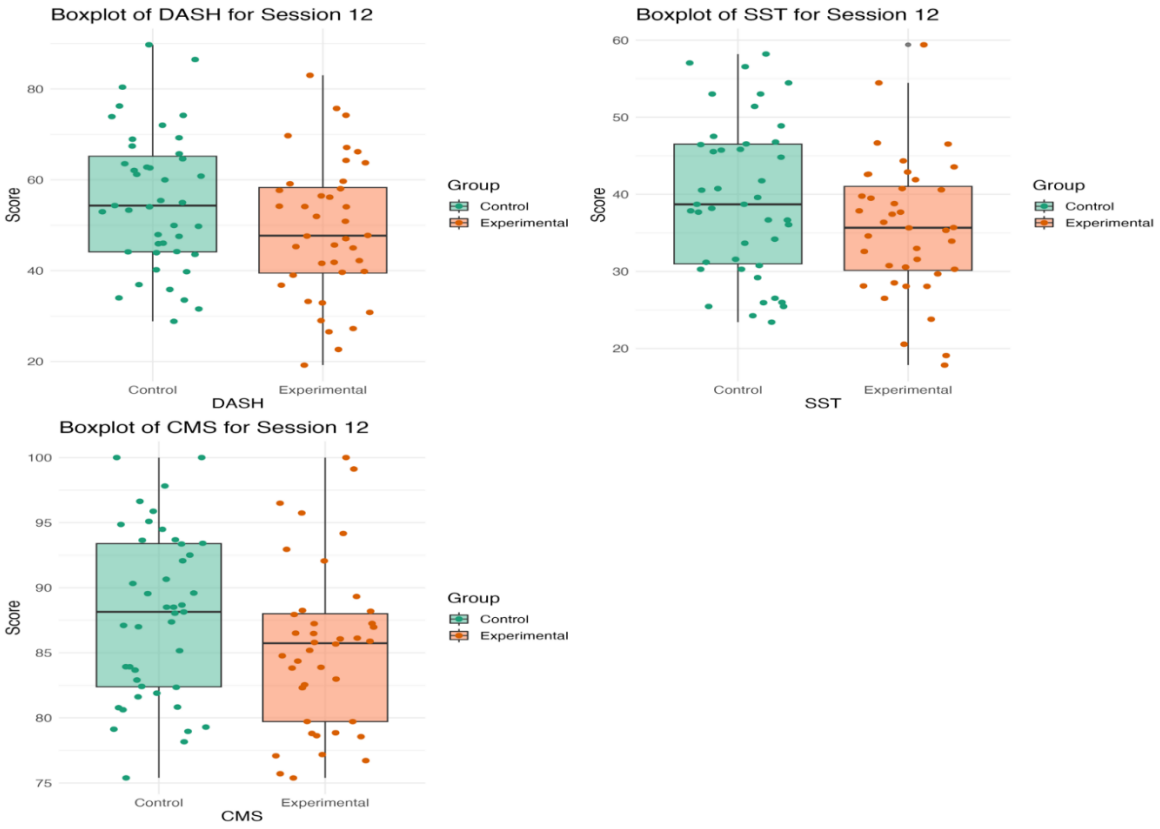


Figure 8 - Boxplot for outlier analysis - Session 12, both groups, CMS, DASH, SST

Data from T2 suggest that the experimental group generally experienced better shoulder function outcomes and lower disability compared to the control group. The scores of the experimental group are more closely clustered, showing consistency in the positive effects of the treatment.

Testing in T3

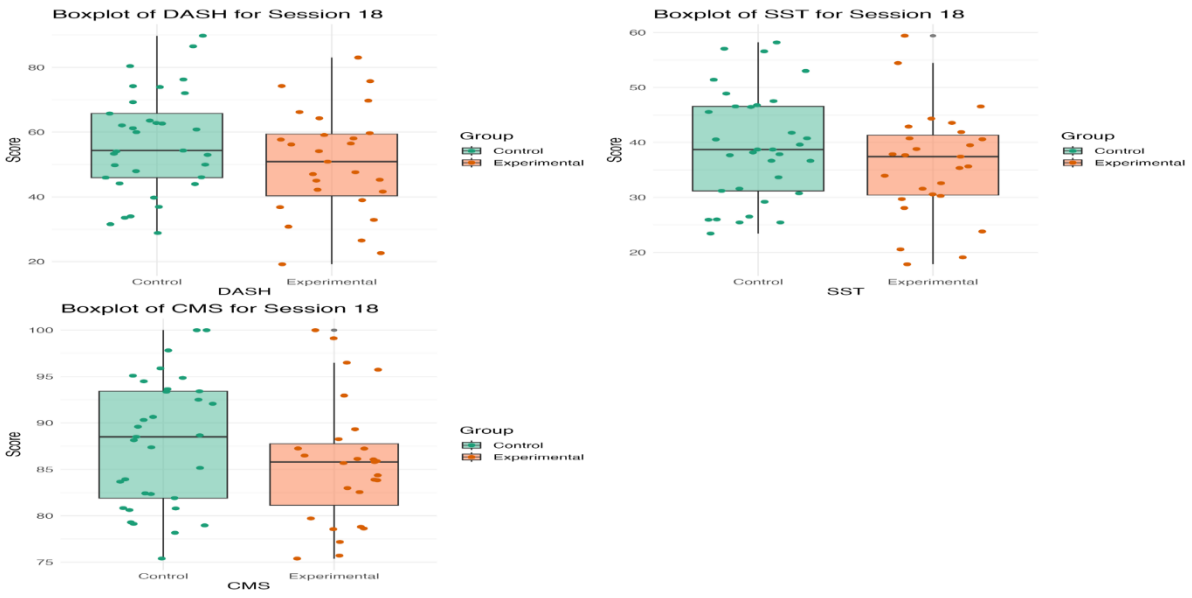


Figure 9 - Box plots for comparative analysis of extreme values – T3 - DASH, SST, CMS

The DASH boxplot reveals a marginally lower mean score for the experimental group, suggesting diminished disability in this cohort. Notably, the interquartile ranges (IQRs) for both groups overlap significantly, indicating substantial consistency of disability levels across cohorts, albeit with a slight edge over the experimental group.

In the SST boxplot, higher mean scores are observed for the experimental group, indicating better 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 experimental group tends toward greater function.

The CMS boxplot shows a lower mean score for the experimental group, which at first glance might suggest reduced overall shoulder function. However, the distribution of scores, especially the proximity of the 25th percentile and the median, implies a concentration of the scores of the experimental group towards the upper end of the functional spectrum, a predictable aspect since session 6 (T1).

CHAPTER XI
ANALYSIS OF RECOVERY TRENDS

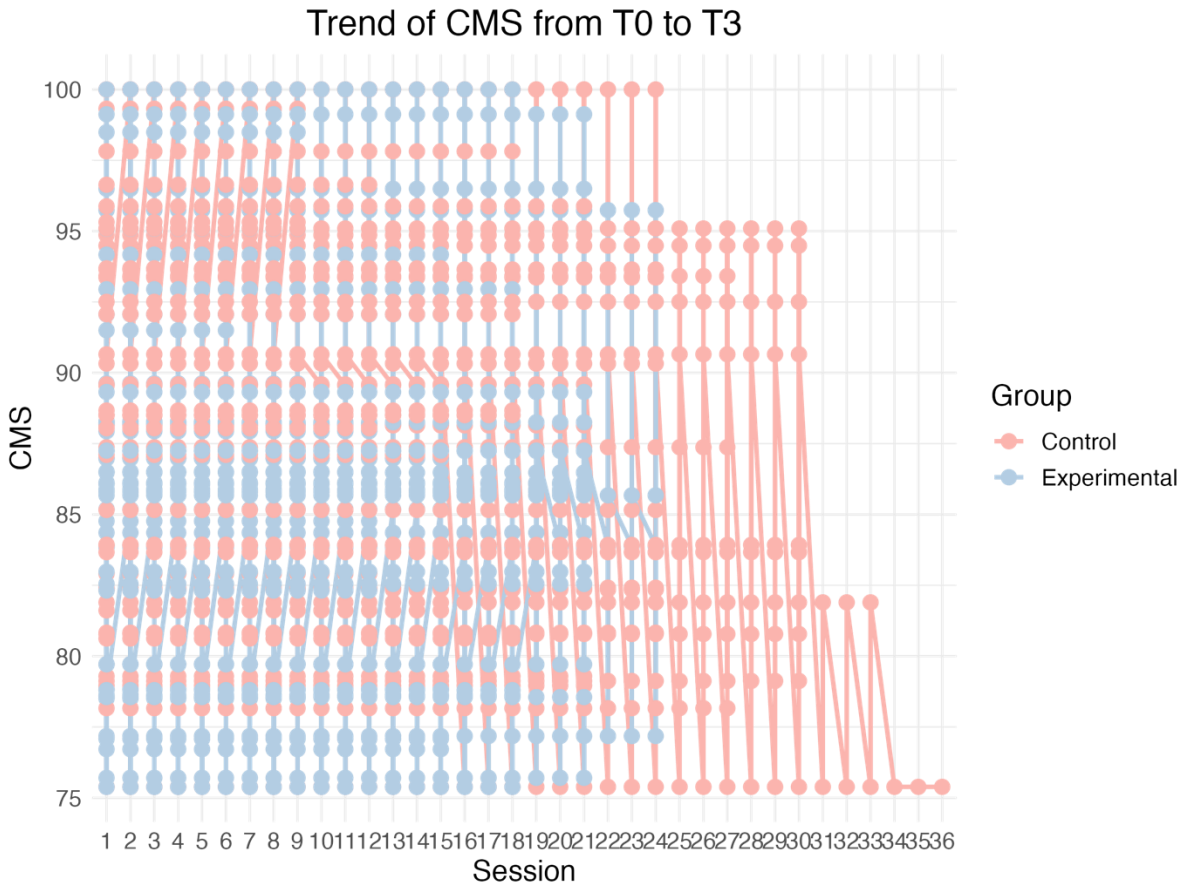


Figure 10 - CMS trend from T0 to T3

This graph shows the recovery as measured by the Constant-Murley Score (CMS) from the baseline assessment (T0) to the third assessment (T3) during treatment. CMS, a measure of shoulder function that includes pain, mobility, strength, and ability to perform daily activities, provides an index of recovery from subacromial impingement syndrome. Red data points

(control group) show gradual improvement in shoulder function, while blue data points (experimental group) show faster improvement. This accelerated improvement suggests a possible superiority of the treatment applied to the experimental group. The graph serves as a visual summary of the data and as a diagnostic tool for patterns of recovery in the studied cohorts.

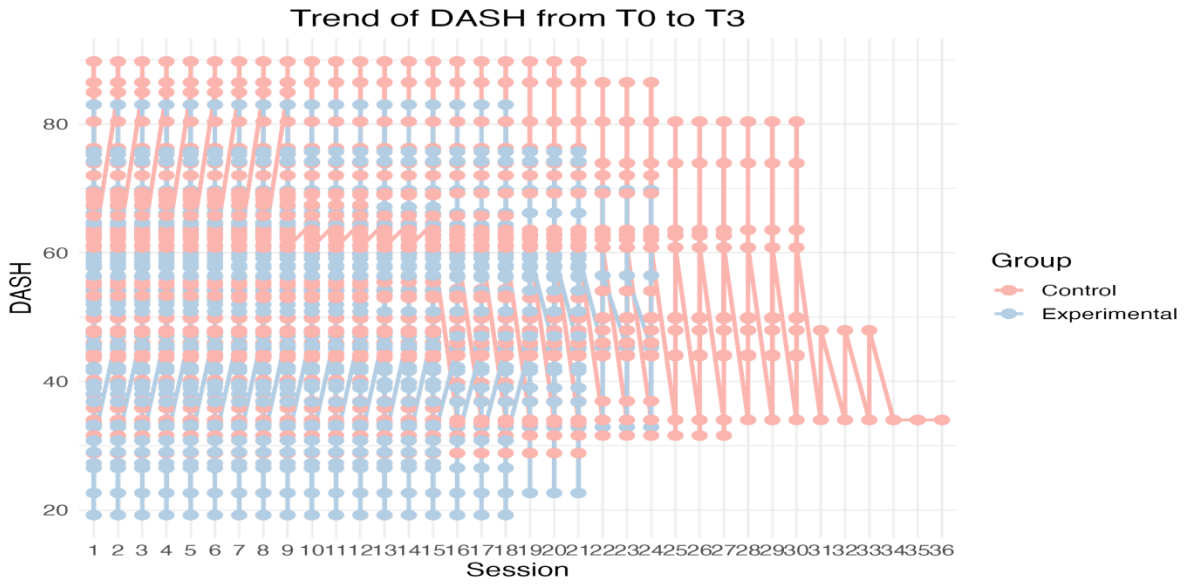


Figure 11 - DASH trend from T0 to T3

This scatterplot is useful for individualizing recovery profiles and aggregating trends. Unlike average scores that combine individual variances into one, this graph preserves details about each participant in their recovery journey. This is particularly useful in physical therapy research, where differences in patient responses can inform the effectiveness and tailoring of interventions. The graph also allows the identification of outliers whose recovery paths differ from the central tendency, which may warrant further investigation to clarify the underlying factors—whether biological, behavioral, or otherwise—that contribute to abnormal recovery rates.

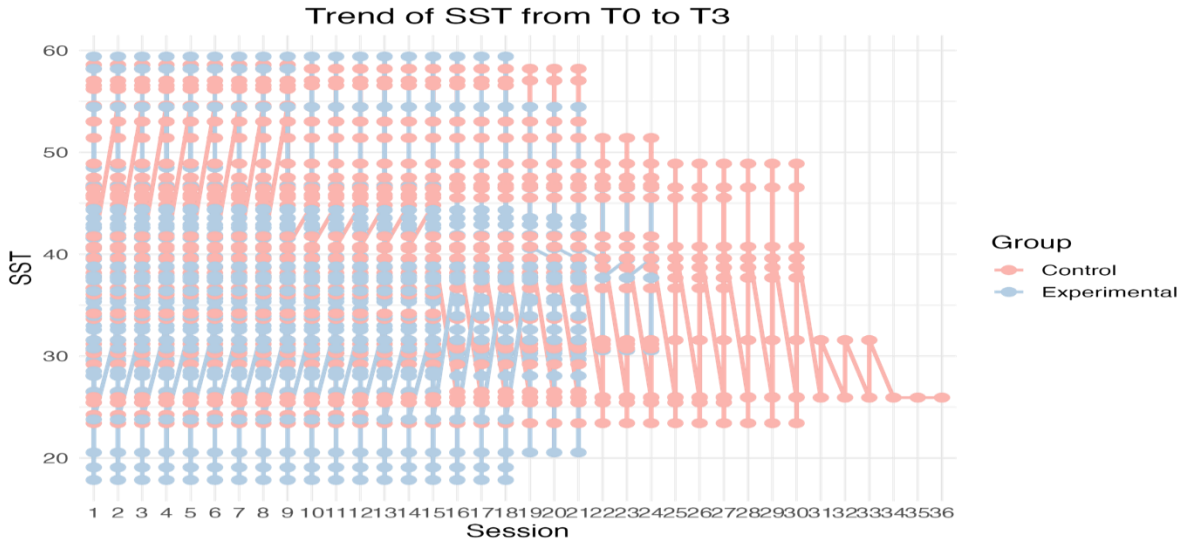


Figure 12 - SST trend from T0 to T3

We can follow the same trend in the graph of SST values, we can visualize the improvement trend from the perspective of the fragmentation of the average progress in recovery between the control group and the experimental group.

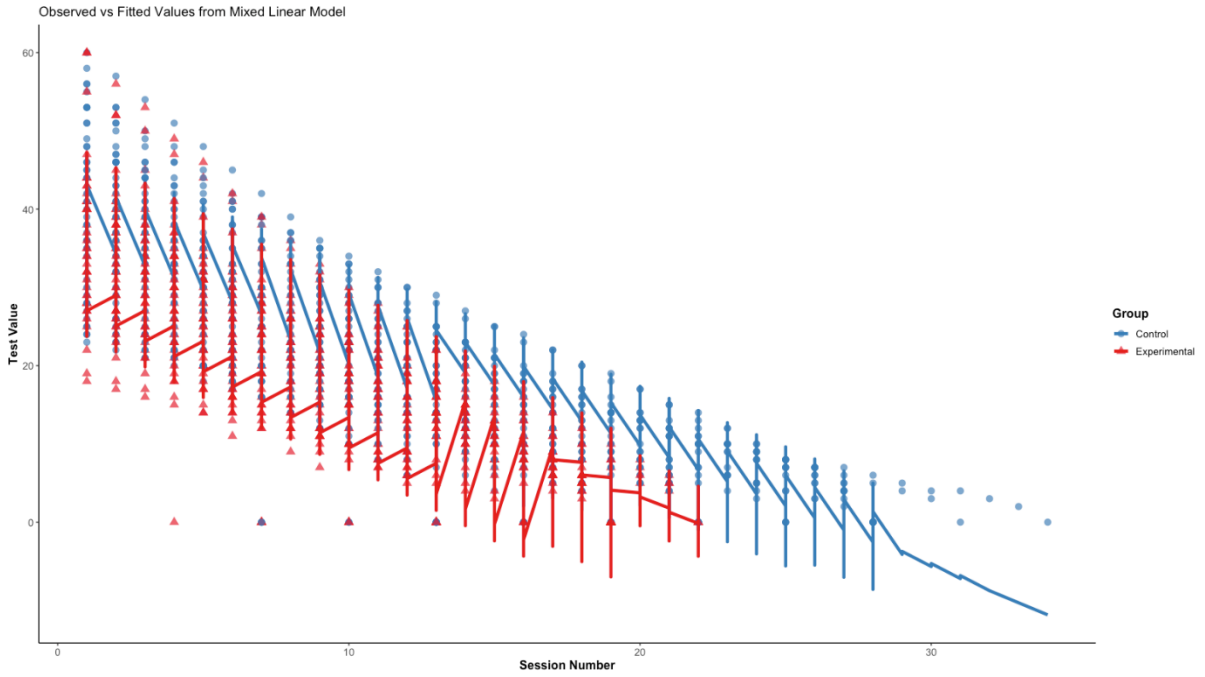


Figure 13 - General trend combined main scores

Control group (red): Showed a decrease in test scores as the number of sessions increased. The trend line is downward sloping, indicating an average decrease in scores.

Experimental group (blue): Also showed a decline in test scores over time, but the slope of the line may be less steep than that of the control group. It is possible that the rate of decline was slower in the experimental group.

Comparative analysis: Comparing the slopes of the two trend lines, if the line for the experimental group is less steep, this suggests that the experimental treatment had a positive effect, perhaps slowing down the decline in test scores. The graph clearly and visually indicates that the experimental group recovers faster than the control group. However, a more detailed analysis of test components and relationships is needed to highlight their behavior at a finer level.

GENERAL CONCLUSIONS, NEWS ELEMENTS AND FUTURE RESEARCH DIRECTIONS

These results have significant implications for clinical practice, suggesting that VR therapy should be considered as an effective and non-invasive therapeutic option for patients with subacromial impingement syndrome. Given that this condition can have a significant negative impact on patients' quality of life, identifying an effective therapy is of crucial importance.

In addition, detailed analysis of recovery trajectories provided a deeper understanding of the course of the disorder and factors influencing recovery. This can help practitioners develop personalized treatment strategies and provide patients with a more effective care plan. However, it is important to note that the study also has some limitations. For example, the patient sample was relatively small and its representativeness may be limited. Also, the

duration of follow-up was limited and did not allow a long-term evaluation of the results of VR therapy.

Therefore, future research could explore the effects of VR therapy on long-term recovery in more detail and include a larger number of participants for stronger validity of the results. It would also be beneficial to compare VR therapy with other treatment modalities for subacromial impingement syndrome to better assess its effectiveness compared to other available therapeutic options.

In conclusion, this study provides strong evidence for the effectiveness of VR therapy in accelerating recovery in patients with subacromial impingement syndrome. This opens new perspectives in the treatment of musculoskeletal conditions and offers the possibility to improve the quality of life of patients by using a non-invasive and personalized therapy.

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