

**EFFECTS OF MOTOR CONTROL EXERCISES ON PAIN,
FUNCTIONAL ACTIVITY AND CORE MUSCLE
STRENGTH IN CHRONIC NON-SPECIFIC
LOW BACK PAIN**

Thesis Submitted for the Award of the Degree of

**DOCTOR OF PHILOSOPHY
in**

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2026

DECLARATION

I, hereby declared that the presented work in the thesis entitled “Effects of Motor Control Exercises on Pain, Functional Activity and Core Muscle Strength in Chronic Non-Specific Low Back Pain” in fulfilment of degree of **Doctor of Philosophy (Ph. D.)** is outcome of research work carried out by me under the supervision of Dr. Arun B, working as Physiotherapist in the Government Head Quarters Hospital, Erode and Dr. Suresh Mani, working as Professor, in the Department of Physiotherapy/School of Allied Medical Sciences of Lovely Professional University, Punjab, India. In keeping with general practice of reporting scientific observations, due acknowledgements have been made whenever work described here has been based on findings of other investigator. This work has not been submitted in part or full to any other University or Institute for the award of any degree.

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CERTIFICATE

This is to certify that the work reported in the Ph. D. thesis entitled “Effects of Motor Control Exercises on Pain, Functional Activity and Core Muscle Strength in Chronic Non-Specific Low Back Pain” submitted in fulfillment of the requirement for the award of degree of **Doctor of Philosophy (Ph.D.)** in the Department of Physiotherapy, Lovely School of Allied Medical Sciences, is a research work carried out by G. V. Ramakrishnan, 41400198, is bonafide record of his original work carried out under my supervision and that no part of thesis has been submitted for any other degree, diploma or equivalent course.



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ABSTRACT

INTRODUCTION: Low Back Pain (LBP) is a major health concern with substantial impact on healthcare systems, particularly in developed as well as in developing countries, due to work absenteeism and high medical costs. Non-Specific Low Back Pain (NSLBP), diagnosed when no underlying pathology is identified, is the fifth leading cause of workplace absenteeism and remains challenging to manage. Contributing factors include prolonged awkward postures, improper lifting, and repetitive twisting, which overtime place stress on spinal musculature over time. Exercise is a key strategy in preventing and treating Chronic NSLBP (CNSLBP). Conventional exercise programs, though beneficial, often fail to address impaired neuromuscular control of deep trunk stabilizers such as the transversus abdominis and lumbar multifidus. Among various approaches, Motor Control Exercises (MCE) and Lumbar Stabilization Exercises (LSE) are widely prescribed. MCE isolates and activates specific core muscles, while LSE targets the core musculature as a functional unit. Real-Time Ultrasound (RTUS) imaging provides biofeedback by visualizing muscle and tendon activity, thereby enhancing patient performance. The use of Real-Time Ultrasound (RTUS) biofeedback offers an innovative, non-invasive approach to visualize and enhance deep muscle activation during rehabilitation. When combined with MCE, RTUS feedback improves core muscle contraction and functional efficiency. This study aimed to investigate the comparative effects of MCE with RTUS biofeedback versus conventional Lumbar Stabilization Exercises (LSE) on pain, functional activity, and core muscle strength in individuals with CNSLBP.

OBJECTIVES: The General Objectives of this research are to evaluate the effects of Motor Control exercises on pain, functional activity, and core muscle strength in CNSLBP and to evaluate the effects of Lumbar Stabilization exercises on pain, functional activity, and core muscle strength in CNSLBP. The Specific Objective of this research study is to compare the effects of Motor Control exercises and Lumbar Stabilization exercises on pain, functional activity and core muscle strength in CNSLBP

METHODS: A quasi-experimental study with consecutive sampling was employed. Ninety-six participants aged between 35–55 years with CNSLBP were randomly assigned to two groups (n = 48 per group). The experimental group received MCE integrated with RTUS biofeedback, while the control group performed LSE without biofeedback. Both interventions were delivered over 8 weeks (12 sessions of 30–45 minutes). Outcome measures included the Numerical Pain Rating Scale (NPRS) for Pain intensity, Oswestry Disability Index (ODI) for Functional activity, and Pressure Bio-Feedback (PBF) for Core muscle strength. Pretest assessment was taken prior to the implementation of treatment,

and post-intervention data, which were collected after completing the 8 weeks of treatment, were analyzed using paired and independent t-tests, with $p < 0.05$ considered statistically significant.

RESULTS: The data were analyzed using SPSS version 27, and parametric tests were applied after confirming acceptable skewness and kurtosis values. Both groups showed significant within-group improvements in pain, functional activity, and core muscle strength ($p < 0.001$). However, the experimental group (MCE + RTUS) demonstrated substantially greater improvements compared to the control group, including larger reductions in pain (90.8% vs. 55.8%), greater improvement in functional disability (83.1% vs. 49.6%), and higher gains in core muscle strength (23.1% vs. 11.8%), all with $p < 0.001$. Effect sizes (Cohen's d : -2.35, -1.90, -3.34) indicated strong treatment impact, and all improvements exceeded Minimal Clinically Important Difference (MCID) thresholds. No adverse events occurred during the intervention.

CONCLUSION: The findings of this study highlight that Motor Control Exercises supplemented with Real-Time Ultrasound biofeedback are significantly more effective than conventional Lumbar Stabilization Exercises in reducing pain, enhancing functional activity, and improving core muscle strength in individuals with Chronic Non-Specific Low Back Pain. Incorporating biofeedback mechanisms promotes better neuromuscular control, engagement, and rehabilitation precision. These results support the integration of feedback-based motor retraining into physiotherapy interventions, allowing for more precise neuromuscular control and movement optimization.

Keywords: Chronic Non-specific low back pain, Lumbar Stabilization Exercises, Motor Control Exercises, Real-Time Ultrasound. Numeric Pain Rating Scale, Oswestry Disability Index, Pressure Bio-Feedback

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LIST OF ABBREVIATIONS

ACP	American College of Physicians
ADIM	Abdominal Drawing-In Maneuver
AUC	Area Under the Curve
AXSPA	Axial Spondyloarthritis
BF	Bio-Feedback
CLBP	Chronic Low Back Pain
CNSLBP	Chronic Non-Specific Low Back Pain
COR	Conservation of Resource Theory
DALYS	Disability-Adjusted Life Years
DRS	Derangement Syndrome
DFS	Dysfunction Syndrome
EMG	Electromyography
FAB	Fear and Avoidance Belief
GP	General Practitioner
GRCS	Global Rating of Change Scale
LBP	Low Back Pain
LPU	Lovely Professional University
LSE	Lumbar Stabilization Exercises
MI	Movement Impairment
MCE	Motor Control Exercises

MCI	Movement Control Impairment
MCID	Minimal Clinically Relevant Difference
MCID	Minimum Clinically Relevant Difference
MD	Mean Difference
MDC	Minimum Detectable Change
MIC	Minimal Important Change
MODI	Modified Oswestry Disability Index
NPRS	Numerical Pain Rating Scale
NRS	Numerical Rating Scale
NSAID	Non-Steroidal Anti-Inflammatory Drugs
NSLBP	Non-Specific Low Back Pain
ODI	Oswestry Disability Index
ODI-G	Oswestry Disability Index-Gujarati
PACIC	Patient Assessment of Chronic Illness Care questionnaire
PBF	Pressure Bio-Feedback
PBFU	Pressure Bio-Feedback Unit
PCP	Primary Care Providers
PS	Postural Syndrome
PSEQ	Pain Self-Efficacy Questionnaire
PSFS	Patient-Specific Functional Scale
QBPDQ	Quebec Back Pain Disability Questionnaire

QDS	Quebec Back Pain Disability Scale
QOL	Quality of Life
RCT	Randomized Control Trial
RMDI	Roland Morris Disability Index
RMDQ-G	Roland Morris Disability Questionnaire-Gujarati
RRC	Research Review Committee
RTUS	Real-Time Ultrasound
ROC	Receiver Operating Characteristic
SEM	Standard Error of Measurement
SOTA	State of the Art
SRM	Standardized Response Mean
SSS	Swiss Spinal Stenosis Scale
SUCRA	Surface Under the Cumulative RAnking
TrA	Transversus Abdominis
VAS	Visual Analog Scale
VAS-G	Visual Analog Scale-Gujarati
YLD	Years Lived with Disability

OPERATIONAL DEFINITIONS

Term	Definition
Non-specific Low Back Pain	Non-Specific Low Back Pain is defined as pain or discomfort localized between the costal margin and the inferior gluteal folds, with or without leg pain, that is not attributable to a recognizable or specific pathology such as infection, tumor, osteoporosis, fracture, structural deformity, inflammatory disorder, radicular syndrome, or cauda equina syndrome.
Chronic Non-specific Low Back Pain	chronic non-specific low back pain is pain localized to the area between the costal margins and gluteal folds, persisting for at least 3 months, occurring on at least half the days in the past 6 months, not attributable to a specific diagnosable cause such as infection, malignancy, fracture, inflammatory disease, radiculopathy, or other spinal pathology.
Motor Control Exercises	Motor Control Exercises in a research thesis describes them as purposeful, structured activities that apply motor learning principles to improve the coordination, activation, and control of specific muscle groups for functional movement tasks
Lumbar Stabilization Exercises	Lumbar Stabilization Exercises describes a set of physical exercises targeting the strengthening and coordination of deep lumbar, abdominal, and back muscles, aimed at improving spinal stability and neuromuscular control
Numerical Pain Rating Scale	The Numerical Pain Rating Scale (NPRS) is defined as a self-reported measure in which participants are asked to quantify their pain intensity by choosing a single number on

an 11-point scale, where **0 indicates “no pain” and 10 indicates “the worst possible pain”**.

Oswestry Disability
Index

Oswestry Disability Index refers to a validated, self-administered questionnaire comprising 10 sections, where each section assesses a specific aspect of disability related to low back pain: pain intensity, personal care, lifting, walking, sitting, standing, sleeping, sexual life, social life, and traveling. Each section is scored from 0 (least disability) to 5 (most disability), with the total score summed and then multiplied by 2 to yield a value between 0 (no disability) and 100 (maximum disability).

Pressure Bio-
Feedback

Pressure Bio-Feedback (PBF) is defined as a non-invasive, portable measurement technique using a calibrated pressure biofeedback unit (PBU) consisting of an air-filled cuff connected to a pressure gauge which will be placed under the lumbar region or abdomen and inflated to a baseline pressure (e.g., 40-70 mmHg) before measuring the core muscle contraction activity.

CHAPTER I

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Low back pain (LBP) is one of the most prevalent musculoskeletal and neuromuscular conditions, affecting nearly all individuals at some point during their lifetime (Fromoyer J W, 1988). The condition's progression depends on various factors which determine whether the condition will reoccur. If the condition recurs there is every possibility of the condition becoming a chronic LBP. But the fact is almost all LBP is self-limiting (Nasser, 2005). It is also noted that LBP has a high recurrence rate of 85% even though on average, every episode is self-limiting in a period of 4 to 8 weeks in 50% of the patients (Nasser, 2005).

LBP is classified to three categories based on the duration of the ailment. The LBP that lasts only up to 6 weeks or less is termed acute LBP. The LBP that lasts between 6 weeks to 12 weeks is termed sub-acute, and the conditions that last more than 12 weeks are determined as chronic LBP (Carey et al., 1995). The detailed etiology-based classification of LBP is presented in Figure 1. 1.

People from all walks of life tend to suffer from LBP; however, its prevalence surely depends on various determining factors like gender, age, literacy rate, and job nature predominantly. As far as gender is concerned, females are more susceptible to LBP than men, although the ratio is documented in varying magnitude. The main reason for this phenomenon may be that females are physically weaker and have less social mobility than males. There are fewer diversions, and women tend to exhibit more negative behavior to pain compared to men. Aging is also documented as an important risk factor for LBP. The onset of a more severe form of LBP commences from the age of 83, according to a study, and the recurrence of LBP is more common from the start of the 65th year of life. Lower

educational status influences the prevalence of LBP; at the same time, it also influences the hospital stay and the duration of the ailment (C. Maher et al., 2017).

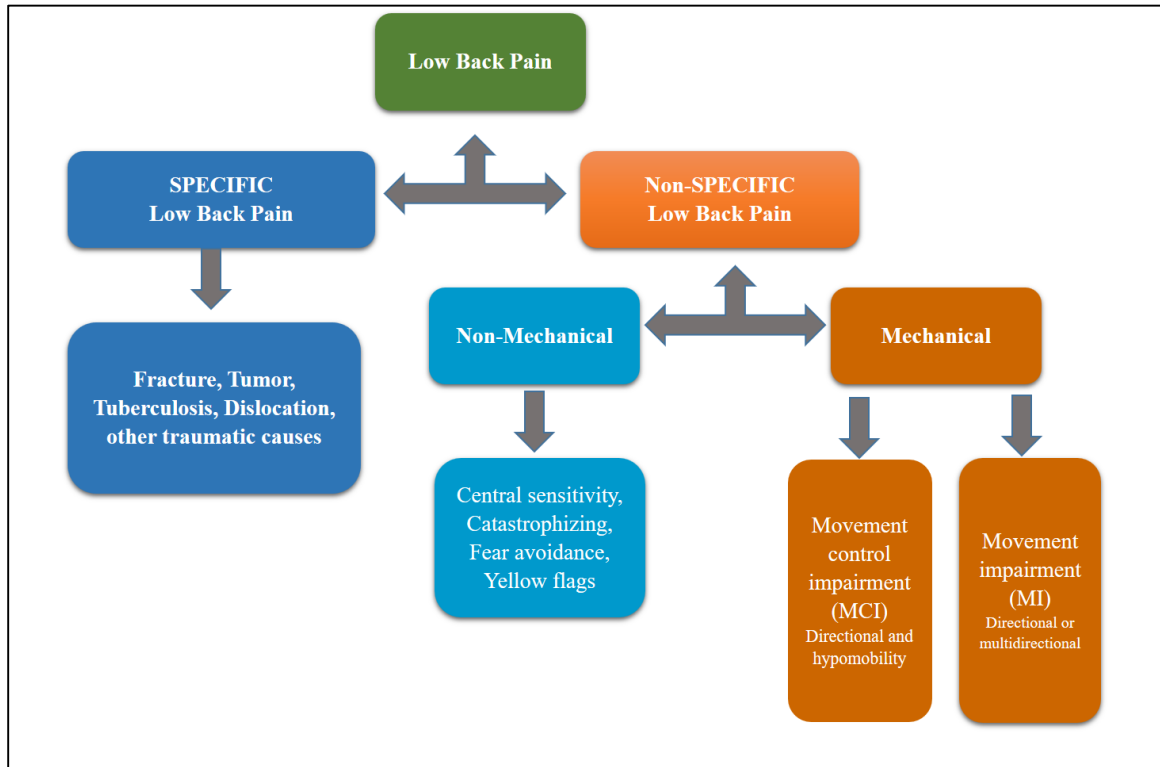


Figure 1. 1 The classification of Low Back Pain based on etiological factor.

Based on an analysis of 56 studies, Walker (2000) reported that the point prevalence of LBP ranged from 12% to 33% (Walker, 2000). There is documentation that, when LBP occurs without any significant anatomical or physiological impairment, condition is likely to be self-limiting and have a good prognosis. However, when the pain is unaltered by positioning or medication or time of the day or rest and activity, then there is a high possibility of serious musculoskeletal problems ranging from bone tumor to tuberculosis or infection (Hoy et al., 2010).

The study by Hoy et al. (2012) addresses a critical methodological gap in epidemiological research by developing and validating a standardized tool to assess the risk of bias in prevalence studies, particularly in the context of conditions such as low back

and neck pain. Recognizing that existing quality assessment tools were largely designed for experimental studies and were inadequate for observational prevalence research, the authors systematically modified prior checklists through literature review, expert consensus, and iterative testing to produce a 10-item instrument covering key domains of external and internal validity. The tool demonstrated high interrater reliability (91% agreement; kappa = 0.82), indicating strong consistency and practical usability. Importantly, this study distinguishes between methodological quality and risk of bias, emphasizing that even well-conducted studies may yield biased estimates if underlying design limitations are not addressed. This study highlights the need to explicitly evaluate necessity of explicitly evaluate bias in prevalence data to avoid misestimation of disease burden, thereby strengthening the validity of systematic reviews and informing more accurate public health decision-making (Hoy, Brooks, et al., 2012).

The Global Burden of Disease (GBD) 2017 study by Wu A et al (2020) identifies LBP as a leading cause of disability worldwide, emphasizing its substantial and persistent public health impact. Although age-standardized prevalence rates remained relatively stable between 1990 and 2017, the total number of affected individuals increased markedly from approximately 377.5 million to 577 million due to population growth and aging, while the years lived with disability due to LBP increased by 52.7%, reaching 64.9 million in 2017 indicating an expanding absolute burden. This condition disproportionately affects the working-age population, peaking among individuals aged 35–49 years, resulting in substantial productivity losses and healthcare expenditures (Wu et al., 2020). Collectively, these insights reinforce the multifactorial and enduring nature of LBP and the urgent need for integrated, prevention-focused and management-driven healthcare strategies.

A recent scoping review by Abas et al. (2023) highlights that LBP is highly prevalent among diverse populations in Malaysia, including healthcare workers, industrial employees, office workers, and students. The reported prevalence of LBP ranged from 12.4% to 84.6%, with particularly high rates among nurses (67.9%) and drivers (65.7%). The wide variation across studies suggests that LBP burden is influenced by work-related

physical demands, postural load, body mass index, age, gender, and psychosocial factors such as mental health and work hours (Abas et al., 2023).

Non-specific Low Back Pain (NSLBP) is a challenging condition to treat for any physical therapist, as there is a lack of clear cause identified. In the literature NSLBP is being documented as a condition that presents with localized or generalized pain in the low back region for which there is no identifiable etiology. Anatomical studies claim that the nonspecific pain is more common in the lower back compared to the upper back due to the morphological difference between the first 4 lumbar vertebrae and the fifth lumbar vertebra. With no clear target tissues to attest to, the treatment often depends on the clinical decision-making based on the patient feedback and prognosis. There are other challenges, such as individual variability in pain-related behavior, a high probability of reoccurrence, limited treatment generalizability, and so on (C. Maher et al., 2017). With such high complexity, the prevalence of NSLBP is always on the rise, with a 2012 large-scale global data collection revealing that the point prevalence was 18.3%, which is a huge value (Hoy, Bain, et al., 2012). Adding to the problems, it was reported that only 58% of the NSLBP are being reported to any clinical setup. It was found that, more than the pain intensity, the rate of disability due to NSLBP accounted for high medical attendance (Ferreira et al., 2010)

The prevalence of Chronic Non-Specific Low Back Pain (CNSLBP) in Malaysia is 15.4%, and notably, it is more than the specific type 9.3% in Malaysia (Iizuka et al., 2017). CNSLBP remains a widespread health issue worldwide, impacting millions of individuals and placing a heavy burden on both society and affected persons. It is known that CNSLBP is common among Malaysian adolescents, predominantly females, when they are sedentary and spend long engagement periods with electronic gadgets (Masiero et al., 2021).

NSLBP can be classified solely on the basis of the temporal determinant and grouped as acute, sub-acute, and chronic. However, there are many other classifications of LBP that have gained attention in the past, which are both clinically and theoretically practical. McKenzie's classification of low back pain is one such classification that

classifies LBP using terminologies like derangement syndrome (DRS), dysfunction syndrome (DFS), and postural syndromes (PS). In this, DRS is defined as a condition that is highly volatile and more directional in symptoms. These symptoms keep changing location, nature, and consistency. They may be focal or generalized, can be localized to the low back or radiate down to the legs either unilaterally or bilaterally. In DRS, the onset of pain can either be sudden or gradual, and the pain can be aggravated by a specific movement or a particular posture.

The DFS is longer in duration compared to the DRS, with specific anatomical changes happening to the underlying structures like scar formation or adhesion or changes in the bone or ligament. The hall mark of this syndrome is limitation of movements with pain at the end range. Usually, pain gets aggravated by movement. Symptoms are always intermittent, and the patients usually give a history of 8-12 weeks.

PS, on the other hand, is exactly the opposite of DFS. Here, the pain appears only on sustaining a particular posture and disappears when the patient performs movement. Only static posture provokes pain, and the treatment is counselling and postural correction followed by exercises. In all three classification McKenzie did not mention specifically mention any structure, as identifying and labeling a single structure as the culprit is always difficult in a complex region like the lumbar spine.

The lumbar spine segment of the spine is vital in providing structural stability and permitting functional motion while carrying substantial body loads. According to Panjabi & White (1980), its anatomical and biomechanical characteristics render it particularly vulnerable to LBP. The lumbar vertebrae are the largest in the spinal column, designed to support the weight of the upper body and transmit forces efficiently to the pelvis and lower extremities. The intervertebral discs, facet joints, and surrounding musculature collectively contribute to load distribution, shock absorption, and mobility. However, these structures also make the region susceptible to degenerative changes, mechanical stress, and injury (Panjabi & White, 1980).

The lumbar intervertebral discs are prone to degeneration due to their avascular nature, which limits their capacity for repair and regeneration. Over time, repetitive mechanical loading can lead to annular tears, disc protrusion, or extrusion, resulting in altering biomechanics and contributing to pain and dysfunction. The facet joints, which guide and constrain spinal motion, are also susceptible to degenerative changes and instability, particularly under abnormal loading conditions. Additionally, the lumbar spine's unique curvature and high mechanical demands increase shear and compressive forces, predisposing the region to mechanical failure and pain. The deep stabilizing muscles of the lumbar region, such as the multifidus (MF) and Transversus Abdominis (TrA), are essential for ensuring spinal stability. When these muscles become weak or impaired, it may result in altered movement patterns, excessive strain on passive spinal structures, and the development of pain-related conditions.

According to White and Panjabi, “NSLBP stems from the combined effects of biomechanical, neurological, and inflammatory factors, making it a condition with multiple underlying contributors”. The pathophysiology of NSLBP is largely attributed to altered spinal mechanics, impaired load distribution, and dysfunction of the neuromuscular control system. Repeated micro-injuries to spinal components, especially the facet joints and intervertebral discs, contribute to tissue degeneration and trigger nociceptive responses. The accumulation of inflammatory mediators, such as cytokines and prostaglandins, sensitizes pain receptors and contributes to chronic pain states (Panjabi & White, 1980).

Proprioceptive deficits in the lumbar spine disrupt normal movement patterns and postural control, leading to maladaptive motor strategies that perpetuate pain and dysfunction. Muscular imbalances, including hyperactivity of superficial musculature and inhibition of deep stabilizers, further contribute to spinal instability and mechanical stress. Psychological and social factors, including stress, anxiety, and altered pain perception, also play an important role in the chronicity of NSLBP. White and Panjabi (1980) emphasize the importance of a comprehensive approach to management, incorporating biomechanical correction, neuromuscular re-education, and addressing psychosocial influences to restore optimal function and alleviate pain.

The literature is strongly supportive of managing LBP across various capacities using non-pharmacological means rather than pharmacological treatment (Jorgensen et al., 2018). There are various reasons for this, but the primary one is the diverse nature of pain perception, which is compounded by various factors. There are three management tools with strong evidence. Patient education and empowerment, exercises, and activity promotion are the three most evidence-based components (O'Connell et al., 2016; Foster et al., 2018).

There is strong evidence of mismanagement and inappropriate prescription of imaging techniques. Studies strongly recommend that imaging techniques be delayed while managing the LBP, as the incidental findings and co-findings may be clinically irrelevant. These findings can distract the therapist and threaten the patient with dire consequences and influence the bio psycho social integrity (O'Connell et al., 2016).

Evidence also accumulate on the need for skilled assessment to deliver a tailor-made exercise protocol tailored to the patient's capacity and needs. A skilled assessment will reduce the need for imaging, and a skilled therapist with their clinical examination can rule out the impairments and also diagnose the serious pathology which may need imaging and invasive interventions.

A considerable number of publications on community healthcare programs emphasize that encouraging physical activity is essential in managing LBP, and such programs particularly focus on educating patients that prolonged rest is not an effective solution for LBP (Steffens et al., 2016).

1.2 RESEARCH PROBLEM

Physiotherapists commonly prescribe individual muscle exercises for musculoskeletal conditions, including non-specific low back pain (NSLBP), although the effectiveness of such approaches remains debated. Evidence suggests that NSLBP should not be treated as a homogeneous condition, as this limits the identification of effective interventions; instead, subgrouping patients is essential to improve clinical decision-making (Brennan et al., 2006). In particular, chronic NSLBP (CNSLBP) has received attention as exercise-based interventions show limited and inconsistent evidence in acute cases (Airaksinen et al., 2006; J. Hayden et al., 2005).

Despite widespread use of exercise therapy, there is no clear consensus on the most effective exercise approach for CNSLBP. Interventions vary considerably, ranging from home-based programmes to supervised and structured exercise regimens, with no definitive evidence demonstrating superiority among them (J. Hayden et al., 2005; Choi et al., 2010).

Further classification of CNSLBP into movement impairment and movement control dysfunction subgroups has been proposed to refine treatment selection; however, clinical application remains inconsistent. The current best intervention for CNSLBP is presented in Figure 1.2.

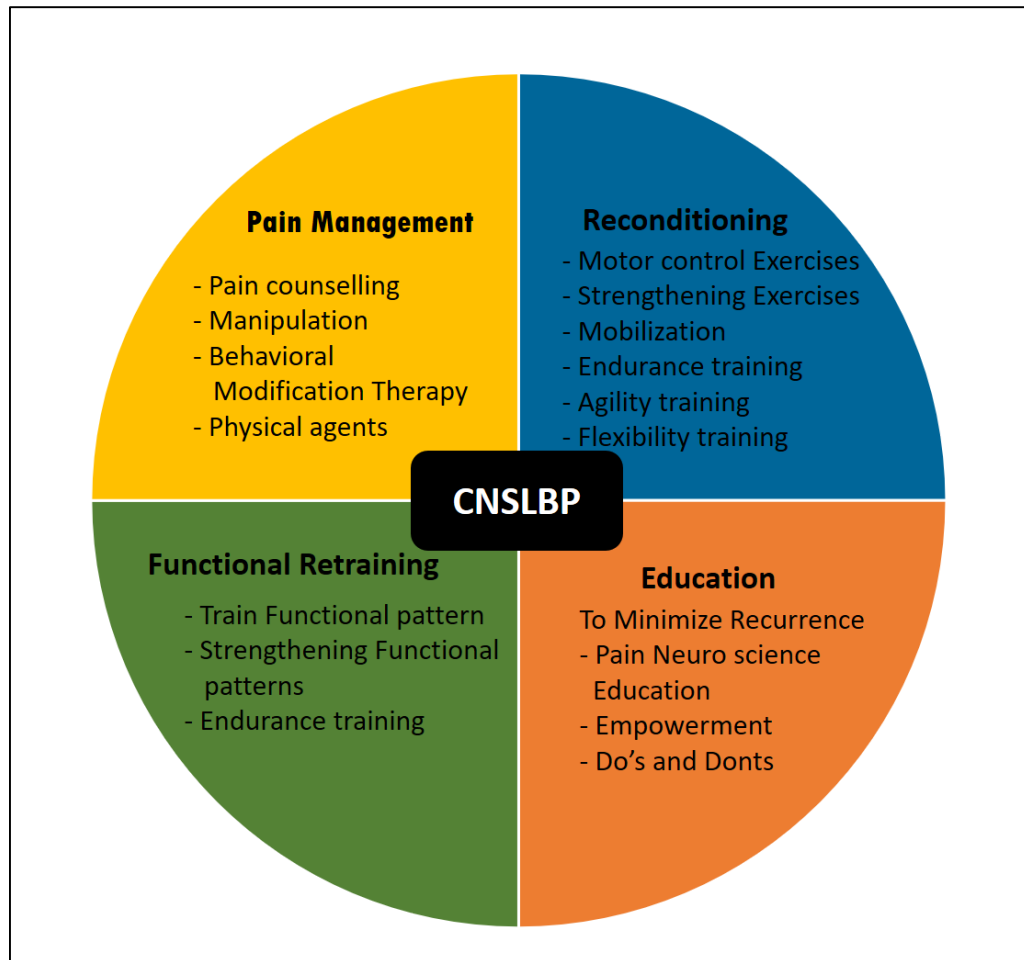


Figure 1. 2 A schematic representation of multi-dimensional approach to Chronic Non-Specific Low Back Pain

Motor control theory provides a key framework for understanding movement regulation, motor learning, and motor adaptation across the lifespan. It distinguishes motor development (acquisition and refinement of movement) from motor learning (changes in movement patterns through practice and experience). While these mechanisms support normal movement acquisition, they also explain how maladaptive motor patterns may become reinforced in chronic pain conditions. In CNSLBP, such learned dysfunctional movement strategies can persist and are difficult to reverse, posing a significant rehabilitation challenge.

A key feature of normal lumbopelvic motor control is anticipatory activation of deep stabilizing muscles, particularly the transversus abdominis and multifidus, which pre-activate to stabilize spinal segments prior to limb movement (Chon et al., 2010; Lynders, 2019). In individuals with NSLBP, this anticipatory activation is often impaired, resulting in altered movement coordination and increased spinal vulnerability. Motor control theories therefore emphasize re-education of these stabilizing muscles as a central component in managing CNSLBP recurrence and progression.

Although lumbar/core stabilization exercises (LSE/CSE) based on motor control retraining are widely recommended, clinical studies report inconsistent outcomes (May & Johnson, 2008; Grooten et al., 2022). These inconsistencies may be partly attributed to difficulties in accurately activating deep trunk muscles without external guidance or feedback, particularly in patients experiencing pain. This suggests that biofeedback-assisted Motor Control Exercises (MCE) may improve exercise accuracy, adherence, and therapeutic outcomes.

Therefore, this study focuses on evaluating the effects of MCE with structured biofeedback on pain and functional ability in patients with chronic NSLBP, addressing a critical gap in evidence regarding effective, targeted rehabilitation strategies.

The theoretical framework of the interplay between LBP and Motor Control Adaptations is explained in Figure 1.3.

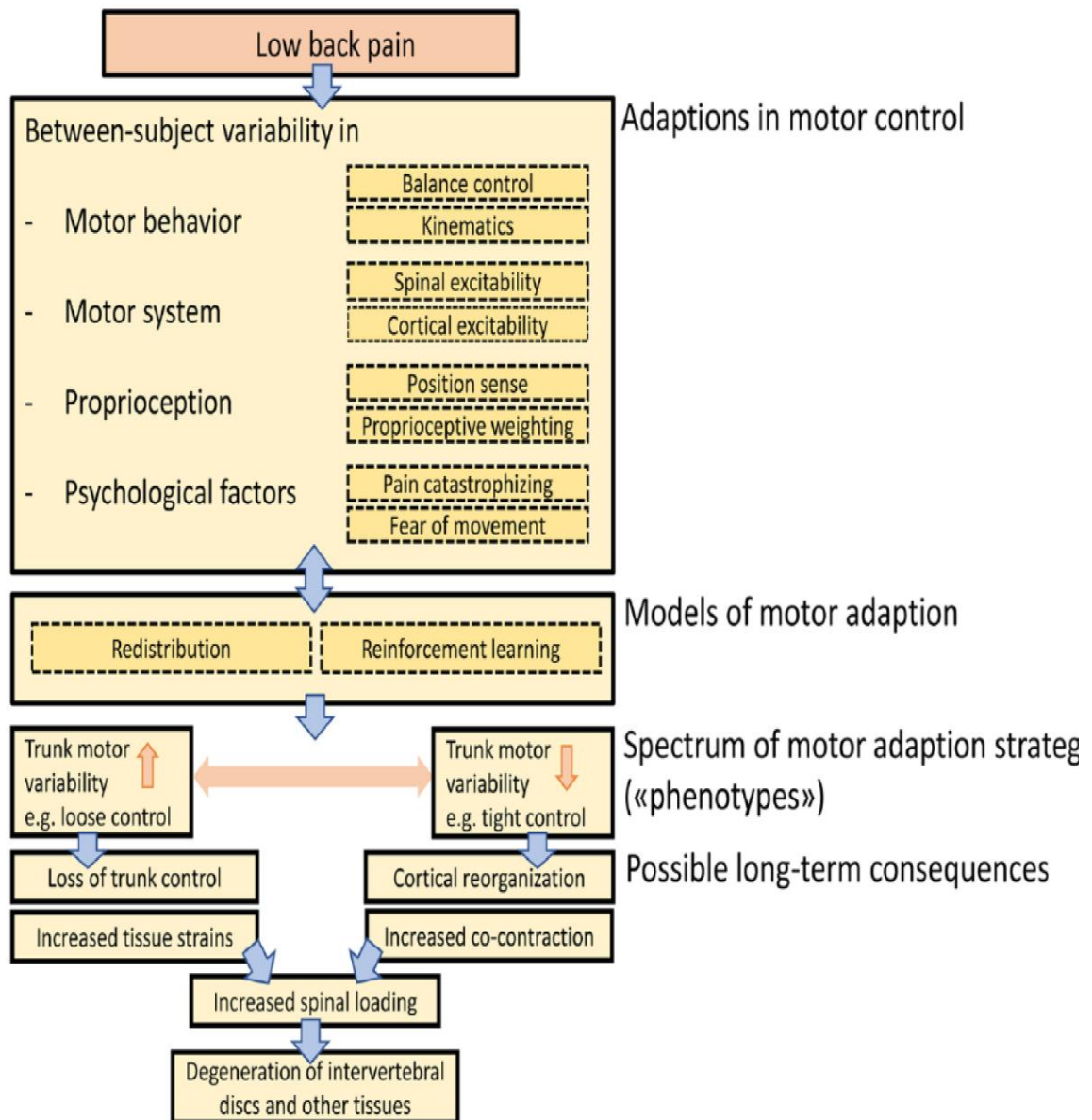


Figure 1. 3 Interplay between low back pain and motor control adaptations (Adopted from Meier et al., 2019)

The proposed theoretical framework suggests that LBP induces alterations in motor behavior, proprioception, and psychological factors such as fear avoidance and catastrophizing. These changes contribute to motor adaptations, resulting in either “loose control” (increased mechanical strain) or “tight control” (excessive co-contraction and cortical reorganization). Both maladaptive patterns increase spinal loading and may accelerate degenerative changes, highlighting the need for interventions that restore balanced and efficient motor control.

1.3 CONCEPTUAL OVERLAP BETWEEN MCE AND LSE

Motor control exercises (MCE) and lumbar stabilization exercises (LSE) are related concepts, but they are not fully interchangeable. Both approaches aim to improve spinal control and reduce pain in chronic non-specific low back pain; however, they differ in their primary therapeutic emphasis. MCE focuses on restoring the precise activation, timing, and coordination of the deep local stabilizing muscles, especially the transversus abdominis and multifidus, so that the lumbar spine can be controlled during movement and functional tasks. In contrast, LSE emphasizes on enhancing the endurance and stiffness of the trunk musculature to support the spine under load and maintain segmental stability during daily activity (Hides et al., 2001).

From a mechanistic perspective, MCE is guided by the idea that low back pain is associated with altered neuromuscular control, delayed activation of deep trunk muscles, and compensatory overuse of superficial global muscles. Therefore, MCE is usually delivered in a graded progression that begins with isolated contraction of the deep muscles, then advances to limb movements, unstable postures, and finally functional activities while maintaining controlled spinal alignment. LSE, however, is typically structured around maintaining a neutral spine, improving trunk endurance, and increasing resistance to movement-related deformation, with exercises such as bridges, planks, bird-dog variations, and other co-contraction-based tasks (Cairns et al., 2006).

Although both interventions may include similar exercises, the conceptual distinction lies in the treatment goal. MCE is fundamentally a **motor relearning strategy**, whereas LSE is more of a **capacity-building strategy** for trunk support and endurance. This overlap is one reason why studies sometimes report similar clinical outcomes between the two approaches, and why careful intervention labeling is important in low back pain research. In the present study, MCE should therefore be described as an intervention aimed at retraining selective deep trunk muscle control and movement coordination rather than simply strengthening the core (C. G. Maher et al., 2005).

1.4 RESEARCH SIGNIFICANCE

Bio-Feedback (BF) is considered as one of the important method of rehabilitation which is commonly used in the form of neuromuscular biofeedback, Electromyography feedback, and Real-Time Ultrasound (RTUS) biofeedback (Giggins et al., 2013). BF technique can be used as a part of the management of LBP. It involves the use of electronic monitoring equipment to provide individuals with real-time information about their physiological processes in their body, such as heart rate, muscle tension, and skin temperature. The goal of BF in the management of LBP is to help individuals gain better control over these physiological processes, which can in turn lead to reduced pain and improved function. Here's how BF can be useful in managing LBP (Dellve et al., 2011).

BF can help individuals learn to relax and control the tension in their back muscles. When people experience LBP, it's common for muscles in the back to become tense and tight. BF can provide real-time information about muscle tension, enabling individuals to practice relaxation techniques to reduce it and alleviate pain. Poor posture can contribute to LBP. BF can be used to monitor posture and provide feedback on proper alignment. This feedback can help individuals make conscious adjustments to their posture to reduce strain on the lower back (Voerman et al., 2007).

Stress and anxiety can exacerbate LBP. BF can assist in managing stress by monitoring physiological indicators like heart rate and skin conductance. Through BF training, individuals can learn relaxation techniques to reduce stress and its impact on their pain. BF can also help individuals modulate their perception of pain. By learning to control physiological responses associated with pain, individuals may perceive their pain as less severe, making it more manageable (Sielski et al., 2017).

Some BF systems can provide feedback on body movements. This can be particularly helpful in teaching individuals to move in ways that minimize stress on their lower back, improving overall function and reducing the risk of further injury. BF allows for personalized treatment plans. It tailors the training to an individual's specific needs and

responses, making it a versatile tool in the management of pain. It is important to take note that BF is often used as part of a comprehensive pain management program, which includes other interventions such as physical therapy, medications, and lifestyle modifications (Lazaridou et al., 2023).

RTUS imaging is a useful visual BF method of rehabilitation in which the movement of the anatomical structures such as muscles and tendons observed to provide feedback to patients, which helps to enhance the performance of the muscle / tendon work (Hides et al., 1998). Hides, Richardson, & Jull (2008) also stated that in RTUS, the moving image structures are used as an assessment and rehabilitation feedback tool during the contraction of the TrA muscle. RTUS imaging is quite widely used in the rehabilitation of CNSLBP withn MCE. Research has been conducted to assess the contraction of the TrA muscle and to train it using RTUS as a feedback tool in CNSLBP patients (Teyhen et al., 2005; Akbari et al., 2008).

1.5 RATIONALE FOR THE RESEARCH

As low back problem persists to be a major quotient of patient load in any physiotherapy or rehabilitation center, there needs to be more understanding about the mechanism of the disease and the management strategies to have a better treatment outcome. The primary researcher's source of research question came when there were differences in the treatment output when patients with NSLBP were treated with various exercises and by varying levels of feedback. In addition to the need for a substantial body of research on NSLBP, there is also a need to develop advanced tools to manage the condition. There are more objective outcome measures and treatment tools needed, particularly in pain management. However, only a limited number of such tools are available now.

Motor control and learning are one area where there have been great advancements over the past two years. It is imperative to devise the intervention of the physiotherapist based on the current knowledge about how movement happens. In other words, the intervention needs to be continually updated based on current levels of scientific knowledge. In the field of physiotherapy, unlearning certain treatment strategies is very

difficult. One such intervention strategy is the training of the trunk extensors in prone lying and standing for improvement of the LBP severity. However, there is poor evidence that treating patients in a nonfunctional position provides less feedback to the conscious higher centers, leading to no learning from the exercises. If there is no learning from an exercise and it is not functionally useful to human kinetics, then the exercise is said to be of no use. Any amount of muscle strength doesn't necessarily lead to improved function unless the movement pattern or the motor program itself is practiced.

There is literature supporting the idea that monotonous exercises tend to reduce patient's ability to adhere to the exercise, whereas variety in exercises leads to greater more functional improvement and more degrees of freedom and range of activity among patients with NSLBP (Kamper et al., 2016). Hence, this study tries a new BF for the monitoring of low back exercises, which is taught uniquely. To our knowledge, no studies have yet tested the effect of BF in the management of NSLBP. Current treatments for LBP in physiotherapy have their own queries about their effectiveness (Van Middelkoop et al., 2011). Patients with CNSLBP benefit from exercises, it is unknown that which exercise is most effective (Luk et al., 2010). MCE improves the quality of life and function in patients with CNSLBP (Macedo et al., 2009; Saragiotto et al., 2016). Stabilization exercises for the lumbar spine have been shown to improve the outcomes in patients suffering from CNSLBP (Brumitt et al., 2013). However, a limited number of studies are available on comparing these two types of treatments (Costa et al., 2009; Macedo, Maher, Latimer, & Mcauley, 2009; Wang et al., 2012; Lamba et al., 2013). Hence, it is necessary to find out which of the two treatments, MCE or LSE, will be beneficial for CNSLBP patients.

Visual feedback enhances motor control by integrating sensory input with motor output to refine movement accuracy and coordination. The central nervous system processes visual stimuli through the occipital lobe, integrating this information with proprioceptive and vestibular input to adjust motor commands. The cerebellum plays a critical role in error detection and correction by continuously comparing expected and actual movement outcomes, leading to precise muscle activation. Motor learning is facilitated through feedback loops involving the basal ganglia and primary motor cortex,

reinforcing efficient neuromuscular patterns. In the absence of visual feedback, motor planning and execution are compromised, leading to reduced movement precision and increased compensatory mechanisms that disturbing the sensorimotor integration, causing inefficient muscle recruitment and altered biomechanics.

The novelty of applying MCE guided by Real-Time Ultrasound Imaging (RTUS) for CNSLBP patients depends on the following key aspects:

- **Real-Time Visual Feedback:** RTUS provides immediate visual feedback to both patients and Physiotherapists. For chronic NSLBP, where motor control deficits (especially in core stability muscles like the transverse abdominis and multifidus) are common, Visualization through RTUS helps patients understand how to activate and control deep stabilizing muscles, which patients often have difficulty engaging. This biofeedback enhances motor control retraining and improves exercise performance.
- **Precise Targeting of Deep Muscles:** Unlike surface Electromyography or other traditional feedback methods, RTUS can directly visualize the transverse abdominis and multifidus, which are crucial for spinal stability, and enabling more accurate, targeted exercise interventions aimed at these muscles.
- **Improved Motor Learning:** Visualizing the contraction of the muscles in real time enhances motor learning. Patients can facilitate the muscle activation targeting the specific muscle and can achieve better coordination and motor control over time. This is crucial for chronic NSLBP, where poor muscle control or faulty movement patterns often exacerbate pain or contribute to the condition.
- **Objective Monitoring and Progress Tracking:** RTUS enables physiotherapists to objectively assess and monitor patients' muscle function and improvement over time. It allows for more personalized treatment plans as physiotherapist can plan and adjust the exercise prescription based on real-time information about muscle performance and progress.

- **Engagement and Motivation:** Seeing their muscles in action can motivate patients, increasing their engagement in the rehabilitation process. This is important in managing chronic conditions like NSLBP, where adherence to therapeutic exercises can be challenging.
- **Non-Invasive, Safe Approach:** RTUS is a non-invasive and safe method of treatment, making it suitable for repeated use during therapy sessions. This ensures continuous monitoring without increasing the patient's risk.

In summary, using RTUS in MCE for NSLBP patients introduces a novel approach that improves muscle targeting accuracy, enhances patient engagement, and provides real-time visual feedback to optimize motor retraining for pain reduction and improved function.

Hence, there is a need to incorporate an effective feedback mechanism that is more objective and superior to the subjective, conventional visual feedback provided by mirrors.

1.6 RESEARCH QUESTIONS

1. What are the effects of Motor Control Exercises on reducing pain in individuals with CNSLBP?
2. How do Motor Control Exercises influence functional activity in patients with CNSLBP?
3. To what extent do Motor Control Exercises improve core muscle strength in individuals with CNSLBP?
4. What are the effects of Lumbar Stabilization Exercises on pain reduction in patients with CNSLBP?
5. How do Lumbar Stabilization Exercises affect functional activity in individuals with CNSLBP?
6. To what extent do Lumbar Stabilization Exercises enhance core muscle strength in patients with CNSLBP?
7. How do the effects of Motor Control Exercises compare with those of Lumbar Stabilization Exercises in improving pain, functional activity, and core muscle strength in individuals with CNSLBP?

1.7 RESEARCH OBJECTIVES:

1.7.1 General Objective

- To evaluate the effects of Motor Control Exercises on pain functional activity and core muscle strength in Chronic Non-Specific Low Back Pain

1.7.2 Specific Objectives

- To evaluate the effects of Lumbar Stabilization Exercises on pain functional activity and core muscle strength in Chronic Non-Specific Low Back Pain
- To compare the effects of Motor Control Exercises Versus Lumbar Stabilization Exercises on pain, functional activity and core muscle strength in Chronic Non-Specific Low Back Pain

1.8 HYPOTHESIS

1.8.1 Null Hypothesis (H0)

- There was no significant difference with Motor control exercises on pain, functional activity and core muscle strength in patients with Chronic Non Specific Low Back Pain.

1.8.2 Alternate Hypothesis (H1)

- There was a significant difference with Motor control exercises on pain, functional activity and core muscle strength in patients with Chronic Non Specific Low Back Pain.

CHAPTER II

REVIEW OF LITERATURE

This chapter deals with the evidences related to various components such as the incidence / prevalence of NSLBP, Determinants of LBP, Various Physiotherapy Interventions, MCE for NSLBP, LSE for NSLBP, Differential Diagnosis for NSLBP, Numerical Pain Rating Scale (NPRS), Oswestry Disability Index (ODI), and Pressure Bio-Feedback (PBF).

2.1 PREVALENCE OF LOW BACK PAIN / NON-SPECIFIC LOW BACK PAIN

NSLBP is a major global health concern due to its high prevalence, recurrent nature, and substantial impact on daily function and work capacity. It refers to low back pain without a clearly identifiable structural cause, even after appropriate clinical assessment and imaging when indicated. Epidemiological studies show that low back pain affects up to 84% of individuals at some point in life, with non-specific cases forming the vast majority. Approximately 23% develop chronic symptoms, and about 11–12% experience severe disability related to the condition. Given its high prevalence, along with significant direct and indirect healthcare costs such as productivity loss and reduced quality of life, NSLBP represents a major public health burden. Therefore, reviewing its prevalence is essential to understand its magnitude across populations and age groups, and to support further analysis of its risk factors, prevention, and management strategies.

The scoping review by Abas et al (2023) provides a valuable synthesis of the prevalence and risk factors of low back pain (LBP) in Malaysia by systematically mapping evidence from multiple databases and including 21 cross-sectional studies conducted between 2016 and 2020. A key strength of the study is its use of the Arksey and O'Malley scoping review framework, which ensures a transparent and reproducible approach to literature identification, screening, and data charting. The review effectively highlights the wide range of LBP prevalence (12.4%–84.6%) across diverse Malaysian populations and identifies consistent occupational and individual risk factors including prolonged standing,

heavy lifting, BMI, age, and gender. However, a major limitation is the absence of a formal quality assessment of included studies, which limits the ability to assess the robustness of the synthesized evidence. In addition, the heavy reliance on self-reported questionnaires (e.g., NMQ and other non-standardized tools) introduces potential recall and reporting bias, reducing comparability across studies. The heterogeneity in study populations, settings, and measurement instruments further limits the generalizability and prevents meta-analytic estimation. Moreover, the restricting the analysis to studies published between 2016 and 2020 may have excluded earlier foundational epidemiological evidence, potentially narrowing the contextual understanding. The review also identifies important geographical gaps, particularly the lack of data from several Malaysian states, indicating uneven research distribution. Despite these limitations, the study provides important epidemiological insight and clearly justifies the need for standardized diagnostic tools and broader nationwide surveillance of LBP in Malaysia (Abas et al., 2023).

Wong et al. (2022) conducted a PRISMA-guided systematic review and meta-analysis to examine the prevalence, incidence, and associated factors of non-specific chronic low back pain (CLBP) in community-dwelling older adults aged ≥ 60 years, synthesizing evidence from 10 studies involving 31,080 participants across multiple countries. The study demonstrates strong methodological rigor through PROSPERO registration, comprehensive database searching, dual independent screening, and use of AXIS and QUIPS tools alongside modified GRADE for evidence certainty; however, findings are substantially constrained by high heterogeneity ($I^2 > 99\%$), variability in CLBP definitions (3 to 12 months duration), and predominance of cross-sectional designs. The pooled prevalence estimates (20.6% point prevalence and 36.1% 12-month prevalence) suggest that CLBP is highly common in older adults, yet the reliability of these estimates is limited by inconsistent measurement methods and a moderate-to-high risk of bias in the included studies. Although 41 associated factors were identified, including obesity, psychological distress, comorbidities, and degenerative spinal changes, most associations were graded as “very limited” evidence, reflecting weak causal inference and inadequate control of confounding across studies. Importantly, no robust prognostic factors were identified,

highlighting a major gap in longitudinal research. Overall, while the review provides valuable epidemiological mapping of CLBP in aging populations, its conclusions remain exploratory rather than confirmatory, and future research requires standardized CLBP definitions, stronger prospective cohort designs, and improved adjustment for confounders to establish clinically meaningful risk profiles (Wong et al., 2022).

A backward analysis using 529 records of adult employees from a private company's database. Based on the amount of the time spent in each posture, the most common lumbar posture associated with work was identified and categorized. 22 individuals, professional, clinical, and psychological variables were assessed. The study's findings included LBP symptoms over the last year and the previous seven days. The categorization of lumbar posture variables to LBP was analyzed independently by the multivariate analysis model. Adjusted logistic regression revealed that walking reduced the likelihood of reporting LBP within the past year compared to standing (OR = 0.54; 95%). Significant associations with LBP were also observed for gender, manual work, frequent fatigue, pain at other body sites, prior LBP, and repetitive tasks. Discomfort in any other body area over the preceding week's work, and past LBP were all linked to recent LBP. Comparing walking versus standing posture, there is a higher chance of reporting LBP in the last year. LBP was linked to clinical and personal variables throughout the previous year and the preceding week. (Leivas et al., 2022).

Shetty et al. (2022) conducted a study to determine how common LBP is in India. The full results of epidemiological point, yearly, and lifetime prevalence markers have not been the subject of a meta-analysis before. Analysis, subgroup analysis, sensitivity analysis, and analyses of publication bias were used to support this. 54 research (55.5%) were determined to be of better methodological quality in this assessment, which comprised 97 studies overall. In India, the prevalence of LBP over the long term, on a yearly basis, and cumulatively was 48%. According to reports, females, primary school employees, and those living in rural areas had the highest rates of pooled prevalence. Compared to other ethnic groups and the general population, Indians have the greatest

incidence rates of LBP, which affects a larger share of the population, especially women, primary school teachers, and rural residents. The results of this study may serve as a basis for formulating policies to manage and prevent LBP (Shetty et al., 2022).

Fatoye et al. (2019) conducted a PRISMA-guided systematic review to synthesize the real-world incidence and prevalence of low back pain (LBP) using routinely collected electronic health records, claims, and registry data, providing an important shift from traditional population surveys toward real-world evidence synthesis. The review included 13 studies drawn predominantly from high-income countries (USA, Netherlands, Canada, Sweden, Finland, Belgium, and Israel), indicating a clear geographical evidence gap for low- and middle-income settings. A major strength of the study lies in its large pooled sample sizes (ranging from 3,900 to 7.5 million participants) and generally low risk of bias, which enhance internal validity and support more robust epidemiological inference. However, the authors identified substantial heterogeneity in both prevalence (1.4–20.0%) and incidence (0.024–7.0%) estimates, reflecting inconsistencies in study populations, healthcare databases, and methodological approaches. Notably, variability in LBP case definitions (e.g., differing ICD codes and diagnostic classifications) limits comparability across studies and introduces classification bias. The review also highlights inconsistent findings regarding gender as a risk factor, with some studies suggesting higher odds in males while others report the opposite, indicating unresolved epidemiological uncertainty. While the use of real-world data improves external validity and policy relevance, reliance on retrospective administrative datasets may introduce underreporting, coding errors, and selection bias. Furthermore, excluding non-English studies and underrepresenting developing countries reduces global generalizability. Overall, this review provides valuable evidence that LBP is a significant global health burden, but underscores the need for standardized definitions, improved data harmonization, and more diverse international datasets to strengthen future epidemiological estimates and healthcare planning (Fatoye et al., 2019).

Morris, Daniels, Ganguli, and Louw (2018) conducted a systematic review and meta-analysis to update evidence on the prevalence of LBP in Africa, addressing gaps since Louw et al.'s 2007 review. Using a pre-registered protocol, they analyzed 65 population-based studies, mostly from Nigeria (47%) and South Africa (25%), with 66% rated higher quality. Despite indexing challenges limiting access to African research, pooled prevalence estimates were high: lifetime 47%, annual 57%, and point 39%. These figures are comparable to or higher than global averages, highlighting LBP as a significant public health issue. Prevalence increased with age, was higher among adults than among adolescents, and showed a notable male predominance contrary to with global trends. Heterogeneity was considerable due to inconsistent case definitions and recall periods. Publication bias analyses indicated possible overestimation, yet even conservative estimates reflected a substantial burden, often exceeding rates in high-income countries. This review emphasizes that LBP remains under-prioritized in Africa, where health resources focus on communicable diseases. The authors recommend standardized definitions, more representative studies across under-researched regions, and improved visibility of African outputs. Importantly, they highlight early-onset LBP as a risk for chronicity, stressing preventive strategies for school-age populations (Morris et al., 2018).

2.2 DETERMINANTS OF LOW BACK PAIN

Nearly 60–80% of people have LBP at some point in their lives, making it the sixth most frequent reason for doctor visits. According to few research studies, upto 23% of individual worldwide experience persistent low back discomfort. A one-year recurrence rate of 24% to 80% has also been seen in this cohort. In the adult population, some lifetime prevalence estimates reach 84%. An annual rate of 11.8% to 33% for teenagers with back pain was found by a systematic study, and between 11 and 12% of the population reported LBP as a disability.

Mazhak and Fister (2025) examine sociodemographic and psychosocial determinants of low back pain severity among Ukrainian refugees in Czechia, addressing a highly vulnerable and under-studied population. Using a cross-sectional design (n = 341)

and validated tools such as PHQ-9 and BAI, the study provides methodologically sound evidence linking low back pain severity with socioeconomic status, functional limitations, lifestyle factors, and anxiety levels. The regression models showed strong explanatory power for physical determinants ($R^2 = 0.517$), but weaker for mental health factors ($R^2 = 0.228$), indicating partial model coverage. Interestingly, depression was not significantly associated with pain severity, contrasting with much prior literature and possibly reflecting context-specific stressors linked to displacement. While the study benefits from robust measures and a relatively large sample, its convenience sampling, online self-report design, and female-dominant cohort limit generalisability. The cross-sectional nature also restricts causal inference. Overall, the study highlights the multidimensional interaction between forced migration, psychosocial distress, and pain, supporting the need for integrated physical–mental health approaches in refugee populations (Mazhak & Fister, 2025).

Alotaibi et al. (2024) conducted a large cross-sectional study to explore the association between lifestyle behaviors and LBP among Saudi adolescents, addressing an important public health concern during a critical developmental stage. The study recruited 2000 high school students from five major regions in Saudi Arabia, with an average age of 16.7 years. The prevalence of LBP in this population was found to be 57.9%, indicating that more than half of adolescents experienced back pain, consistent with global reports of rising LBP in youth populations. Data collection employed validated tools, including the Health-Promoting Lifestyle Profile II (HPLP-II), to assess lifestyle domains such as physical activity, nutrition, stress management, interpersonal relations, and spiritual growth, along with standardized measures of sleep quality and sedentary time. Findings revealed that adolescents with LBP scored significantly lower on overall health-promoting lifestyle behaviors compared to those without pain (mean HPLP-II score: 20.94 vs. 22.64). Among the subscales, physical activity had the lowest mean, while spiritual growth had the highest. Logistic regression analysis showed that lower lifestyle scores increased the odds of LBP by 75%, whereas longer sedentary duration increased the risk by 80%. Poor sleep quality was also a significant predictor, with higher global sleep quality scores associated with decreased LBP occurrence. Further regression modeling confirmed that

sedentary behavior and poor sleep quality remained strong predictors of pain severity, even after adjusting for age, sex, and BMI. Interestingly, no significant associations were found between individual HPLP-II subscales and pain severity after full adjustment, underscoring the dominant role of sedentary time and sleep in LBP among adolescents. In conclusion, this study underscores the critical impact of lifestyle behaviors—particularly inactivity and inadequate sleep—on the prevalence and severity of adolescent LBP. The findings highlight the need for preventive interventions that promote physical activity, reduce sedentary behavior, and improve sleep quality to mitigate LBP during adolescence (Alotaibi et al., 2024).

Fay and Black (2024) conducted a systematic review to identify risk factors for low back pain (LBP) among adults in Nigeria and South Africa by synthesizing evidence from 39 studies. The review demonstrated that advancing age, female gender, obesity, occupational posture, manual handling, prolonged work duration, limited job autonomy, and psychosocial factors were consistently associated with LBP. A major strength of the study lies in its comprehensive search strategy, inclusion of grey literature, PROSPERO registration, and rigorous quality appraisal using AXIS and CASP tools, which enhanced the methodological credibility of the findings. However, the review was limited by the predominance of cross-sectional studies, substantial methodological heterogeneity, and inconsistent definitions of LBP across included studies, which restricted causal inference and prevented meta-analysis. Furthermore, the findings are specific to Nigeria and South Africa, which may limit their generalizability to other populations. Nevertheless, this review provides robust evidence that LBP is influenced by multidimensional sociodemographic, occupational, lifestyle, and psychosocial factors, supporting the need for comprehensive risk assessment and targeted preventive interventions in both clinical practice and future research (Fay & Black, 2024).

Orlando et al (2023) conducted a systematic review to identify the predictors of hospitalization for NSLBP, and this study employed a PRISMA-guided methodology with protocol registration and comprehensive database searching, strengthening methodological

transparency and reproducibility. A total of 23 heterogeneous studies encompassing over two million participants identified 52 potential predictors across personal, clinical, occupational, psychosocial, and health-system domains. The synthesis indicates moderate evidence that older age and ambulance arrival to emergency departments consistently increase the likelihood of hospitalization, suggesting a strong link between perceived severity and admission decisions. In contrast, low-level evidence supports associations with high pain intensity, previous LBP episodes, opioid use, and occupational factors, indicating weaker and less consistent predictive value. Notably, psychosocial and behavioral determinants were underrepresented, revealing a significant gap in understanding non-clinical drivers of hospitalization. Methodological strengths include the large aggregated sample size, diverse international settings, and structured risk-of-bias assessment using CASP tools. However, substantial heterogeneity in study design, outcome definitions, and predictor measurement prevented meta-analysis and limits quantitative synthesis. The predominance of retrospective cohort designs and the lack of confounder control could further increase susceptibility to bias and restrict causal inference. Overall, findings suggest hospitalization for LBP is shaped more by health-system pathways and perceived clinical severity than by isolated biomedical factors. Future research should prioritize psychological, social, and health-service determinants using prospective, standardized methodologies to improve predictive accuracy and reduce avoidable admissions (Orlando et al., 2023).

Agnus Tom et al. (2022) conducted a systematic review to synthesize the breadth of quantitative research on determinants affecting the QOL in individuals with CLBP, and to evaluate intervention strategies with potential to enhance QOL. In 2017, 577 million people worldwide suffered from low back discomfort. This systematic review compiles the available data about the elements that affect their QOL among people with CLBP and aims to discover tactics to enhance their QOL. 26, out of the 10,851 studies that were initially found were chosen for the review because they satisfied the inclusion criteria. Five studies evaluated the effect of interventions on QOL, while 21 studies showed a link between QOL and putative factors. The identified factors were grouped into domains, including

kinesiophobia, fear-avoidance beliefs, and perceptions of pain; work-related elements; pain intensity and disability; levels of physical activity; personal characteristics such as age, gender, and employment status; and additional psychological aspects like anxiety, sleep quality, and health-related locus of control. Interventions such as Mindfulness-Based Stress Reduction (MBSR), Pilates, and the Back School Program were found to enhance quality of life in individuals with CLBP, and their QOL was influenced by their individual's physical health and psychosocial aspects. (Agnus Tom et al., 2022).

The systematic review by Rezaei et al. (2021) examined the prevalence of LBP and its associated risk factors among healthcare providers, a population particularly vulnerable due to the physical and psychosocial demands of their profession. The primary objective of this study was to synthesize available evidence on the burden of LBP among hospital-based health workers and to identify occupational, demographic, and behavioral determinants of its occurrence. The authors employed a systematic search strategy across multiple databases, reviewed studies focused on LBP among healthcare providers, and critically analyzed findings to extract patterns of risk. The review revealed that LBP was highly prevalent among healthcare workers, with rates ranging from 50% to 90% depending on occupational role and work environment. Nurses, in particular, demonstrated the highest risk, largely due to repetitive patient handling, prolonged standing, awkward postures, and physically demanding tasks. Demographic variables such as age, gender, and years of work experience also influenced the occurrence of LBP, with female workers and those with longer job tenure reporting higher rates. Moreover, psychosocial factors—including job dissatisfaction, work-related stress, and lack of organizational support—emerged as significant contributors to the persistence of pain. Importantly, lifestyle-related factors such as reduced physical activity, obesity, and poor sleep quality were also correlated with LBP incidence. The authors concluded that LBP among healthcare providers is a multifactorial issue with both physical and psychological determinants, highlighting the urgent need for preventive strategies tailored to occupational settings. This comprehensive review underscores the importance of addressing ergonomic practices,

workplace stress management, and health promotion measures to reduce the burden of LBP in the healthcare workforce (Rezaei et al., 2021).

2.3 DIFFERENTIAL DIAGNOSIS IN NSLBP

Non-specific low back pain is defined as LBP not caused by a clear-cut, well-known pathology (e.g., infection, tumor, osteoporosis, lumbar spine fracture, structural deformity, inflammatory condition, radicular syndrome, or cauda equina syndrome). Acute, subacute, and CLBP are the three most commonly recognized types. This split is made depending on how long the back discomfort has persisted. Acute LBP is a flare-up lasting less than six weeks, subacute LBP lasts between six and twelve weeks, and chronic pain lasts for twelve weeks or more.

The narrative review by Ferdinandov et al (2024) provides a broad synthesis of low back pain (LBP) aetiologies by stratifying causes into intrinsic spinal, systemic non-mechanical, and referred visceral categories, thereby reinforcing the multidimensional nature of LBP in contemporary clinical practice. While this tripartite framework improves conceptual clarity, it oversimplifies the frequent clinical overlap between degenerative, inflammatory, infectious, and visceral pain generators. The review's major strength lies in its comprehensive coverage of pathologies ranging from discogenic disease to malignancy and infection, reinforcing the importance of red-flag recognition in LBP assessment. However, the narrative design introduces selection bias and limits methodological transparency, thereby reducing reproducibility and the strength of the evidence hierarchy.

Reliance on heterogeneous observational studies and case reports further weakens comparative inference and limits generalizability across populations. Although imaging and clinical history are appropriately highlighted as key diagnostic tools, the discussion underrepresents emerging stratified care models and validated clinical decision rules. Compared with contemporary guideline-driven literature, the review remains largely descriptive rather than analytical or algorithmic. Nonetheless, its emphasis on systemic and non-spinal causes strengthens diagnostic vigilance, particularly for serious underlying pathology. The inclusion of rare conditions enhances clinical scope but lacks weighting by

prevalence or probability, which may affect practical prioritization. Overall, the paper provides a structured but largely conceptual overview, with limited integration of quantitative synthesis or predictive diagnostic frameworks needed for higher-level clinical decision-making (Ferdinandov et al., 2024).

The reviewed article by Hatice Rosarlu (2023) on diagnostic approaches to low back pain synthesizes current clinical frameworks reinforcing the predominance of nonspecific low back pain (~85%) and the consequent emphasis on conservative, non-imaging-based management at early presentation, aligning with prevailing primary care guidelines. It effectively integrates the biopsychosocial model by distinguishing mechanical, non-mechanical, and psychosocial (“yellow flag”) determinants, reflecting a broader shift in contemporary musculoskeletal literature away from purely biomedical explanations. A key strength lies in its structured red flag stratification, which supports early identification of serious pathologies such as malignancy, infection, and cauda equina syndrome, thereby improving diagnostic safety in primary care settings. However, the article remains largely narrative in design and lacks empirical validation or quantitative synthesis, limiting its capacity to establish diagnostic accuracy or predictive value of proposed clinical indicators. Furthermore, while it appropriately discourages routine imaging, it does not critically engage with the documented variability in guideline adherence or the persistence of imaging overutilization in real-world clinical practice reported in broader studies.

The discussion of mechanical versus non-mechanical pain is clinically useful but somewhat reductionist, as recent evidence increasingly emphasizes overlapping pathophysiology and multimodal pain generator. In comparison with contemporary systematic reviews, the article aligns well with consensus recommendations from organizations such as the American College of Physicians, particularly regarding stepped care and risk stratification. Nevertheless, it underrepresents emerging evidence on stratified care models and prognostic screening tools that integrate multidimensional risk algorithms. The inclusion of psychosocial risk (“yellow flags”) is conceptually strong, yet the article does not critically evaluate measurement tools or their validated thresholds, which are

central to implementation science. Overall, while the article provides a clear and clinically applicable diagnostic framework, its reliance on descriptive synthesis rather than critical appraisal of evidence hierarchy limits its contribution to advancing diagnostic precision in low back pain research. Consequently, it is best interpreted as a practical guideline-oriented narrative review rather than a rigorously analytical or evidence-weighted synthesis of diagnostic strategies in contemporary low back pain management (Hatice Resorlu, 2023).

An investigation was made of the initial LBP treatment recommendations made by primary care providers (PCPs) after the publication of guidelines. With 72 PCPs from three community-based outpatient clinics in low-income areas, convenience sampling was used in a cross-sectional, structured study. We conducted the interviews between December 2017 and March 2018. Over three-fourths of the participating PCPs (76%-87% at 3 clinics)—72 in total—who were male and had an average of 13.8 years of practice—said they were familiar with the American College of Physician’s recommendation. PCPs frequently recommended staying active (81%) and administered medication (97%; mostly NSAIDs) to treat acute LBP. PCPs were more likely to prescribe nonpharmacological therapy for chronic LBP than for acute LBP (85% vs. 0%, $p < 0.001$), and the expense of these treatments was thought to be a deterrent. However, PCPs from high-income neighborhood clinics were equally as likely to advise nonpharmacological treatments as those from low-income clinics. (Roseen et al., 2021).

For patients with NSLBP in primary care, research was conducted with the purpose of presenting an overview of the recommendations on the diagnosis and therapy found in current clinical practice guidelines. Additionally, it was evaluated to see which suggestions had changed since the last overview. Electronic databases were explored from 2008 to 2017 for clinical practice recommendations. A multidisciplinary audience in a primary care setting deemed eligible for the guidelines was provided with information on either the diagnosis or management of NSLBP. The creation of guidelines was used to extract information on diagnostic suggestions, therapeutic courses, and procedures. The therapy of LBP in a primary care setting for the diagnosis of patients with NSLBP was indicated in

15 clinical practice recommendations. The use of imaging if significant disease is suspected (but discourages routine usage) and the investigation of psychosocial variables were all advised by the clinical guidelines. Neurological testing to detect radicular syndrome was also advised.

The guidelines advised giving patients with acute LBP reassurance about their good prognosis and advising them to resume their regular activities, avoid bed rest, use nonsteroidal anti-inflammatory medicines (NSAIDs), and use mild opioids for brief periods of time. The guidelines advise the use of NSAIDs and antidepressants, exercise therapy, and psychological therapies for the management of people with persistent LBP. Additionally, a specialist referral is advised if there is any indication of a particular pathology or radiculopathy or if there has been no improvement after 4 weeks. Although there were some differences among the existing clinical practice standards, a significant number of the suggestions were consistently accepted. With regard to the recommendations for the evaluation of psychosocial factors, the use of some medications (such as paracetamol), and the growing body of knowledge surrounding various forms of exercise, delivery methods, acupuncture, herbal remedies, and invasive treatments, we found some differences between the current review and the previous overview which can be found under "Electronic Supplementary Material." (Oliveira et al., 2018).

A study looked at NSLBP, which affects people of all ages and contributes significantly to the global disease burden. Management guidelines recommend triage to find the rare cases of LBP that are brought on by medically serious pathology and, as a result, need diagnostic testing, specialist referral, or both. Treatment for NSLBP is focused on lessening pain and associated side effects because the patho-anatomical origin is unknown. Analgesic medications, non-pharmacological treatments, education and assurance, and timely reassessment make up management. Low back discomfort often has a favorable clinical outcome; thus, few individuals actually need to see a doctor. Both a phased strategy, which starts with simpler care and progresses if the patient doesn't improve, and the use of straight forward risk-prediction techniques to tailor the type and

amount of care are now employed as treatment tactics. Overuse of imaging, painkillers, and surgery is still a major issue. (C. Maher et al., 2017).

According to the study by Van Hoeven et al (2016), the main symptom of axial spondylarthritis (axSpA), an incapacitating inflammatory joint condition, is chronic low back discomfort. For general practitioners (GPs), identifying axSpA in a significant proportion of patients with CLBP can be challenging. By contrasting the usage of the approach with standard therapy, this assessment intends to determine the impact of a strategy for axSpA in young primary care patients with CLBP. Patient-reported outcomes (also known as clinical impact), process, and cost assessment are the three levels at which the effect is evaluated. This research uses GP's as clusters in a cluster-randomized controlled experiment. All Dutch general practitioners are invited to participate and are randomly assigned to either the intervention or the control group. Patients with LBP who have never had (ICPC L03) and are between the ages of 18 and 45 are asked to enroll from participating GPs. Patients must have both acute LBP and CLBP (lasting more than 12 weeks) in order to participate in the research. Patients with CLBP will get treatment as usual in the control arm while those in the intervention arm will use a referral approach for axSpA. It was hoped that implementing the axSpA referral method for primary care CLBP patients would improve their quality of life, lead to more rheumatologists to make proper axSpA diagnosis, and be cost effective. The findings of this study might ultimately help launch a nationwide axSpA referral plan to identify CLBP patients with axSpA in a timely manner. (Van Hoeven et al., 2016).

2.4 PHYSIOTHERAPY INTERVENTIONS FOR NON-SPECIFIC LOW BACK PAIN

Physiotherapy for NSLBP focuses on reducing pain, improving function, and enabling long-term self-management through a multimodal, evidence-based approach. First-line care includes patient education, activity modification, and exercise therapy, with emphasis on aerobic conditioning, core stabilization, and motor control training to restore function and reduce recurrence. Manual therapy may be used as an adjunct for short-term pain relief

and mobility improvement, while modalities such as heat and TENS are secondary options. Psychosocial factors such as fear-avoidance, are also addressed through education and graded exposure within a biopsychosocial model. Overall, treatment is individualized and prioritizes functional recovery over pain relief alone.

This randomized clinical trial investigated the comparative effectiveness of passive (lying) versus active (functional movement) IASTM application in individuals with CNSLBP. Seventy-four participants were randomized and received six sessions over three weeks, with outcomes assessing pain (VAS), disability (ODI), spinal mobility, flexibility, and trunk extensor endurance. Results demonstrated that both intervention groups exhibited significant reductions in pain and disability along with improvements in spinal mobility, hamstring flexibility, thoracolumbar fascia flexibility, and muscular endurance. Notably, improvements were time-dependent, with progressive gains observed from baseline through the 1st to the 6th intervention, suggesting cumulative therapeutic effects. However, inter-group comparisons revealed no significant differences for most functional outcomes, indicating comparable efficacy between passive and active IASTM protocols.

The only exception was a greater reduction in resting pain in the functional (active) IASTM group, potentially reflecting enhanced neurovascular stimulation and circulation during movement-based application. These findings support proposed mechanisms such as fascial glide improvement, mechanoreceptor activation, and central pain modulation, while suggesting that adding functional movement may not substantially enhance overall functional recovery. Clinically, IASTM appears effective as a standalone short-term intervention for symptom relief and functional improvement in CNSLBP, though protocol standardization remains necessary. Nevertheless, the absence of a control group and the short follow-up period limit causal inference and long-term applicability, highlighting the need for future high-quality trials with longer-term outcomes and comparative multimodal designs (Güzelşemme & Oksüz, 2025).

The study by Tanveer et al. (2023) investigated the effectiveness of Kinesio Taping (KT) combined with conventional physiotherapy for non-specific chronic low back pain using a quasi-experimental design with 30 participants randomly assigned to two equal groups. Findings indicated that both KT + conventional therapy and conventional therapy alone produced statistically significant improvements in pain (NPRS) and disability (ODI), highlighting the effectiveness of standard physiotherapy interventions. However, the KT adjunct group demonstrated comparatively greater reductions in pain scores, supporting a potential additive therapeutic effect of taping when integrated with exercise-based rehabilitation. These findings align with prior evidence suggesting that KT may enhance proprioception, muscle activation, and postural control, although its standalone efficacy remains limited. Notably, the study reinforces the broader literature indicating that KT is not superior to conventional therapy when used in isolation, but may offer short-term symptomatic relief when combined with exercise therapy. The reported improvements, however, must be interpreted cautiously due to the small sample size, non-randomized sampling, and short intervention duration, which limit external validity and causal inference.

Additionally, baseline comparability and potential selection bias in quasi-experimental designs may have influenced observed treatment effects. Existing systematic reviews similarly report mixed evidence, with some showing minimal clinically significant benefit of KT over sham or standard physiotherapy in CLBP populations. Nevertheless, the study contributes regionally relevant clinical evidence supporting multimodal rehabilitation approaches in musculoskeletal pain management. Overall, the literature suggests KT should be considered an adjunct rather than a primary intervention within evidence-based physiotherapy practice for chronic low back pain (Tanveer et al., 2023).

The study by Koppenaal et al. (2023) evaluated the long-term effectiveness and cost-effectiveness of a stratified blended physiotherapy intervention (e-Exercise LBP) compared with conventional face-to-face physiotherapy in patients with nonspecific low back pain (LBP), using a cluster-randomized controlled trial design. The intervention

integrated a stratified, app-supported self-management programme based on risk profiling, aiming to enhance adherence and functional recovery. Results showed no statistically or clinically significant improvement in physical functioning, with an adjusted mean difference in ODI of -1.1 (95% CI: -3.9 to 1.7) over 12 months ($p > 0.05$ indicated non-significance). Similarly, health-related quality of life demonstrated a negligible effect, with a QALY difference of 0.026 (95% CI -0.020 to 0.072), indicating no meaningful gain in utility. Pain intensity also showed minimal between-group change (-0.3 ; 95% CI -0.9 to 0.2), reinforcing the absence of clinically relevant superiority. However, fear-avoidance beliefs were significantly reduced in the intervention group (MD -4.3 ; 95% CI -7.3 to -1.3 ; $p < 0.05$), suggesting a measurable psychological benefit. Self-reported adherence improved at 3 months (MD 0.8 ; 95% CI 0.1 – 1.6 ; $p < 0.05$), but this effect was not sustained at 12 months. However, these improvements did not translate into superior overall functional outcomes or sustained clinical advantage.

From an economic standpoint, stratified blended physiotherapy resulted in higher societal and healthcare costs than standard physiotherapy, although the differences were not statistically significant. Economically, stratified blended physiotherapy resulted in higher societal costs (€972; 95% CI $-€1090$ to $€3264$) and higher healthcare costs (€73; 95% CI $-€59$ to $€225$), both statistically non-significant. The incremental cost-effectiveness ratio (ICER) for QALYs was €49,159 per QALY gained, with a probability of cost-effectiveness, indicating weak economic dominance. Subgroup analyses reinforced the absence of economic advantage across different risk profiles for persistent LBP. Overall, the study critically challenges the assumption that digital blended physiotherapy necessarily enhances value-based care, highlighting that improved adherence alone may not be sufficient to drive meaningful long-term clinical or economic benefits (Koppelaar et al., 2023).

The study by Akhtar et al. (2022) evaluated the comparative effectiveness of Kinesio Taping combined with conventional physiotherapy versus conventional physiotherapy alone in patients with non-specific low back pain (NSLBP) using a

randomized controlled trial design. The intervention incorporated Kinesio Taping alongside standard modalities (hot packs and back isometrics), reflecting a multimodal conservative rehabilitation approach. Findings demonstrated statistically significant greater improvements in the KT group in both pain reduction and functional disability compared to control (VAS and RMQ, $p=0.000$). The reduction in VAS scores in the experimental group indicates a stronger short-term analgesic effect when KT is integrated into rehabilitation protocols. Similarly, RMQ outcomes indicate enhanced functional recovery and improved daily activity performance in the KT group compared with physiotherapy alone. These results support the hypothesis that elastic therapeutic taping may facilitate proprioceptive feedback, muscle relaxation, and spinal support mechanisms. However, the clinical interpretation is limited by the small sample size ($n=36$) and short intervention duration (2 weeks), which restricts long-term generalizability. Additionally, the near-uniform demographic distribution may reduce variability but limits external validity across broader NSLBP populations. While statistical significance is strong, the study provides limited evidence regarding sustained functional outcomes beyond the immediate post-intervention phase. Overall, the evidence positions Kinesio Taping as an effective adjunct rather than a standalone intervention within conservative NSLBP management. Future high-quality trials with longer follow-up and larger heterogeneous samples are required to confirm the durability and clinical relevance of these findings (Akthar et al., 2022).

The study by Lara-Palomo et al. (2022) presents a randomized controlled trial protocol comparing electrical dry needling with conventional physiotherapy for nonspecific chronic low back pain associated with myofascial trigger points. CLBP is contextualized as a major global burden, strongly linked to disability, reduced quality of life, and high socioeconomic cost, thereby justifying investigation of more effective interventions. A key clinical rationale is the involvement of active and latent myofascial trigger points in lumbar musculature, which may perpetuate pain sensitization and functional limitation. The intervention arm utilizes electrical dry needling with low-frequency stimulation targeting quadratus lumborum, multifidus, and iliocostalis muscles,

reflecting a neurophysiological pain modulation approach. The comparator, conventional physiotherapy, integrates ischaemic compression, stretching, and home exercise, representing guideline-consistent conservative care. Methodologically, the study demonstrates strong internal validity through randomized allocation, assessor blinding, and standardized treatment dosing over 6 weeks with follow-up at 2 months. Outcome measures are comprehensive, incorporating pain (VAS), disability (RMDQ, ODI), psychological distress (HADS, TSK), sleep quality (PSQI), and functional performance including algometry and spinal mobility testing. This multidimensional assessment framework strengthens construct validity by capturing both nociceptive and biopsychosocial dimensions of CLBP. However, as a protocol study, no empirical effectiveness results are yet available, limiting current evidence to hypothesised superiority of electrical dry needling. Potential limitations include inability to blind therapists, relatively short follow-up for chronic pain recurrence patterns, and heterogeneity in trigger point presentation. Overall, the trial addresses a significant evidence gap regarding invasive versus non-invasive physiotherapy approaches, and its findings may refine clinical decision-making in the management of CLBP (Lara-Palomo et al., 2022).

The randomized controlled trial by Matarán-Peñarrocha et al (2020). compared supervised versus non-supervised core exercise programs in 64 patients with chronic non-specific low back pain over 8 weeks with 6-months follow-up. Both interventions were based on standardized lumbopelvic stabilization and strengthening exercises, delivered either face-to-face or through structured home prescription. Results demonstrated statistically significant short-term between-group differences in pain intensity measured by VAS, favoring supervised exercise (2.5 ± 2.1 vs 3.5 ± 1.5 ; $p=0.028$). However, at 6 months, between-group differences in pain were no longer statistically significant ($p>0.05$), indicating attenuation of treatment effects over time. Disability outcomes showed greater improvement in the supervised group for RMQ and ODI, with mean change scores of 5.2 vs 5.0 and 12.2 vs 9.4 respectively. Despite these numerical advantages, most between-group differences were small and below clear clinical relevance thresholds. Effect sizes ranged from small to moderate (e.g., Cohen's $d \approx 0.41-0.65$), suggesting limited practical

superiority of supervision. Quality-of-life improvements were observed in both groups, with only the SF-36 general health domain showing significant between-group difference at 6 months ($p=0.002$). Importantly, fear of movement did not differ significantly between interventions, indicating minimal psychological modulation by supervision level. Overall, findings suggest that while supervised exercise yields slightly superior short-term outcomes, home-based exercise achieves comparable long-term efficacy when adherence is maintained. This supports the interpretation that structured non-supervised programmes may represent a cost-effective alternative without substantial loss of clinical benefit in the management of chronic low back pain (Matarán-Peñarrocha et al., 2020).

2.5 REAL-TIME ULTRASOUND AND MOTOR CONTROL TRAINING FOR NSLBP

Motor control exercises focus on retraining the activation and coordination of deep trunk muscles to improve spinal stability and restore efficient movement patterns, particularly in individuals with low back pain. The integration of real-time ultrasound imaging enhances this approach by providing visual biofeedback, allowing patients to observe and refine the activation of key stabilizing muscles such as the transversus abdominis and multifidus. Together, this combination supports more accurate motor learning and improved neuromuscular control.

The randomized controlled trial by Sarafadeen et al. (2025) investigated the effectiveness of LSE with and without real-time ultrasound imaging (RUSI) biofeedback in 90 patients with CNSLBP, using a three-arm single-blind design with an 8-week intervention and 20-week follow-up. Outcome measures included lumbar multifidus (LM) cross-sectional area (CSA) as the primary outcome, and secondary outcomes of pain intensity (NPRS), functional disability (RMDQ), and quality of life (SF-12 PCS and MCS). The study demonstrated a significant group $\times$ time interaction for all outcomes ($p<0.001$), indicating differential treatment effects across interventions. At 8 weeks, LSE with RUSI produced significantly greater LM CSA improvement compared to LSE without biofeedback (mean difference 0.81) and minimal intervention (1.79), with large effect sizes

up to 1.10. These gains were sustained at 20 weeks, with between-group differences increasing to 1.61 and 2.66 respectively, confirming durability of morphological adaptation. Both active interventions significantly reduced pain compared to control (approximately -3.3 to -4.0 NPRS points, $p < 0.001$), exceeding clinically meaningful thresholds. Similarly, functional disability improved substantially in both exercise groups (-7.1 to -7.8 RMDQ points), with large effect sizes (> 3.0) relative to minimal intervention.

Quality of life outcomes showed differential patterns, where RUSI-based LSE yielded superior mental health improvement (MCS increase of 3.63 at 8 weeks and 7.34 at 20 weeks), whereas non-biofeedback LSE showed slightly better physical health gains at 20 weeks (PCS difference -4.89). Correlation analysis revealed moderate negative associations between increases in LM CSA and reductions in pain ($r = -0.40$ to -0.50) and disability ($r = -0.38$ to -0.42) in the RUSI group, suggesting a biomechanical-functional linkage. Overall, both interventions were effective; however, RUSI-enhanced LSE demonstrated superior neuromuscular adaptation, particularly in LM hypertrophy and psychological outcomes. These findings support the clinical integration of visual biofeedback to optimize motor control retraining in CLBP rehabilitation, although long-term sustainability and resource feasibility remain considerations (Sarafadeen et al., 2025).

Taxiarchopoulos et al. (2023) conducted a prospective randomized controlled pilot trial to investigate whether real-time diagnostic ultrasound (RTUS) biofeedback enhances transversus abdominis (TrA) re-education in patients with CNSLBP compared with traditional motor control exercise (MCE) alone. The study involved 23 participants (US-guided $n=12$; control $n=11$) who completed a 7-week, twice-weekly standardized MCE programme. Outcome measures included the Numeric Pain Rating Scale (NPRS), Roland–Morris Disability Questionnaire (RMDQ), Hospital Anxiety and Depression Scale (HADS), TrA activation level via pressure biofeedback, and seven validated motor control tests. Both groups demonstrated significant within-group reductions in pain intensity, with mean worst NPRS decreasing from 7.87 to 2.61 ($p < 0.001$), indicating a clinically large

improvement (~5-point reduction). Functional disability (RMDQ) also improved markedly from 9.91 to 2.43 ($p<0.001$), reflecting substantial functional recovery post-intervention.

Psychological outcomes showed no significant change in anxiety ($p=0.460$), while depression scores improved modestly from 5.39 to 3.91 ($p=0.023$). Motor control performance and TrA activation levels improved significantly across the whole sample ($p<0.05$), indicating enhanced lumbopelvic neuromuscular control. However, two-way ANOVA revealed no significant group-by-time interactions ($p>0.05$), indicating that RTUS biofeedback was not superior to conventional tactile/verbal feedback. TrA biofeedback level progression improved ($p=0.017$), but between-group comparisons remained non-significant ($p=0.898$). Overall, both interventions were equally effective in improving pain, disability, and motor control, supporting the efficacy of MCE rather than the added advantage of ultrasound guidance in this population. The study concludes that while RTUS enhance motor learning with little superior clinical outcomes over standard physiotherapy in chronic NSLBP within this pilot sample (Taxiarchopoulos et al., 2023).

Sarafadeen et al. (2020) conducted a pilot quasi-experimental single-group pretest–posttest study to evaluate spinal stabilization exercise combined with real-time ultrasound imaging (RUSI) biofeedback in patients with chronic nonspecific low back pain (CNLBP). The intervention was administered twice weekly for 6 weeks focusing on lumbar multifidus activation, with outcomes assessed pre- and post-intervention. Primary outcome measures included lumbar multifidus muscle cross-sectional area (CSA), pain intensity (NPRS), functional disability (Roland–Morris Disability Questionnaire), and quality of life (SF-12).

Results demonstrated a significant increase in multifidus CSA from 8.15 ± 2.05 to 9.87 ± 2.97 (mean change -1.72 ± 1.65 , $P=0.010$, $d=1.03$), indicating large effect size improvement in muscle morphology. Pain intensity decreased from 6.70 ± 0.48 to 2.80 ± 1.22 (mean change 3.90 ± 1.52 , $P<0.001$, $d=2.56$), reflecting a very large clinical effect. Functional disability also improved significantly, decreasing from 8.60 ± 3.77 to 4.10 ± 1.52 (mean change 4.50 ± 3.13 , $P=0.001$, $d=1.43$). However, quality-of-life outcomes showed no significant changes in either the physical (PCS-12, $P=0.151$) or mental health (MCS-12,

$P=0.572$) components. Effect sizes across musculoskeletal outcomes ranged from large to very large, supporting strong short-term therapeutic efficacy of RUSI-guided stabilization training. The study also reported feasibility indicators, including a 75% recruitment rate and 83% retention rate, with no adverse events observed. Overall, findings suggest that RUSI biofeedback enhances motor control and multifidus activation, leading to clinically meaningful reductions in pain and disability in CNLBP. Nevertheless, the absence of a control group and small sample size limit causal inference, supporting the need for a fully powered randomized controlled trial (Sarafadeen et al., 2020).

The study by Mohammadi et al. (2017) investigated the effect of an 8-week motor control training (MCT) programme on pain, disability, and kinetic motor control variables in 30 patients with non-specific low back pain (NSLBP) and movement control impairment (MCI), compared with a normal activity group. A prospective observational design was used, with outcomes assessed pre- and post-intervention using the Roland Morris Disability Questionnaire (RMQ), Patient Specific Functional Scale (PSFS), center of pressure (CoP), ground reaction force (GRF) components, and free moment (T_z) during a flexion–extension task. Results demonstrated significant clinical improvement in the MCT group, with RMQ reduced by 39% and PSFS improved by 43% ($p < 0.001$) compared to minimal changes in controls. Kinetic analysis showed a significant reduction in anterior–posterior CoP displacement (CoPy decreased by $\sim 6.6\%$, $p = 0.02$), indicating improved postural control after training. Among GRF variables, $F_{x\min}$ decreased significantly ($\sim 13\%$, $p = 0.01$) and $F_{z\max}$ decreased ($\sim 4\%$, $p = 0.001$), while other force components showed non-significant changes.

Between-group comparisons confirmed significant improvements in RMQ, PSFS, $F_{x\min}$, and $F_{z\max}$ in favor of the MCT intervention ($p = 0.000$ – 0.016). Time-to-peak GRF variables and free moment (T_z) did not show significant post-intervention changes, suggesting limited sensitivity of temporal force parameters. Correlation analysis revealed moderately significant associations between disability reduction and $F_{z\max}$ ($r = 0.43$) and CoPy ($r = 0.44$), indicating linkage between functional

recovery and improved kinetic control. Overall, the findings support the notion that motor control training improves pain-related disability and selectively enhances sagittal-plane postural and force control in NSLBP with MCI. The authors conclude that CoPy and GRF measures are responsive biomarkers of neuromuscular adaptation following motor control rehabilitation. However, unchanged temporal and free-moment variables suggest that not all kinetic parameters are equally sensitive to clinical improvement, highlighting targeted motor adaptations rather than global biomechanical change (Mohammadi et al., 2017).

Saragiotto et al. (2016) conducted a Cochrane systematic review to evaluate the effectiveness of motor control exercise (MCE) for CNSLBP. This review was warranted due to the widespread use of MCE, which targets the deep trunk muscles to restore coordination and stability, and the availability of new clinical trials. The authors included 29 randomized controlled trials involving of 2,431 participants, primarily middle-aged adults recruited from primary and tertiary care settings. Intervention programs ranged from 20 days to 12 weeks, with session frequencies of one to five per week. The review compared MCE against other exercise forms, manual therapy, minimal intervention, and combinations of exercise with electrophysical agents (EPA). The findings revealed that MCE was not significantly more effective than other forms of exercise or manual therapy across outcomes of pain, disability, and function, with moderate to high-quality evidence supporting this conclusion. However, compared to minimal intervention, MCE demonstrated moderate improvements in pain and disability at short-, intermediate-, and long-term follow-ups, with a mean pain reduction of -12.97 points on the visual analogue scale (95% CI -18.51 to -7.42) at long-term follow-up. Similarly, functional outcomes and global recovery impressions favored MCE in this comparison. When compared with exercise plus EPA, evidence of low to very low quality suggested that MCE produced medium to large effect sizes for pain and disability reduction, particularly in the short term (MD -30.18 ; 95% CI -35.32 to -25.05). Importantly, the review reported few or no adverse events across studies. In conclusion, the review highlights that while MCE offers benefits over minimal or inactive interventions, it is not superior to other exercise modalities or manual therapies. The choice of exercise for CNSLBP may therefore depend more on

patient preference, therapist expertise, and resource considerations than on the proven superiority of any one approach (Saragiotto et al., 2016).

A single-arm cohort study was undertaken in three physiotherapy clinics in the German-speaking region of Switzerland as the primary study. 40 patients (23 men and 17 women) with NSLBP and impaired movement control received treatment. Patients were evaluated both at the beginning of therapy and just after. Exercises for lumbopelvic control and graphesthesia training to increase tactile acuity were part of the treatment. The Patient-Specific Functional Scale (PSFS) and the Roland Morris Disability Questionnaire (RMDQ) were used to assess the effectiveness of the treatment. In addition, the results of a battery of six movement control tests and lumbar two-point discrimination were evaluated. A historical control group comparable to the original research but comprising solely MCE was used to compare the findings of this cohort study. The combined training considerably improved all of the outcomes (RMDQ 2.2 points, PSFS 2.8 points, MCTB 2.02 points, and TPD 17.07 mm; all $p < 0.05$). Movement control, patient-specific functional complaints, or impairment did not change significantly across the groups as compared to the results of the historic control. According to this study's findings, combined tactile acuity and motor control training considerably enhanced the outcome when compared to the state before the intervention. In contrast to a previous study, the tactile acuity training had no further impact on the outcomes. Because allocation bias is not accounted for when historical controls are included, a randomized controlled trial is needed to confirm these findings. (Gutknecht et al., 2015).

Costa et al. (2009) conducted one of the first randomized placebo-controlled trials to evaluate the efficacy of motor control exercise (MCE) in CLBP, addressing limitations of earlier studies that lacked placebo comparisons. A total of 154 participants with nonspecific CLBP of more than 12 weeks' duration were recruited from an Australian outpatient physical therapy department and randomized to receive either 12 sessions of MCE or placebo treatment involving detuned ultrasound and shortwave diathermy over eight weeks. The trial assessed pain intensity, activity using the Patient-Specific Functional

Scale (PSFS), and global impression of recovery at two months as primary outcomes, while secondary outcomes included disability via the Roland-Morris Disability Questionnaire (RMDQ) and recurrence rates at six and twelve months. The results demonstrated that MCE significantly improved functional activity and global recovery compared to placebo. At two months, mean improvements were 1.1 points on the PSFS and 1.5 points on the global impression scale. While pain reduction was not significant at 2 or 6 months, a modest but statistically significant reduction of 1 point was evident at 12 months. Disability measured by the RMDQ improved significantly at 2 and 6 months but not at 12 months. Furthermore, 22% of participants in the MCE group achieved recovery compared with 9% in the placebo group, with a 10% reduction in persistent or recurrent pain favoring exercise. The study concluded that MCE is effective in enhancing functional ability and perceived recovery in CLBP, though its analgesic benefits are less pronounced in the short term, highlighting its value as a functional rehabilitation approach (Costa et al., 2009).

The randomized controlled trial by Akbari et al. (2008) investigated the effect of motor control exercises versus general exercises on lumbar multifidus (LM) and transversus abdominis (TA) muscle thickness, pain, and functional limitation in patients with chronic low back pain (LBP). The study included 49 participants (motor control n=25; general exercise n=24) over an 8-week intervention with twice-weekly supervised sessions. Outcomes were measured as muscle thickness measurements of Transversus Abdominis and Lumbar Multifidus, Activity limitation using the Back Performance Scale, and Pain measured using Visual Analog Scale. Results demonstrated significant within-group improvements in both interventions, with TA thickness increasing from 1.87 ± 0.63 mm to 2.39 ± 0.63 mm in the motor control group and from 1.93 ± 0.49 mm to 2.22 ± 0.47 mm in the general exercise group ($p < 0.0001$). Similarly, LM thickness increased significantly from 8.63 ± 2.37 mm to 9.69 ± 2.49 mm versus 8.83 ± 1.53 mm to 9.26 ± 1.56 mm, respectively ($p < 0.0001$). Pain reduction was more pronounced in the motor control group (VAS 7.25 ± 0.97 to 2.5 ± 1.24) compared to the general exercise group (8 ± 1.21 to 4 ± 1.54), with a significant between-group difference post-intervention ($p = 0.015$). Activity limitation (BPS

score) improved significantly in both groups ($p < 0.0001$), but no statistically significant between-group difference was observed ($p > 0.05$).

Importantly, improvement ratios for muscle thickness favored motor control training, with greater gains in TA ($p = 0.005$) and LM ($p = 0.004$) compared to general exercise. However, most functional subscales did not differ significantly between groups, indicating comparable functional recovery pathways. The findings suggest that both exercise strategies enhance neuromuscular activation and spinal stability mechanisms, but motor control training may more effectively target deep stabilizing musculature. From a clinical perspective, the results support the concept that restoration of deep trunk muscle function is associated with improved pain modulation in chronic LBP populations. Overall, while both interventions are beneficial, motor control exercises demonstrate a superior effect in pain reduction and muscle activation efficiency, although functional outcomes remain broadly comparable (Akbari et al., 2008)

2.6 LUMBAR STABILIZATION EXERCISES FOR NSLBP

Exercises are defined as the facilitation of deep spinal muscles (primarily the transversus abdominis or multifidus) at a low level, integrated into exercise, progressing to functional activity. Lumbar stabilization exercises are commonly used in the management of CNSLBP to improve the control and endurance of the deep trunk muscles that support the spine. These exercises aim to enhance spinal stability, reduce excessive segmental movement, and improve functional movement patterns, thereby decreasing pain and disability while supporting long-term recovery.

This randomized controlled trial conducted by Hafez et al. (2025) investigated the effectiveness of supervised core stability exercises versus home-based exercise programs in 30 hypertensive patients with chronic mechanical non-specific low back pain (CMNSLBP) over a 6-week intervention period. The study utilized validated outcome measures including pain intensity (Visual Analog Scale, VAS), lumbar flexion range of motion (Modified-modified Schober test), and functional disability (Oswestry Disability

Index, ODI). Both groups demonstrated statistically significant within-group improvements in all outcomes ($p < 0.001$). In Group A (supervised), VAS improved from 7.13 ± 1.07 to 5.13 ± 0.07 , while Group B (home-based) reduced from 7.13 ± 1.07 to 5.36 ± 0.02 . ODI scores decreased markedly in Group A from 45.55 ± 1.3 to 32.8 ± 0.83 and in Group B from 44.95 ± 2.0 to 33.1 ± 0.13 . Lumbar flexion ROM improved from 3.48 ± 0.49 cm to 3.95 ± 0.39 cm in Group A and from 3.45 ± 0.50 cm to 3.92 ± 0.46 cm in Group B. Between-group analysis revealed statistically significant superiority of supervised training for pain reduction ($p = 0.001$), ROM improvement ($p = 0.02$), and disability reduction ($p = 0.01$). Although effect sizes were small to moderate, supervised exercise consistently demonstrated greater clinical benefit. The findings suggest that structured supervision enhances neuromuscular control and adherence, improving outcomes in this comorbid population. However, home-based exercise still produced significant functional gains and remains a viable low-cost intervention. Overall, both approaches are effective, with supervised programs offering marginally superior therapeutic outcomes in patients with hypertensive CMNSLBP (Hafez et al., 2025).

The randomized controlled trial by Khan et al. (2024) investigated the effects of lumbar stabilization exercises (LSE) with and without jaw clenching in chronic non-specific low back pain, enrolling 80 participants over a 12-week intervention period. The primary outcome measures included pain intensity assessed using the Numeric Pain Rating Scale (NPRS), disability measured using the Roland Morris Disability Questionnaire (RMDQ), and trunk muscle endurance evaluated using a Pressure Biofeedback Unit (PBU). Both the LSE and LSETC groups demonstrated statistically significant within-group improvements across all outcomes at 6 and 12 weeks ($p < 0.001$). In the LSE group, NPRS improved by approximately 40.2% at 12 weeks (mean reduction of ~ 2.25 points), while RMDQ improved by 34.5% (mean reduction of ~ 3.20 points) and PBU showed a modest improvement of 3.2% (~ 2.03 mmHg change). Similarly, the LSETC group demonstrated greater relative improvements, with NPRS improving by 46.1% (mean reduction ~ 2.78 points), RMDQ by 35.8% (mean reduction ~ 3.78 points), and PBU by 3.2% (~ 2.03 mmHg).

Despite these clinically relevant within-group changes, between-group analysis revealed no statistically significant differences at either 6 or 12 weeks ($p > 0.05$), indicating comparable efficacy of both interventions. However, subgroup analysis revealed significantly greater improvements in younger participants (20–30 years) in the LSETC group, particularly at 12 weeks ($p < 0.05$). The findings suggest that while lumbar stabilization exercises effectively reduce pain and disability and improve endurance, the addition of jaw clenching may offer a modest neuromuscular facilitation effect. This may be explained by concurrent potentiation of trigeminal activation and neuromuscular coupling between the trigeminal and cervical-lumbar motor systems. Overall, the study supports LSE as an effective conservative management strategy for CLBP, with potential age-dependent benefits from adjunctive jaw-activation strategies (Khan et al., 2024).

The randomized controlled trial by Yalfani et al. (2023) investigated the effects of core stability exercises combined with abdominal hollowing (CSE+AH) on postural balance in women with chronic non-specific low back pain (CNSLBP), using a double-blind design with 30 participants over 8 weeks. Outcome measures included pain intensity (100 mm VAS), functional disability (Oswestry Disability Index), lumbar proprioception (joint position error via goniometry), and postural stability assessed using the Biodex Balance System (static and dynamic overall stability indices). The experimental group demonstrated a substantial reduction in pain (mean 62.33 to 29.00; $\Delta = -33.33$), compared to a smaller change in the control group (59.66 to 53.20; $\Delta = -6.46$), with statistically significant between-group differences ($P = 0.021$, $\eta^2 = 0.183$).

Disability scores also improved markedly in the intervention group (44.86 to 26.13; $\Delta = -18.73$) versus minimal improvement in controls (40.53 to 34.93; $\Delta = -5.60$), showing significant effects ($P = 0.007$, $\eta^2 = 0.237$). Proprioceptive function improved considerably, with joint position error decreasing from 7.46° to 2.14° ($\Delta = -5.32$), whereas the control group worsened (7.40° to 9.38° ; $\Delta = +1.98$), demonstrating a strong effect size ($P = 0.000$, $\eta^2 = 0.566$). Static balance improved in the experimental group (1.86 to 1.11; $\Delta = -0.75$) but deteriorated in controls (1.47 to 1.79; $\Delta = +0.32$), with significant between-group

differences ($P=0.000$, $\eta^2=0.367$). Similarly, dynamic balance showed the largest improvement (3.48 to 1.90; $\Delta=-1.58$), while the control group worsened (2.92 to 3.80; $\Delta=+0.88$), with a very large effect size ($P=0.000$, $\eta^2=0.757$). ANCOVA confirmed that all primary and secondary outcomes significantly favored the intervention group with large clinical and statistical effects. Overall, the findings suggest that combining CSE with AH effectively enhances motor control by improving deep trunk muscle activation, proprioceptive accuracy, and postural stability. The intervention demonstrates strong clinical relevance in reducing disability and restoring sensorimotor function in CNSLBP populations (Yalfani et al., 2023).

This randomized controlled trial conducted by Karacay et al (2022) investigated the effectiveness of whole-body vibration exercise (WBVE) and core stabilization exercise (CSE) in patients with chronic non-specific low back pain (NLBP) using outcome measures including Visual Analog Scale (VAS), Roland-Morris Disability Questionnaire (RMDQ), progressive isoinertial lifting evaluation (PILE), and isokinetic muscle strength (IKFPT, IKEPT, IKFTW, IKETW) over 8 weeks with a 3-month follow-up. The study demonstrated that both the WBVE and CSE groups showed statistically significant reductions in pain (VAS) and disability (RMDQ) compared with baseline ($p<0.05$), whereas the control group showed minimal change. Mean VAS scores during activity decreased significantly in both intervention groups, with greater improvement than in the control group at post-treatment and 3-month follow-up ($p<0.05$).

Functional capacity as measured by PILE showed significant within-group improvement across all groups; however, WBVE and CSE produced significantly greater mean gains than control, with between-group differences reaching statistical significance ($p<0.05$). Isokinetic strength testing revealed significant increases in trunk flexor and extensor peak torque and total work in all groups ($p<0.05$), with WBVE and CSE demonstrating superior improvements, particularly in flexion total work and extension peak torque ($p<0.05$) compared with control. Overall, the findings indicate that both WBVE and CSE are effective conservative interventions for improving pain, functional

disability, muscle strength, and lifting performance in chronic NLBP, with WBVE showing slightly greater enhancement in muscle strength-related outcomes while both interventions outperform conventional home exercise alone ($p < 0.05$) (Karacay et al., 2022).

Frizziero et al. (2021) conducted a systematic review evaluating the efficacy of core stability exercises in non-specific chronic low back pain (cLBP), synthesizing evidence from 49 studies including randomized controlled trials and systematic reviews. Across the included studies, primary outcome measures consistently involved pain intensity (Visual Analogue Scale, VAS; Numerical Pain Rating Scale, NRS), functional disability (Oswestry Disability Index, ODI; Roland–Morris Disability Questionnaire, RMDQ), and quality of life (SF-36/SF-12), alongside objective neuromuscular outcomes such as transversus abdominis and multifidus muscle thickness (ultrasound imaging), electromyographic activation patterns, and trunk muscle endurance tests. The findings consistently demonstrated that core stability training produced statistically significant reductions in pain (commonly reported VAS reductions of approximately 2–4 points or clinically meaningful percentage decreases) and disability (ODI improvements frequently ranging around 10–20%), with most studies reporting significance levels of $p < 0.05$ to $p < 0.001$.

Comparative analyses showed that core stability was superior to minimal or no intervention in almost all trials, particularly for short-term outcomes, with consistent improvements in muscle activation and morphological adaptations, such as increased core muscle thickness. When compared with general strengthening or stretching exercises, results were mixed; however, a greater proportion of studies favored core stability, especially for early pain reduction and functional gains. Importantly, combined interventions (core stability with respiratory training, NMES, or hip/gluteal strengthening) demonstrated greater therapeutic effects on pain modulation and spinal stability than isolated interventions. Overall, evidence suggests that while long-term superiority remains uncertain, core stability exercises provide robust short-term improvements in pain, disability, and neuromuscular control in cLBP populations, with outcomes strongly influenced by exercise dosage and patient adherence (Frizziero et al., 2021).

The randomized controlled trial by Hlaing et al. (2021) investigated the effects of core stabilization exercise (CSE) versus strengthening exercise (STE) in 36 patients with subacute nonspecific low back pain over a 4-week intervention period. The primary outcome was proprioception measured by joint repositioning error (JRE), while secondary outcomes included balance (SEOS, SECS, SEOUS, SECUS), muscle thickness of transversus abdominis (TrA) and lumbar multifidus (LM) via rehabilitative ultrasound imaging, and pain-related outcomes (VAS, MODQ, TSK). The CSE group demonstrated significantly greater improvement in proprioception, with a between-group mean difference in JRE of -0.30 cm ($p < 0.001$, effect size = 1.38) compared to STE. Balance outcomes also improved significantly in the CSE group, with increases in single-leg standing time under various conditions (e.g., SEOS +6.41 s, SECS +2.30 s, SEOUS +8.30 s; all $p < 0.05$). Muscle morphology showed significantly higher percentage change in TrA thickness ($\approx 13\text{--}16\%$) and LM thickness ($\approx 3\text{--}4\%$) in the CSE group compared to STE ($p \leq 0.001$). Although both groups showed pain reduction, between-group difference in VAS was not significant (mean difference -0.68 , $p = 0.093$). However, functional disability (MODQ) significantly decreased in the CSE group (-7.01 , $p = 0.010$, ES = 0.61). Fear of movement (TSK) also improved significantly (-3.02 , $p = 0.001$, ES = 0.80), favoring CSE over STE. Within-group analyses further confirmed significant improvements across most outcomes in both interventions ($p < 0.001$). Overall, the study demonstrates that CSE is superior to STE in enhancing sensorimotor control, postural stability, and functional outcomes in subacute NSLBP (Hlaing et al., 2021).

Waseem et al. (2019) conducted a single-blinded randomized controlled trial to evaluate the effectiveness of core stabilization exercises versus routine physical therapy in patients with chronic non-specific low back pain, focusing on disability reduction measured by the Oswestry Disability Index (ODI). The study included 120 participants aged 20–60 years, randomly allocated to two groups, both of which received adjunct modalities (TENS and therapeutic ultrasound) alongside exercise-based rehabilitation. Outcome assessment was performed at baseline, 2nd, 4th, and 6th weeks using the ODI, with nonparametric analyses (Mann–Whitney U and Friedman ANOVA) used to determine

within- and between-group differences. Results demonstrated a statistically significant reduction in disability over time in both groups ($p < 0.05$); however, the core stabilization group showed superior improvement. The mean reduction in ODI score was 39.44 ± 14.64 in the core stabilization group compared to 31.91 ± 12.31 in the routine physical therapy group. Post-intervention ODI values at 6 weeks were 17.02 ± 7.56 versus 25.84 ± 6.11 , respectively, indicating greater functional recovery in the experimental group. Between-group differences were statistically significant across follow-up periods ($p < 0.01$), with progressively larger mean differences from week 2 to week 6. These findings suggest that targeted activation of deep trunk musculature provides superior neuromuscular control and spinal stability compared to conventional strengthening approaches. The study also noted gender-based variations, with males responding more favorably to core stabilization than females in terms of ODI reduction. Overall, the evidence supports the clinical superiority of core stabilization exercises in reducing disability and improving functional outcomes in CLBP populations over a 6-week rehabilitation period. These results reinforce current rehabilitation models that emphasize motor control and deep muscle retraining as key components of CLBP management (Waseem et al., 2019).

A search of PubMed, CINAHL, AMED, Pedro, and The Cochrane Library from October 2006 to October 2013 was conducted via an analysis of a systematically reviewed 2008 publication. Separately choosing the research and extracting the data involved two authors. The PEDro scale was used to assess the methodological quality. Meta-analysis was done when it was necessary. The study comprised 29 reviews, 22 studies ($n = 2,258$), and 24 studies ($n = 2,359$), each providing information on the effects of therapy on pain and disability, respectively. Scores for discomfort and impairment were converted to a 0–100 scale. For long-term pain and impairment, stability exercises significantly outperformed all other therapies and the control, with mean differences of -6.39 (95% CI -10.14 to -2.65) and -3.92 (95% CI -7.25 to -0.59), respectively. Clinically speaking, the difference between the groups was negligible. There was no statistically or clinically meaningful distinction between the two types of exercise. Pain had a mean difference of 3.06 (95% CI: -6.74 to 0.63) and, disability had a mean difference of 1.89 (95% CI: -5.10 to 1.33). Strong data

suggest that the long-term effectiveness of stabilizing exercises does not outweigh that of any other vigorous exercise. Long-term follow-up studies support our present findings, and further research is unlikely to significantly alter this conclusion, given the low variability and the abundance of high-quality methodological studies now available (Smith et al., 2014).

2.7 OUTCOME MEASURES IN NSLBP

Four primary care sites were included in a study that used an observational pre/post study design to assess a 6-month multidisciplinary treatment program for people with LBP. The Patient Assessment of Chronic Illness Care questionnaire (PACIC), which was completed at baseline and 6 months after the intervention (n=132), was used to assess the in-patient experience. The majority of patients (53%), were female, on average, 57 (SD:14) years old, when descriptive and multivariable analyses were conducted using SAS version 9.3. At baseline, the mean total PACIC score was 2.6 (SD: 1.1), and at six months, it was 3.6 (SD: 0.9). According to the Minimum Clinically Relevant Difference (MCID), 62% of the participants reported an improvement in their experience receiving care. The multivariable regression models failed to uncover any significant predictors of the total PACIC change score. Further investigation of the PACIC ad's characteristics with a bigger sample is necessary due to the absence of a relationship between the predicted factors. Future research is required to determine how better patient outcomes are related to patient experience. (Gogovor et al., 2019).

According to a research study, patients' Quality of Life (QOL) is receiving significant attention due to the biopsychosocial problem known as CLBP. Self-efficacy, coping behaviors, pain, Fear, and Avoidance Belief (FAB). The study's objective is to investigate how self-efficacy, FAB, and coping mechanisms affect the quality of life of patients with CLBP. 221 individuals with CLBP are included in this study, which uses a multisite, cross-sectional approach. Structural equation modeling and stepwise multiple regression was used. A low global QOL was experienced by the CLBP patients. Self-efficacy had a direct, favorable impact on predicting the QOL for patients with CLBP (=

0.35), as well as an indirect, favorable impact on predicting QOL for patients ($\beta = 0.19$) via active coping behaviors ($\beta = 0.31$). Coping strategies are significant mediating variables that help explain the relationships between self-efficacy, FAB, and overall QOL. Self-efficacy and active coping help CLBP patients have better quality of life, while FAB and passive coping put them at risk. The medical staff suggests health education measures to increase CLBP patients' pain self-efficacy, reduce pain FAB, and change their pain coping mechanisms to improve their overall quality of life (QOL). (Du et al., 2018).

A thorough evaluation of the English-language literature was conducted by Chapman et al. (2011) for papers released between January 2001 and December 31, 2010. Measures used to assess outcomes across six distinct domains for patients with CLBP were identified through searches of electronic databases and the reference lists of key studies. To ascertain which of these metrics were most frequently mentioned in the literature and which had been verified in populations with CLBP, the titles and abstracts of the peer-reviewed literature on LBP were examined. It was discovered that CLBP was evaluated using 75 outcome measures. Only one citation prevented 29 of these outcome measures from being used, leaving 46 for study. The Short Form 36, Nottingham Health Profile, Short Form 12, and Sickness Impact Profile were the most frequently reported measures of general quality of life. The Fear Avoidance Beliefs Questionnaire, Tampa Scale for Kinesiophobia, and Beck Depression Inventory were the most frequently used assessments for psychosocial function. The most popular metrics for general quality of life were the short form 36, the Nottingham Health Profile, the Short Form 12, and the Sickness Impact Profile. The employment status/return to work, problems or adverse effects, and medication use were the most often mentioned objective metrics. The Euro-Qol 5 dimensions and Short Form 6 dimensions were the most often mentioned preference-based metrics. All questionnaire's validity, dependability, responsiveness, universality, and possible and any proprietary needs are summarized. Patients with CLBP should frequently have their outcome measures evaluated frequently. For each, the standards for validity, dependability, responsiveness, universality, and possible proprietaryness are compiled. The goals and methodology of the study, as well as the characteristics of the specific measure within the

context of CLBP, should all be taken into consideration when choosing an acceptable outcome measure (Chapman et al., 2011)

2.7.1 Numerical Pain Rating Scale (NPRS)

Adults, particularly those with chronic pain brought on by numerous conditions, can use the NPRS to assess the intensity of their pain in a single dimension. It is a segmented numerical variation of the VAS, in which the respondent chooses an integer number (0–10) that best captures the degree of discomfort. The typical structure is a horizontal bar or line with phrases representing the extremes of pain severity acting as anchors. Although there are several variations, the 11-item NPRS is the most often used.

In a cohort study, several approaches were used to assess the responsiveness properties of the NPRS in patients with LBP. While several studies have assessed the NPRS's reliability and validity, only a few have examined its responsiveness in LBP patients. By calculating the mean change, standardized effect size, Guyatt Responsiveness Index, area under the receiver operating characteristic curve, minimum clinically significant difference, and minimum detectable change, NPRS changes were assessed at 1 and 4 weeks. Using a 15-point Global Rating of Change scale, the average of the patient's and therapist's reported improvement was compared to the NPRS change from baseline to the 1- and 4-week follow-up. After both 1 and 4 weeks of therapy, the majority of patients showed clinically significant improvement. The standard error of measurement was 1.02, corresponding to a minimum detectable change of 2 points. At the conclusion of the 1- and 4-week follow-up periods, the area under the curve (AUC) was 0.72 (0.62, 0.81) and 0.92 (0.86, 0.97), respectively. Shifts of 2.2 and 1.5 points, respectively, were associated with the minimal clinically significant difference at the 1- and 4-week follow-ups. A clinically significant change that exceeds the measurement error is indicated by a 2-point change on the NPRS. (Childs et al., 2005).

The test-retest reliability, responsiveness, lowest detectable differences, and minimum clinically significant differences for a number of outcomes in patients with lumbar spinal stenosis were studied in a cohort analysis of RCTs. 55 patients with lumbar

spinal stenosis who were seeking physical therapy participated in the study; their average age was 69.5 7.9 years, and 43.1% of them were female. The PSFS, Modified Swiss Spinal Stenosis Scale (SSS), Modified ODI (MODI), and NPRS were used to measure outcomes. The ODI, SSS, NPRS, and PSFS were completed by patients at both the baseline assessment and the follow-up. Patients also completed a 15-point Global Rating of Change at the follow-up visit, which was used to determine whether they had undergone a clinically significant change. The test-retest reliability, responsiveness, minimal detectable, and minimal clinically significant differences were then assessed using the changes noticed in the MODI, SSS, NPRS, and PSFS. The ODI was the only outcome measure to demonstrate outstanding test-retest reliability, with an intraclass correlation value of 0.86 (95% confidence interval, 0.63-0.93). Other metrics fell into the fair to moderate range. The SSS symptoms subscale was 0.36, the patient specific functional scale was 1.3, the NPRS back/buttock symptoms subscale was 1.25, and the thigh/leg symptoms subscale was 1.5, and the minimum clinically significant difference for the ODI was five points. The ODI, SSS, and PSFS have sufficient psychometric properties to serve as outcome measures for patients with lumbar spinal stenosis, according to the study's findings. Confirming these results in other patient models with lumbar spinal stenosis and NSLBP, however, requires further research. (Cleland et al., 2012).

To cross-culturally adapt and validate psychometric testing, research was done. The Global Rating of Change Scale (GRCS) and the NPRS are two frequently used patient-reported outcome measures for a range of pain-related diseases, including LBP. The Hausa language does not currently have NPRS or GRCS. Following suggested principles, the Hausa versions of NPRS (NPRS-H) and GRCS (GRCS-H) were created. 120 individuals with persistent LBP were then given the final versions to test their psychometric qualities. Calculations for the interclass correlation coefficient (ICC) and the minimum detectable change in the stable group were part of the reliability evaluation. The Spearman rank correlation coefficient was used to evaluate concurrent validity and construct validity. Mean change scores, standardized effect sizes, and standard response means were used to evaluate internal responsiveness. Using the area under the curve and the least relevant

change for minor, medium, and large improvements, receiver operating characteristic curves were generated to assess the external responsiveness of the NPRS-H. The VAS for Pain and the ODI for disability were used as outcome measures. The NPRS-H and GRCS-H were successfully created. The NPRS-H (ICC = 0.95) and GRCS-H (ICC = 0.94) both showed high test-retest reliability, with minimal detectable change points of 1.0 and 1.2, respectively. Both had satisfactory reliability, validity, and responsiveness after being effectively translated into Hausa. These evaluation tools are suitable for clinical and academic usage with Hausa-speaking patients. (Ibrahim et al., 2020).

A study was carried out utilizing several approaches to identify significant improvements for back pain. This caused uncertainty over the change that is clinically significant for routinely employed outcome measures for back pain. The Roland Disability Questionnaire (0-24), the ODI (0-100), and the Quebec Back Pain Disability Questionnaire (QBPDQ) (0-100) were all used in the study. The VAS (0-100 mm) and the Numerical Rating Scale (0-10) for pain and function were also used. We searched the literature for empirical data. To establish a global consensus on clinical interpretation, experts and attendees of the VIII International Forum on Primary Care Research on LBP were also contacted. The study's methodology, techniques for estimating Minimal Important Change (MIC), and values for MIC's, which measure the improvement in a patient's clinical state, all varied widely. However, an acceptable consensus was reached following debate among the experts and workshop attendees. A 30% change from baseline for a variety of widely used back pain outcome measures may be regarded as a clinically significant improvement when comparing before and after measurements for specific individuals. The application of these metrics in clinical practice and the comparability of subsequent research was intended to be made easier by these ideas. The suggested MIC values provide a standard place to begin with additional research but are not the whole solution. (Ostelo et al., 2008).

The objective and viewpoint of a single-site cohort quasi-experimental study to assess the responsiveness of the numerical rating scale (NRS) were revealed in a study. To investigate which of the RMDQ, ODI, Pain Self-Efficacy Questionnaire (PSEQ), and PSFS

would best be able to evaluate clinically significant improvement in a group of people with persistent LBP. The effectiveness of therapy in the chronic LBP population is now assessed using a variety of patient-based outcome tools. On what constitutes a "successful" result, what constitutes a meaningful improvement or worsening, and which outcome measures best reflect the efficacy of treatment interventions for the chronic LBP population, there is disagreement, nonetheless. This study involved 63 consecutive chronic LBP patients who were sent to a back exercise and education class; 48 of 63 patients had full data. After the initial 5-week back-class intervention, five surveys were given out. Patients completed a global impression of change survey at 5 weeks as a reflection of a substantive improvement in their health. Standard Error of Measurement (SEM) and Receiver Operating Characteristic (ROC) curves were used to determine clinical improvement in the five separate questionnaires that were scored using distributional and anchor-based approaches. The Minimal Clinically Important Difference (MCID), which is the smallest difference that patients and physicians consider to be valuable, is reported for each instrument based on these techniques. According to ROC curve analysis, the PSFS and PSEQ were more sensitive than the other scales in detecting changes in chronic LBP patients after they had taken part in a back-class program. The single-center and intervention study's results, which should be read cautiously due to the small sample size and absence of any observable worsening of symptoms over time, were nonetheless. (Maughan & Lewis, 2010).

2.7.2 Oswestry Disability Index (ODI)

It is a measure of LBP disability generated from the Oswestry LBP Questionnaire, which is used by medical professionals and researchers. Jeremy Fairbank and colleagues initially published this validated questionnaire in *Physiotherapy* in 1980. The most recent edition was released in the year 2000 in the journal *Spine*. The 10 topics on the self-completed questionnaire are: pain intensity, lifting, self-care capacity, walking, sitting, sexual function, standing, social life, sleep quality, and travel capacity. There are comments explaining several probable events in the patient's life related to each issue group. The patient then evaluates the statement that most accurately describes their circumstance. Each question is given a number between 0 and 5, with the lowest score being the least level of

disability and the highest score representing severe disability. To get the index (with a range of 0 to 100), the scores for all questions answered are added together, then multiplied by two. The maximum disability that can be measured is 100, and zero is considered to be no handicap.

The goal of the suitable ODI cut-off value was revealed through a study that was evaluated. 774 suitable individuals with impairments were included in this study out of a sample of 1,394 LBP patients who were admitted to a hospital with a focus on spinal diseases. During the hospital stay, numerous clinical variables, including a numerical rating score, an ODI, and a patient's level of satisfaction, were recorded. In order to classify patients into the satisfied group and the dissatisfied group, we regarded patient satisfaction level as a crucial criterion for discharge. Through statistical research, the right criteria for choosing patients who are content with their existing status and the cut-off value of ODI were discovered. A pool of several clinical indices was used to derive statistically and logically sound predictions for the cut-off value. When identifying which patients might be discharged, the ODI at the time of discharge was the most reliable. The ODI cutoff value was 30. The ODI questions 4 and 6 were predictors. Its predictor contained dischargeable ODI for LBP inpatients with a disability. (S. won Park et al., 2014).

The ODI, the 23-item RMDQ, the SF36 physical function and bodily pain subscales, the Low Back Pain Rating Scale (LBPRS), and a numerical rating scale for pain (0-10) were all completed by 191 patients from the primary and secondary sectors of the Danish healthcare system. A 7-point transition question and a numerical significance rating scale were used to measure the clinical change. Standardized Response Mean (SRM), area under the Receiver Operating Characteristic curve (ROC), and cut-point analysis were used to operationalize responsiveness. Patients in the primary and secondary sectors who had LBP only or LBP plus/minus leg pain underwent subpopulation analysis. ODI and RMQ showed nearly comparable responsiveness in primary and secondary sector patients with leg pain (ODI: SRM = 0.4-0.9; ROC = 0.76-0.89; RMDQ: SRM - 0.3-0.9; ROC = 0.72-0.88), whereas RMQ was the most responsive instrument in primary and secondary sector

patients with LBP only (SRM = 0.5-1.4; ROC = 0.75-0.94). Patients with main and secondary sectors as well as those with LBP alone exhibited greater reactivity to the RMDQ (SRM = 1.3–1.7), but patients with leg pain showed about similar responsiveness to the RMDQ and ODI (SR = 1.3 and 1.2, respectively). ODI and RMDQ are appropriate for patients with leg pain regardless of the patient entrance point, and RMDQ is appropriate for monitoring the change in LBP-only patients. Baseline scores affect the MCID, but only in some subpopulations. When patients met the criteria for an important improvement, the baseline score had no bearing on the relative change assessed using the ODI and RMDQ. (Lauridsen et al., 2006).

At a clinic in Gujarat, India, 120 patients with non-specific LBP were enrolled in a cross-sectional study to assess the validity of the ODI-Gujarati. These patients were receiving physiotherapy. Data were gathered on the initial visit and 48 hours afterward. Patients filled out the RMDQ-Gujarati (RMDQ-G), the Visual Analog Scale-Pain (VAS-P), and the ODI-Gujarati (ODI-G) at both visits. Cronbach's alpha was used to evaluate internal consistency. High internal consistency was discovered in the Gujarati translation ($r = 0.96$). The intra-class correlation coefficient, which was used to gauge test-retest reliability, showed a very good correlation (ICC = 0.92). Concurrent validity showed a moderate association with VAS-P ($r = 0.50$), while concept validity was supported by a good correlation with RMDQ-G ($r = 0.76$). The ODI was loaded on 1 factor, as revealed by factor analysis. Gujarati speakers were able to correctly translate the ODI version 2.1a, which had outstanding psychometric features. As a result, it may be utilized for both clinical and research reasons to assess the level of impairment among the Gujarati population with LBP. (Shah & Balaganapathy, 2017).

The ODI and RMDQ in Italian were tested to see how well they responded to patients with subacute or CLBP. 179 patients completed a booklet including the ODI, RMDQ, a 0–10 NRS, and the 36-item Short-Form Health Survey (SF-36) at the start and completion of an 8-week rehabilitation program. At the completion of the program, the global perception of change scale was also finished and compressed into a dichotomous

approach Minimum Detectable Change (MDC), effect size (ES), Standardized Response Means (SRM), and anchor-based techniques (ROC curves)). The ES was 0.53 and 0.68, the SRM was 0.80 and 0.81, and the MDC for the ODI and RMDQ were 13.67 and 4.87, respectively. The ODI and RMDQ both have an area under the curve of 0.64 and 0.71, respectively, according to ROC analysis. After receiving conservative therapy for subacute and chronic LBP, the Italian ODI and RMDQ demonstrated their sensitivity in identifying clinical improvements. Our results are in line with those found in the literature, allowing for cross-cultural comparisons and igniting international research. (Monticone et al., 2012).

The ODI, RMDQ, and Quebec Back Pain Disability Scale (QDS) have all been translated into Persian. A study on cross-cultural translation and psychometric testing has also been done to examine the psychometric qualities of the Persian versions that have been produced. The original surveys were translated and cross-culturally modified in accordance with established procedures. A questionnaire booklet containing the Persian translations of the ODI, RDQ, QDS, SF-36, and VAS assessment of pain was given to a total of 100 patients with CLBP. 31 patients with persistent LBP who were chosen at random were asked to complete the second questionnaire booklet 24 hours later. The ODI, RDQ, and QDS each have a Cronbach-alpha of 0.75, 0.83, and 0.92, respectively. Excellent test-retest reliability was demonstrated by the ODI, RDQ, and QDS (intra-class correlation coefficients of 0.91, 0.86, and 0.86, respectively) ($p < 0.001$). The ODI, RDQ, and QDS in Persian are valid and trustworthy tools for assessing functional status in Persian-speaking LBP patients. They can be used in clinical settings and upcoming outcome studies in Iran since they are quick and easy to utilize (Mousavi et al., 2006).

2.7.3 Pressure Bio-Feedback (PBF)

An established mind-body approach called biofeedback uses visual or aural feedback to help people acquire control over their involuntary bodily activities. A technology (instrument) called pressure biofeedback was created by physiotherapists to help with muscle re-education and activation by monitoring movement of the neck or lumbar spine. By moving the spine, the device measures deep abdominal (core) or deep flexor contraction

around an air-filled balloon. Physiotherapists have long employed this instrument, which provides excellent results in determining pressure and, consequently, muscle contraction. Although very useful, the usage of a pressure biofeedback unit has, until recently, been restricted to the spine.

A study was done to see if employing a Pressure Biofeedback (PBF) device as a biofeedback tool to manage lumbo-pelvic motion would have any influence on center of pressure displacement and abdominal muscle activation. With and without pressure biofeedback, 18 volunteers with persistent NSLBP (age: 21.28 1.41) engaged in an active straight leg raise (dynamic postural challenge). Bilateral electromyographic abdominal muscle activity was measured together with changes in the pressure biofeedback unit and the center of pressure displacement. Valsalva maneuvers were not permitted for participants. Neither the medio-lateral center of pressure displacement nor the activity of the abdominal muscles were substantially linked with pressure fluctuation. While doing an active straight leg raise with a regular breathing pattern, there was a substantial increase in practically all abdominal muscle activity as well as a decrease in pressure variation and medio-lateral center of pressure displacement. The pressure biofeedback unit may be quite relevant when used in clinics for biofeedback purposes in patients with LBP, despite not being an indication of abdominal muscle activation or medio-lateral load transfer in the supine position (Crasto et al., 2019).

A study looked at practicing Abdominal Drawing-In Maneuver (ADIM) exercises with a biofeedback pressure device while varying the leg angle to see which was most beneficial for abdominal muscle activation. The biofeedback pressure unit's tip was positioned beneath the posterior superior iliac spine while the participants were advised to assume a supine position. Following that, the pressure was changed to 40mmHg while using the pressure gauge attached to the biofeedback pressure device. The spoken command "Start" was followed by instructions for the subjects to use the drawing-in method to boost the pressure by 10 mmHg and to keep it there. The number of seconds that the pressure was kept within a 1-2mmHg error range was recorded. The rectus abdominis,

internal and external obliques, and transversus abdominis all became more active during the abdominal drawing-in exercises as the knee joint flexion angle rose from 45° to 120°. By gradually increasing the knee joint angle while performing abdominal drawing-in exercises with a biofeedback pressure unit, trunk muscle strength can be effectively increased when the trunk stabilization exercises are performed at the same pressure to reduce damage after the acute phase of LBP. (Lee et al., 2013).

In order to determine the effects of a pressure biofeedback system (PBS)-based audiovisual trunk stabilization training on stroke patients, a study was conducted. 43 chronic stroke patients who could sit and walk on their own and had suffered a stroke more than six months prior took part in the trial. The participants were divided into two groups at random: an experimental group (n = 21) and a control group (n = 22). For six weeks, the experimental group underwent audiovisual biofeedback-based trunk stability training for 50 minutes per day, five days per week. Training in trunk stability without any biofeedback was given to the control group. The thickness of the trunk muscles was the study's main finding. Static and dynamic seated balance abilities were included in the secondary results. When compared to the control group, the experimental group's thickness of the trunk muscles, static sitting balance, and dynamic sitting balance abilities all considerably improved ($p < 0.005$). The results of the current study demonstrated that PBS-based trunk stability training improved both balancing ability and the contraction ratio of trunk muscles. The PBS allows for precise and efficient training of the trunk muscles and is a useful technique for trunk stabilization since it offers audiovisual feedback. (Jung et al., 2017).

A study was done to see how elite swimmers responded to tests of their Lumbo-Pelvic Motor Control (LPMC) when they got visual input from a sphygmomanometer. 31 competitive swimmers took part in the study. The pressure biofeedback unit's manometer experienced the greatest absolute mmHg change during four LPMC tests both with and without visual input. Visual feedback, test type, and test results all had a substantial impact on test scores ($F = 10.07$, $p = 0.002$, $\eta^2_p = 0.117$, and $\eta^2_p = 0.300$). Therefore, professional

swimmers' scores on the Active Straight Leg Raise Test (ASLR) and the Knee Lift Abdominal Test (KLAT) benefit from the visual feedback. (Solana-Tramunt et al., 2019).

In a research study, the ideal pressure variation for successfully executing the ADIM was determined. Using a Pressure Bio-Feedback Unit (PBU) during an ADIM in the supine position, the abdominal muscle thickness fluctuations and contraction ratios were investigated regarding pressure variations. Twenty healthy volunteers (12 men and 8 women) had the PBU positioned indistinguishably between their lumbar lordosis while maintaining a 40 mmHg pressure. The thickness of the TrA, internal oblique abdominal muscle (IO), and external oblique abdominal muscle (EO) were then determined using ultrasonography while the individuals did ADIM at the four random pressure changes (0,2,4 or 6 mmHg). In comparison to pressure rises of 6 mmHg, pressure increases of 0–2 mmHg led to a considerable reduction in IO and EO thickness. In comparison to pressure rises of 6 mmHg, increases of 0–2 mmHg also led to a substantial drop in the IO + EO and EO contraction ratios, while the TrA's preferred activation ratio rose. A rise of 0–2 mmHg efficiently controlled the thickness and contraction ratios of superficial muscles like IO and EO as opposed to the thickness and contraction ratio of the TrA, which had high and indirect preferential activation ratios. Therefore, workouts that encourage small increases of 0–2 mmHg from a baseline of 40 mmHg are preferred for effective ADIM as opposed to employing high PBU pressure increases. (D. J. Park & Lee, 2013).

2.8 SYNTHESIS OF REVIEW OF LITERATURE

A synthesis of the review of literature in table format is needed to organize large volumes of research in a clear, structured, and comparable way. It allows key study characteristics—such as design, population, interventions, and outcomes—to be viewed side by side, making patterns, similarities, and gaps in the evidence easier to identify. This approach improves clarity, reduces repetition, and supports critical analysis rather than descriptive reporting. It also enhances readability and helps justify the rationale for the current study by presenting consolidated evidence in a systematic format. The synthesis of the literature reviewed above from section 2.1 to 2.7 is provided in the tables given below.

Table 2.1 This table presents findings from epidemiological studies reporting the prevalence of non-specific low back pain (NSLBP) across different populations. It highlights how NSLBP is highly prevalent worldwide, affecting individuals across various age groups, occupational settings, and socioeconomic backgrounds. The studies included demonstrate variability in prevalence rates depending on study design, sample characteristics, and geographical regions. Overall, this table emphasizes that NSLBP remains a major global musculoskeletal health concern with significant burden on individuals and healthcare systems.

Table 2.2 summarizes the key determinants and risk factors associated with non-specific low back pain as reported in the literature. It includes physical, psychological, occupational, and lifestyle-related contributors such as poor posture, heavy manual work, prolonged sitting, obesity, age, stress, and low physical activity levels. The studies highlight that NSLBP is multifactorial in origin, with both modifiable and non-modifiable risk factors contributing to its onset and persistence. This table provides an overview of the complex interaction of factors influencing the development of NSLBP.

Table 2.3 presents literature related to the differential diagnosis of non-specific low back pain, focusing on conditions that must be excluded during clinical assessment. It includes studies discussing red flag conditions such as spinal infections, fractures, malignancies, radiculopathy, and inflammatory disorders. The aim is to distinguish NSLBP from specific pathological causes to ensure accurate diagnosis and appropriate management. The table also highlights commonly used clinical screening approaches and diagnostic criteria.

Table 2. 1 Prevalence of Low Back Pain / Non-Specific Low Back Pain

S. No.	Author(s) & Year	Study Design / Type	Population / Sample	Exposure / Focus	Outcome Measures	Key Findings	Limitations	Relevance to Current Study
1	Morris et al., 2018	Systematic review & meta-analysis	65 population-based African studies	Epidemiology of LBP	Prevalence estimates	Lifetime 47%, annual 57%, point 39%; high burden in Africa	High heterogeneity, recall bias, inconsistent definitions	Establishes global burden baseline
2	Fatoye et al., 2019	Systematic review (real-world data)	13 registry/health record studies (up to 7.5 million)	Real-world LBP incidence/prevalence	ICD coding, registry data	Prevalence 1.4–20%; strong variability across datasets	Coding inconsistency, underreporting, Western bias	Highlights epidemiological variability
3	Shetty et al., 2022	Systematic review & meta-analysis	97 studies (India)	National LBP prevalence	Epidemiological pooling	Overall prevalence ~48%; higher in females & rural workers	Heterogeneous methods, variable quality	Shows demographic disparities
4	Wong et al., 2022	Systematic review & meta-analysis	31,080 older adults (≥60 yrs)	Chronic NSLBP in elderly	Prevalence & risk factors	20.6% point, 36.1% annual prevalence	$I^2 > 99\%$, weak causal inference	Age-related prevalence insight
5	Abas et al., 2023	Scoping review	21 Malaysian cross-sectional studies	Malaysian LBP prevalence	Self-reported questionnaires (NMQ etc.)	Prevalence 12.4%–84.6%	No quality appraisal, heterogeneity	Direct local epidemiological relevance

Table 2. 2 Determinants of Low Back Pain

S. No.	Author(s) & Year	Study Design / Type	Population / Sample	Exposure / Focus	Outcome Measures	Key Findings	Limitations	Relevance to Current Study
1	Fay & Black, 2024	Systematic review	Adults (Nigeria & South Africa)	Occupational, psychosocial, lifestyle factors	Risk factor synthesis	Age, female gender, manual work, and stress linked to LBP	Cross-sectional dominance, heterogeneity	Strong determinant framework
2	Alotaibi et al., 2024	Cross-sectional	2000 Saudi adolescents	Lifestyle behaviors	HPLP-II, sleep quality, sedentary time	Sedentary lifestyle ↑ LBP risk by 80%; poor sleep significant predictor	Self-report bias, cross-sectional	Highlights behavioral determinants
3	Mazhak & Fister, 2025	Cross-sectional	341 Ukrainian refugees	Socioeconomic + psychological factors	PHQ-9, BAI, regression models	Pain severity linked to anxiety, SES, functional limitation ($R^2=0.517$)	Convenience sampling, female bias	Psychosocial model support
4	Rezaei et al., 2021	Systematic review	Healthcare workers	Occupational + psychosocial risks	Narrative synthesis	Work, posture, stress, obesity linked to LBP	Study heterogeneity	Occupational risk evidence
5	Orlando et al., 2023	Systematic review	>2 million patients	Hospitalisation predictors	PRISMA synthesis	Age, pain severity, predictive; psychosocial under-researched	Retrospective bias, heterogeneity	Health-system determinants
6	Tom et al., 2022	Systematic review	CLBP patients	Psychological & lifestyle factors	QoL measures (SF-36, etc.)	Fear avoidance, anxiety, sleep, inactivity worsen outcomes	Limited intervention evidence	Psychosocial determinant support

Table 2. 3 Differential diagnosis in NSLBP

S. No.	Author(s) & Year	Study Design / Type	Population / Sample	Exposure / Focus	Outcome Measures	Key Findings	Limitations	Relevance to Current Study
1	Ferdinando v et al. (2024)	Narrative Review	Not applicable (multi-source literature synthesis)	Classification of LBP into intrinsic spinal, systemic non-mechanical, and referred visceral causes	Clinical diagnostic interpretation (no standardized tools)	LBP has multiple aetiologies including degenerative, infectious, neoplastic, inflammatory, and visceral sources; emphasizes red flag screening	Narrative design, selection bias, no quantitative synthesis, lack of prevalence weighting	Provides structured framework for excluding serious pathology in NSLBP diagnosis
2	Hatice Resorlu (2023)	Narrative Review	Primary care LBP population (general)	Diagnostic approach to LBP using red flags, mechanical vs non-mechanical classification	Clinical guidelines, imaging recommendations	~85% LBP is non-specific; imaging not routinely recommended; psychosocial “yellow flags” important	No empirical validation, lacks statistical synthesis, limited evaluation of diagnostic accuracy	Supports clinical reasoning process for ruling out specific pathologies in NSLBP
3	Oliveira et al. (2018)	Clinical Practice Guidelines Overview (Systematic review of guidelines)	Primary care NSLBP patients across multiple studies	Diagnosis and management guidelines for NSLBP	Guideline-based recommendations	Imaging only if serious pathology suspected; NSAIDs, exercise, reassurance recommended; psychosocial screening emphasized	Variability across guidelines; some inconsistencies in recommendations	Strengthens evidence for exclusion-based diagnosis before physiotherapy management

4	Maher et al. (2017)	Narrative Clinical Review	General NSLBP population	Diagnostic triage and stepped-care approach	Clinical outcomes and guideline synthesis	NSLBP management focuses on ruling out serious pathology; most cases resolve spontaneously; overuse of imaging and surgery is common	Limited empirical data, guideline-dependent evidence	Highlights importance of differential diagnosis before intervention planning
5	Van Hoeven et al. (2016)	Cluster Randomized Controlled Trial	18–45 years CLBP patients in primary care (Dutch GPs)	Referral strategy for axial spondyloarthritis (axSpA) detection	Quality of life, diagnostic accuracy, referral outcomes	Early referral improves identification of inflammatory LBP (axSpA); diagnostic delay is common in CLBP	Complex design, limited generalisability, cluster bias	Demonstrates importance of identifying inflammatory causes in differential diagnosis
6	Ferreira et al. (2010)	Meta-analysis	Population-based LBP cohorts	Care-seeking behaviour and associated risk factors	Epidemiological outcomes	Care-seeking influenced by psychosocial and clinical factors; overlapping symptoms complicate diagnosis	Heterogeneity in included studies	Highlights overlap between mechanical and non-specific pain presentations

Table 2.4 summarises a range of physiotherapy interventions used in the management of NSLBP, as reported in the literature. It includes exercise therapy, manual therapy, electrotherapy, education-based approaches, and multimodal rehabilitation programs. The studies compare effectiveness in terms of pain reduction, functional improvement, and disability outcomes. This table provides an overview of evidence-based physiotherapy strategies commonly applied in clinical practice for NSLBP management.

Table 2.5 focuses on studies investigating real-time ultrasound imaging (RTUS) combined with motor control training in NSLBP rehabilitation. It highlights how visual biofeedback is used to improve activation and coordination of deep trunk muscles such as transversus abdominis and multifidus. The table also summarises outcomes related to pain reduction, muscle activation patterns, and functional recovery. Overall, it presents RTUS as a tool to enhance motor learning and patient engagement in rehabilitation.

Table 2.6 reviews literature on lumbar stabilization exercises and their role in managing NSLBP. It includes studies evaluating core strengthening, segmental stabilization, and neuromuscular control training. The findings generally report improvements in pain intensity, functional disability, and spinal stability. The table also highlights variations in exercise protocols, duration, and progression strategies used across different studies.

Table 2.7 summarizes the outcome measures commonly used to assess treatment effectiveness in NSLBP research. It includes pain scales such as the Visual Analog Scale (VAS) and Numeric Pain Rating Scale (NPRS), disability questionnaires like the Oswestry Disability Index (ODI) and Roland-Morris Disability Questionnaire (RMDQ), as well as functional and quality-of-life assessments. The table highlights the importance of standardized tools for comparing clinical outcomes across studies.

Table 2. 4 Various Physiotherapy Interventions for NSLBP

S. No.	Author(s) & Year	Study Design / Type	Population / Sample	Exposure / Focus	Outcome Measures	Key Findings	Limitations	Relevance to Current Study
1	Güzelşem me & Oksüz (2025)	Randomize d Clinical Trial	n = 74 chronic NSLBP patients	Passive (lying) vs active (functional movement) IASTM, 6 sessions/3 weeks	VAS, ODI, spinal mobility, flexibility, trunk endurance	Both groups showed significant pain and disability reduction; no major between-group difference except slightly better pain reduction in active group	No control group, short follow-up, limited long-term inference	Supports IASTM as effective short-term adjunct; no superiority of active vs passive
2	Tanveer et al. (2023)	Quasi-experimenta l study	n = 30 NSCLBP patients	KT + conventional physiotherapy vs conventional physiotherapy	NPRS/VAS , ODI	KT group showed greater pain and disability reduction than control	Small sample, non-randomized design, selection bias, short duration	KT may provide additive short-term benefit
3	Koppenaal et al. (2023)	Cluster RCT	NSLBP patients (risk-stratified sample)	Blended e-Exercise (app-based + physiotherapy) vs conventional physiotherapy	ODI, VAS, QALY, fear-avoidance	No significant improvement in pain, disability, or QALYs; reduced fear-avoidance and short-term adherence only	Higher cost, no long-term clinical advantage	Digital physiotherapy not superior to standard care
4	Akhtar et al. (2022)	Randomize d Controlled Trial	n = 36 NSLBP patients	KT + hot pack + isometric exercise vs conventional physiotherapy	VAS, RMQ	Significant improvement in pain and function in KT group (p = 0.000)	Small sample, short intervention (2 weeks), limited follow-up	Supports KT as adjunct, not standalone therapy
5	Lara-Palomo et al. (2022)	RCT Protocol	CLBP patients with trigger points	Electrical dry needling vs conventional physiotherapy	VAS, ODI, RMDQ, HADS, PSQI	No results yet; study designed to test invasive vs conventional rehab	Protocol only, no outcome data, blinding limitations	Future evidence for invasive vs exercise-based

								treatment comparison
6	Matarán-Peñarrocha et al. (2020)	Randomized Controlled Trial	n = 64 chronic NSLBP patients	Supervised vs non-supervised core stabilization exercise	VAS, ODI, RMQ, SF-36	Supervised group better short-term outcomes; long-term results similar between groups	Small clinical differences, adherence-dependent results	Confirms exercise as core treatment; supervision improves early outcomes

Table 2. 5 Real Time Ultrasound and Motor Control Training for NSLBP

S. No.	Author(s) & Year	Study Design / Type	Population / Sample	Exposure / Focus	Outcome Measures	Key Findings	Limitations	Relevance to Current Study
1	Sarafadeen et al., 2025	3-arm single-blind RCT	n=90 chronic NSLBP patients	LSE + RUSI vs LSE vs minimal intervention (8 weeks + 20-week follow-up)	LM CSA, NPRS, RMDQ, SF-12 (PCS/MCS)	RUSI group showed superior LM hypertrophy, pain reduction (~-3.3 to -4.0), and disability improvement; effects sustained at 20 weeks	Resource-intensive imaging; generalizability; cost-effectiveness unclear	Strong evidence for RUSI-enhanced motor control retraining
2	Taxiarcho poulos et al., 2023	Prospective pilot RCT	n=23 chronic NSLBP	RTUS biofeedback + MCE vs MCE alone (7 weeks)	NPRS, RMDQ, HADS, TrA activation, motor control tests	Both groups improved significantly; no between-group difference → RTUS not superior	Small sample size; pilot nature; limited power	Suggests MCE effective; RTUS adds motor learning benefit but limited clinical superiority
3	Sarafadeen et al., 2020	Single-group quasi-experimental pre-post	CNLBP patients (n not specified clearly in extract)	Spinal stabilization + RUSI (6 weeks)	LM CSA, NPRS, RMDQ, SF-12	Significant improvements in pain, disability, LM activation; large effect sizes	No control group; small sample; weak causal inference	Supports short-term efficacy of RUSI-guided stabilization
4	Mohammadi et al., 2017	Prospective	n=30 NSLBP with	8-week Motor Control	RMQ, PSFS, CoP, GRF,	Improved disability (-39%), better postural/kinetic	No randomization; limited kinetic	Confirms motor control training improves

		observational study	movement control impairment	Training vs normal activity	free moment	control (CoP, GRF changes)	sensitivity in some variables	functional biomechanics
5	Saragiotto et al., 2016	Cochrane systematic review	29 RCTs, n=2,431 CLBP patients	Motor control exercise vs exercise, manual therapy, minimal care	Pain (VAS), disability (RMDQ), global recovery	MCE not superior to other exercise/manual therapy; better than minimal intervention	Heterogeneity; variable study quality; inconsistent protocols	Establishes MCE as effective but not superior intervention
6	Gutknecht et al., 2015	Single-arm cohort + historical control	n=40 NSLBP patients	Motor control + tactile acuity training	PSFS, RMDQ, movement control tests, TPD	Significant improvements vs baseline; no added benefit of tactile training over MCE alone	Allocation bias; no RCT design; historical control limitations	Suggests added sensory training may not enhance outcomes
7	Costa et al., 2009	Placebo-controlled RCT	n=154 CLBP patients	MCE vs placebo (detuned ultrasound + sham therapy)	PSFS, RMDQ, pain, global recovery	MCE improved function and recovery; modest long-term pain benefit	Blinding limitations; moderate pain effect	Strong evidence supporting functional benefits of MCE
8	Akbari et al., 2008	Randomized controlled trial	n=49 CLBP patients	Motor control exercise vs general exercise (8 weeks)	TA & LM thickness (US), VAS, BPS	MCE superior in pain reduction and deep muscle activation	Short follow-up; limited functional differentiation	Supports deep stabilizer muscle activation via MCE

Table 2. 6 Lumbar Stabilization exercises for NSLBP

S. No.	Author(s) & Year	Study Design / Type	Population / Sample	Exposure / Focus	Outcome Measures	Key Findings	Limitations	Relevance to Current Study
1	Hafez et al., 2025	RCT	n=30; chronic mechanical NSLBP with hypertension; 6 weeks	Supervised core stability vs home-based exercise	VAS, Modified Schober test, ODI	Both groups improved significantly ($p<0.001$). Supervised group showed greater reductions in pain, disability, and improved ROM ($p\leq 0.02$).	Small sample size; short duration; comorbid hypertensive population limits generalizability	Supports supervised stabilization as more effective than unsupervised programs
2	Khan et al., 2024	RCT	n=80; chronic NSLBP adults; 12 weeks	Lumbar stabilization exercises $\pm$ jaw clenching	NPRS, RMDQ, Pressure Biofeedback Unit (PBU)	Both groups improved significantly ($p<0.001$). No significant group difference ($p>0.05$), but slight advantage in subgroup with jaw activation	No overall between-group superiority; subgroup effect limits general conclusions	Confirms effectiveness of LSE; adjunct strategies may have limited additional benefit
3	Yalfani et al., 2023	Double-blind RCT	n=30; women with CNSLBP; 8 weeks	Core stability + abdominal hollowing	VAS, ODI, joint position error, Biodex balance system	Strong improvements in pain, disability, proprioception, and balance ($p\leq 0.021$ to $p<0.001$), large effect sizes	Small sample; gender-specific sample limits external validity	Strong evidence for motor control and proprioceptive improvement with stabilization
4	Karacay et al., 2022	RCT	Chronic NSLBP patients; 8 weeks + 3-month follow-up	Whole-body vibration vs core stabilization vs control	VAS, RMDQ, PILE, isokinetic strength	Both WBV and CSE improved pain, disability, and strength significantly ($p<0.05$). WBV slightly superior in strength outcomes	Limited long-term mechanistic explanation; multiple intervention arms complicate interpretation	Confirms CSE effectiveness and functional gains comparable to advanced modalities

5	Frizziero et al., 2021	Systematic review (49 studies)	cLBP populations across studies	Core stability exercise interventions	VAS, NRS, ODI, RMDQ, SF-36, EMG, ultrasound	Consistent short-term improvements in pain (2–4 VAS points) and disability (10–20% ODI). Mixed long-term superiority vs general exercise	Heterogeneity of studies; variable protocols and follow-up durations	High-level evidence supporting core stabilization as effective conservative management
6	Hlaing et al., 2021	RCT	n=36; subacute NSLBP; 4 weeks	Core stabilization vs strengthening exercises	JRE, balance tests, ultrasound muscle thickness, VAS, MODQ, TSK	CSE significantly improved proprioception, balance, muscle thickness, disability, fear of movement ($p<0.05$ – 0.001). Pain improvement not significantly different	Short duration; small sample; subacute population limits chronic extrapolation	Demonstrates superiority of CSE in sensorimotor control and functional outcomes
7	Waseem et al., 2019	Single-blinded RCT	n=120; chronic NSLBP; 6 weeks	Core stabilization vs routine physiotherapy	ODI	Significant disability reduction in both groups, but greater improvement in CSE group ($p<0.01$). Mean ODI reduction: 39.44 vs 31.91	Adjunct modalities (TENS, US) confound pure exercise effect; short follow-up	Strong clinical evidence for superiority of stabilization over conventional therapy
8	Smith et al., 2014	Systematic review & meta-analysis	2,258–2,359 participants across studies	Stabilization vs other exercises/control	Pain (0–100 scale), disability measures	Stabilization slightly superior long-term, but clinically negligible differences; no major advantage over other exercise types	High heterogeneity; small clinical effect sizes; methodological variation	Suggests stabilization is comparable to other exercise forms in long-term outcomes

Table 2. 7 Outcome Measures in NSLBP

S. No.	Author(s) & Year	Study Design / Type	Population / Sample	Exposure / Focus	Outcome Measures	Key Findings	Limitations	Relevance to Current Study
1	Chapman et al., 2011	Systematic review	CLBP literature (2001–2010), multiple studies	Review of outcome measurement tools	SF-36, NHP, SF-12, SIP, ODI, RMDQ, pain scales	Identified 75 outcome measures; ODI, RMDQ, SF-36 most widely validated; strong variability in selection	Heterogeneity of included studies; older evidence base	Establishes core outcome domains for CLBP measurement selection
2	Ostelo et al., 2008	Consensus study	Experts + LBP patients	Clinical significance of change in outcomes	ODI, RMDQ, VAS, NPRS, QBPDQ	~30% change from baseline considered clinically meaningful improvement	Expert-based consensus, not purely empirical	Guides interpretation of clinical improvement in NSLBP outcomes
3	Childs et al., 2005	Cohort (responsiveness study)	LBP patients undergoing therapy	Physical therapy intervention	NPRS	2-point change represents clinically meaningful improvement; high responsiveness (AUC up to 0.92)	Short follow-up duration (1–4 weeks)	Supports NPRS as sensitive pain outcome measure
4	Cleland et al., 2012	Cohort study	55 lumbar spinal stenosis patients	Physical therapy assessment	ODI, NPRS, SSS, PSFS	ODI showed highest test-retest reliability (ICC 0.86); moderate responsiveness across tools	Small sample; specific to stenosis not NSLBP	Supports ODI reliability in spinal disorders

5	Lauridsen et al., 2006	Cohort study	LBP patients (primary & secondary care)	Clinical assessment over time	ODI, RMDQ	RMDQ more responsive in LBP-only; ODI better in leg pain cases	Subgroup variability limits generalization	Helps select ODI vs RMDQ depending on symptom profile
6	Monticone et al., 2012	Clinical trial (rehabilitation cohort)	179 subacute/CLBP patients	8-week rehabilitation program	ODI, RMDQ, SF-36, NRS	Both ODI and RMDQ sensitive to change (SRM ~0.8); MCID established	Single-country sample (Italy)	Confirms responsiveness of disability scales in rehab outcomes
7	Ibrahim et al., 2020	Cross-cultural validation study	120 chronic LBP patients	Translation/validation of NPRS-H & GRCS-H	NPRS, GRCS, VAS, ODI	High reliability (ICC 0.95 NPRS); strong validity and responsiveness	Language-specific limitation (Hausa population)	Supports NPRS reliability across populations
8	Du et al., 2018	Cross-sectional study	221 CLBP patients	Psychosocial assessment	QOL scales, FAB, self-efficacy measures	Self-efficacy improves QOL; FAB negatively impacts outcomes	Cross-sectional design limits causality	Highlights psychosocial outcome measures importance
9	Crasto et al., 2019	Experimental / RCT	NSLBP & stroke patients	Pressure biofeedback training	EMG, pressure feedback, trunk muscle thickness	Biofeedback improves trunk activation & control but not direct muscle activation indicator	Small sample; device-specific variability	Supports use of biofeedback in motor control assessment

Overall, the evidence consistently demonstrates that NSLBP is a highly prevalent global condition affecting up to 80% of individuals across the lifespan, with substantial variability across regions, populations, and methodological approaches. Prevalence is notably higher in occupationally exposed groups, older adults, and populations with poor lifestyle behaviors, while determinants are strongly multidimensional, encompassing biomechanical, psychosocial, occupational, and lifestyle factors. Across studies, psychosocial elements such as fear-avoidance, anxiety, and stress appear to play a critical role alongside physical risk factors such as posture, manual handling, and sedentary behavior. However, most available evidence is derived from cross-sectional designs, limiting causal inference and long-term predictive validity. Therefore, NSLBP should be conceptualized as a biopsychosocial condition requiring integrated assessment and management approaches rather than a purely structural musculoskeletal disorder.

2.9 CONCEPTUAL FRAMEWORK FOR MOTOR CONTROL EXERCISES IN CNSLBP

2.9.1 Population

CNSLBP is the most common type of chronic back characterized by its location (lumbosacral region) and duration (symptoms lasting more than 12 weeks). It is a condition where no specific pathology (vertebral fracture, infection, malignancy, or radiculopathy) can be identified as the cause of pain and discomfort. CNSLBP is heterogeneous in nature with the presence of physical, cognitive, and psychosocial components that coexist to complicate management. NSLBP is a leading cause of Disability-Adjusted Life Years (DALYs) and productivity loss globally and is particularly prevalent among individuals in the prime working-age group of 25–55 years. The Global Burden of Disease (GBD) study group (Vos et al., 2017) reported that LBP was the leading cause of years lived with disability, surpassing ischemic heart disease and diabetes. In the absence of structural abnormalities on clinical examination or imaging, chronic NSLBP patients experience significant functional impairment and reduced health-related quality of life associated with altered neuromuscular function and dysfunctional core muscles.

2.9.2 Effects of Motor control exercises in CNSLBP

Motor control is one of a major impairment frequently seen in patients with NSLBP and involves deficits in the activation and coordinated control of the deep trunk musculature (local trunk stabilizers), including the TrA and the lumbar multifidus. These muscles function to stabilize the spine and provide segmental support during movement and other dynamic activities. Hodges and Richardson (1996) first reported that patients with LBP exhibit delayed and weak activation of the TrA following limb movement of a limb, indicating a lack of appropriate anticipatory postural adjustments. They were later found to be weak in patients with CNSLBP even in the absence of limb movements (Reis et al., 2006; Tsao et al., 2008). It was also established that these neuromuscular deficits are not limited to the timing of isolated muscles but also extend to larger motor control patterns, including impaired proprioception, trunk kinematics, and a failure to use deep stabilizers in preference to the superficial ones (Silfies et al., 2005; Van Dieën et al., 2019b).

MCE's are a set of specific interventions designed to directly address these deficits by retraining proper and coordinated activation and control of deep trunk muscles. This is different from traditional forms of strengthening exercises, where the emphasis is on high loads and repetition of general movements involving global muscle groups. In MCE, there is a specific focus on the retraining of the timing and synergy of deep local trunk muscles to improve overall spinal control and stability in various postures and movements. The rationale for this approach is that enhanced motor control would improve spinal stability, reduce aberrant loading and nociceptive input, and ultimately reduce pain sensitivity. It is supported by the biopsychosocial models of chronic pain that consider the presence of central and peripheral adaptations leading to hyper excitability and neuroplasticity changes that underpin the continued perception of pain even after tissue healing. Motor control training is an example of the application of these neuroplasticity changes as motor learning involves high repetition, task specificity, and feedback to promote motor re-organization and altered sensorimotor cortical maps that have likely gone through maladaptive changes in the setting of chronic pain (Tsao et al., 2008; Tsao & Hodges, 2008).

2.9.3 Stages of Motor Relearning

The motor relearning process involved in MCE can be understood as occurring in three overlapping phases. According to the Fitts and Ponsor Model (1967), the stages of motor learning are classified into 3 stages as follows,

Stage 1 – Cognitive stage of learning, in which the learner is concerned with understanding the nature of task to be carried out, which requires high degree of cognition such as attention, and characterized by slow and inconsistent movements that require cognition to improve the activity

Stage 2 – Associative stage of learning, in which the learner begins to refine the learned skills and is characterized by quite efficient movements and needs less cognition.

Stage 3 Autonomous stage of learning in which a low degree of attention is required for the performance, and it is characterized by accurate and consistent movements

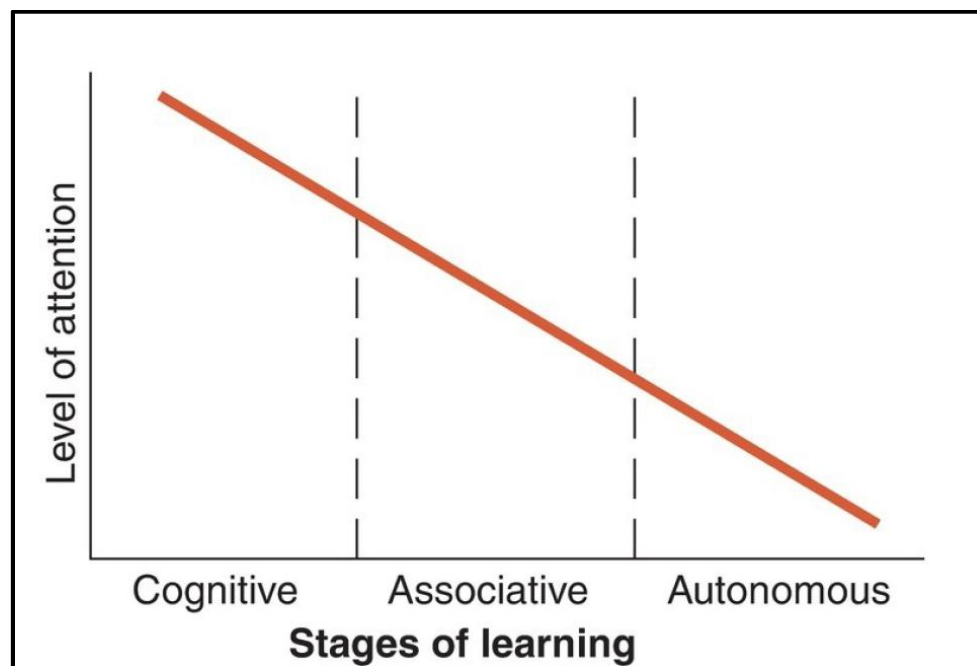


Figure 2.1 Changing attentional demands associated with the 3 stages of motor skill acquisition.

The first phase is the initial one where patients are made aware of their dysfunctional motor control patterns. This may be supplemented with education about the anatomy and function of the deep core stabilizers of the trunk. This is the cognitive or awareness phase where abnormal motor patterns may be identified using biofeedback (real-time ultrasound imaging) or surface electromyography (EMG) and then attempted to be corrected using selective activation of the TrA or multifidus. Several studies have demonstrated the ability of patients with NSLBP to learn to activate these muscles independently with visual or tactile cues provided, which is the basis of the subsequent phase of the intervention (Vasseljen & Fladmark, 2010).

The second phase involves the use of active co-contraction of trunk muscles in a coordinated manner to achieve various positions and movements in a progressive and supervised manner. This is the associative phase, which is more focused on the practice of movement rather than isolated muscle activation. These are further used as the basis for core-strengthening exercises such as bridging, four-point kneeling, or trunk rotation with the requirement of trunk co-contraction and focus on motor quality and symmetry. Motor retraining is focused on with high repetition under supervision to allow for consolidation of neuromuscular patterns. This phase also focuses on motor variability and the controlled co-contraction of the deep and superficial muscles which must be modulated for adaptive spinal control during more complex movements in dynamic settings. Randomized trials have supported this approach, as Ferreira et al. (2007) showed that MCE had significantly better outcomes in pain reduction and functional recovery compared to general exercise or manual therapy (Ferreira et al., 2007).

The third and final phase is focused on the application of motor control principles and selective recruitment of core muscles in high-level functional activities and movements. This is the autonomous phase where the goal is to ensure that the trunk muscles are stable during functional movement in a variety of challenging positions and settings that may be the usual activities of daily living and work tasks that caused re-aggravation in NSLBP patients. The patient is exposed to an increased balance demands,

unstable surfaces, and further challenges to the trunk in the context of the applied motor control strategies during this phase. Higher compliance with the completion of all three phases of MCE's has been shown to be associated with lower recurrence and better long-term outcomes in follow-up when compared with standard physiotherapy management (Costa et al., 2009).

Mechanistically, motor control exercise training results in several benefits, including improved neuromuscular coordination and postural adjustments, reduced loading on passive spinal structures, central modulation of pain via descending inhibitory pathways, and psychological factors. Neuroplasticity changes are thought to be the underlying basis for several of the above changes, including facilitation of motor unit recruitment, conditioned inhibition of nociceptive input, and cognitive as well as affective components of central sensitization. A detailed assessment performed by the researcher along with the help of reliable measurement tools to evaluate the pain level, functional activity and core muscle strength. Not all patients may have the same impairment pattern and a tailor made approach should be used for each patient. The MCE program must be individualized for each patient and exercise selection must be based on specific motor deficits observed thorough the assessment done by the researcher. Furthermore, the selected exercises should also adhere to principles of motor learning, and the cycle should be repeated with emphasis on learning and skill acquisition for the required movements, tasks, and activities.

Patient factors, such as psychosocial factors are significant determinants of outcomes in MCE, as they are major contributors to the chronicity of pain. Factors such as pain catastrophizing, low self-efficacy, and fear of movement have been shown to be highly prevalent in patients with NSLBP and are likely to significantly impact the motor relearning process. The role of cognitive-behavioral interventions, reassurance, and education is often necessary to help provide a proper framework and environment to support motor retraining. MCE can form the core of a biopsychosocial model of care, along with exercise and patient education as part of a comprehensive intervention program for

NSLBP as recommended by recent guidelines (National Institute for Health and Care Excellence, 2016; Hauk, 2017).

A systems-level approach would also emphasize on the role of MCE as an intervention modality for NSLBP, given to several favorable features. It is a relatively low-cost and low-risk approach that can be delivered by appropriately trained physiotherapists in the primary care or community settings. This aligns with recent trends towards active rehabilitation and away from passive treatment modalities. MCE also offers significant benefits to the community and can be delivered through structured exercise sessions in workplace settings or community initiatives. This could help improve outcomes, reduce healthcare costs, and lead to improved population-level function and reduced absenteeism in the workplace.

2.9.4 Conceptual Framework Model

A simple model that can be visualized to consolidate this conceptual framework is shown in Figure 2.2. This is a cyclical loop that begins with the onset of NSLBP, which leads to motor control dysfunction. This is characterized by changes in the activation and timing of muscles, altered proprioceptive and kinematic patterns, and movement behaviors that are maladaptive in nature. MCE is an intervention, comprising a graded set of specific exercises delivered in the three phases described previously along with cognitive and educational components. The outcome of this process is improved neuromuscular control, reduced pain, and functional improvement, which further lowers the risk of recurrent episodes and the perpetuation of the cycle.

Evidence to support this model and the role of MCE in NSLBP is growing. A systematic review and meta-analysis by Saragiotto et al. (2016) reported that motor control exercise was more effective than minimal intervention in reducing pain and disability in adults with CNSLBP (Saragiotto et al., 2016). Long-term follow-up studies have also shown sustained benefits, with improvements in functional outcomes up to 12 months following intervention (Macedo et al., 2012). This provides a basis for routine incorporation of MCE into clinical practice.

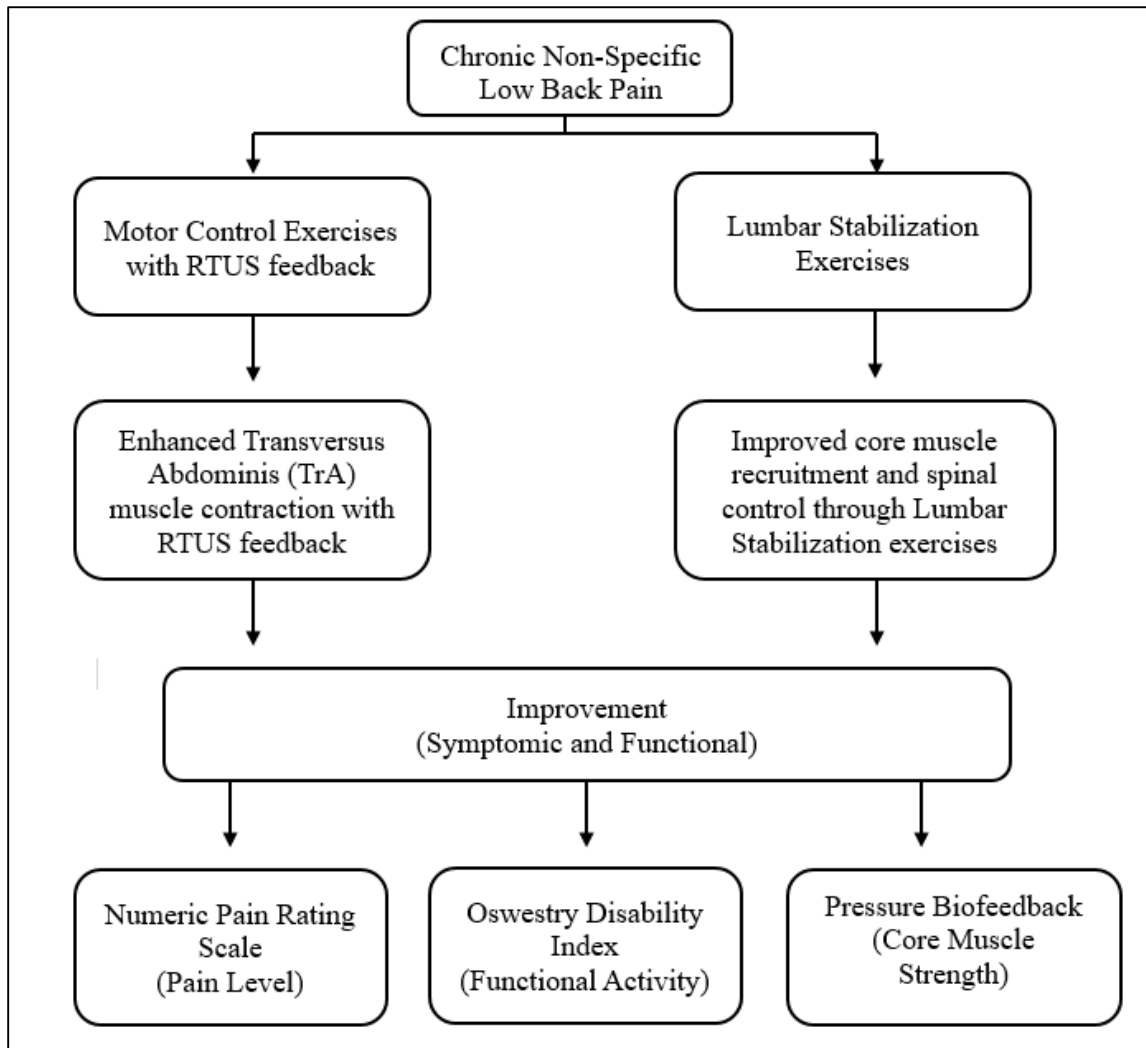


Figure 2.2 Conceptual Framework diagram

There are also several limitations and challenges that must be overcome to optimize the effect of MCE in NSLBP. One of these is the significant heterogeneity and variability in the prescription of MCE across different clinicians and settings. This leads to inconsistent outcomes and underpins the need for standardized protocols and guidelines. Another major challenge is patient engagement in the early phases of treatment when progress is slow, and work effort appears low. Digital tools, tele-rehabilitation approaches, and wearable sensors have the potential to help improve adherence and provide real-time biofeedback and motivation, thereby further improving outcomes.

In conclusion, MCE's can be defined as a physiologically sound and effective clinical intervention for patients with CNSLBP. The above conceptual framework provides a structured approach to the different aspects of this intervention, including its pathophysiological basis, structure of the intervention, and underlying pathways of effect. The rationale for targeting specific deficits and co-contraction of deep trunk muscles in the core-strengthening exercise program has been explained along with a motor relearning process. This is also supported by current evidence and guidelines as MCE provides a biologically informed and relevant intervention that is applicable to a wide patient population. There is also potential for standardization and future directions may include the development of personalized MCE protocols using artificial intelligence and digital health integration, especially in multi-disciplinary settings. With clinician training and an emphasis on appropriate assessment and prescription, MCE is an evidence-based clinically relevant intervention to reduce pain, improve function, and restore patients to work and activity after NSLBP.

CHAPTER III

RESEARCH METHODOLOGY

This study assessed the impact of motor control training when provided along with real-time ultrasound biofeedback in managing pain and disability associated with NSLBP.

3.1 RESEARCH DESIGN

In this study, a quasi-experimental design with parallel group structure was adopted to evaluate the effect of motor control exercises with real-time ultrasound biofeedback on pain, functional activity and core muscle strength in patients with CNSLBP. A quasi-experimental design helps to enhance ecological validity and ensure findings are generalizable to real-world practice settings. Quasi-experimental designs are used when an intervention and a comparison group are present, but certain features of a true randomized clinical trial, such as probability-based sampling or complete blinding, cannot be fully implemented due to practical and ethical constraints (Grimshaw et al., 2000; Handley et al., 2018). Randomized controlled trials are considered the gold standard for causal inference, but a quasi-experimental design was deemed most appropriate given constraints on randomization, while still allowing robust comparisons using matched or naturally occurring groups. For these reasons, a quasi-experimental research design was selected for this research.

3.2 SAMPLING

3.2.1 Sampling Frame

The target population for this research study was the patients who has been diagnosed with CNSLBP with the following inclusion-exclusion criteria

3.2.2 Eligibility Criteria

- **Inclusion Criteria**

To enhance homogeneity and ensure objective inclusion criteria, participants were aged 35–55 years, verified through official identification, and had a physician-confirmed diagnosis of CNSLBP lasting at least 12 weeks, based on clinical examination and medical records. Physical examination confirmed impaired TrA activation, using PBF measurements, with no evidence of neurological deficits, as determined by a standard physiotherapy examination.

- **Exclusion Criteria**

Certain exclusion criteria were applied to eliminate confounding factors. Individuals with radiating pain to the limbs, tingling sensations, or paresthesia were excluded, as these symptoms could indicate underlying neuropathic conditions. Furthermore, participants with a history of recent spinal fractures, spinal stenosis, spondylolisthesis, spondylitis, or spondylolysis were deemed ineligible. Those with significant spinal deformities were also excluded, ensuring that the study focused solely on non-specific back pain rather than structural pathologies. The researcher also excluded patients taking any CNSLBP-related medications. To enhance safety, participants with unstable medical conditions, as perceived by the primary researcher, were excluded. These included individuals with severe hypertension, uncontrolled diabetes, cardiovascular disorders, or neurological deficits. Additionally, those with mental instability were excluded to ensure participants could understand instructions and comply with the intervention protocols.

3.2.3 Sample Size Determination

Sample size determination is critically important in clinical trials research as it ensures that the study has enough participants to detect a clinically relevant treatment effect with sufficient statistical power (Mukti, 2025). A properly calculated sample size avoids two major issues: underpowered studies, which may miss true effects and yield inconclusive or misleading results, and overpowered studies, which could waste resources and time and expose more participants to inferior treatments unnecessarily.

According to Di Francesca Botta (2023), a senior biostatistician, “Underpowered trials risk ethical concerns as they expose participants to risks without a fair chance of answering the research question, while overpowered trials may identify statistically significant but clinically irrelevant differences”. Using the appropriate sample size also optimizes resource use and helps achieve valid, reliable, and generalizable research outcomes (Suresh & Chandrashekara, 2012).

In this study, the sample size was estimated using OpenEpi-info 7 software – an online sample size calculator (<https://www.openepi.com/SampleSize/SSMean.htm>) in which the sample size for the method of comparing two means was selected as the study having 2 groups and comparing the means of dependent variables.

The alpha value of 0.05 and the power of 80 % using the effect size as 0.5 (Domholdt, 2000) and the mean values of the Oswestry disability Index (Unsgaard-Tøndel et al., 2010) were used to calculate the sample size. The posttest mean values and standard deviation of Motor Control Exercise (12.78 ± 7.62) and General Exercise (17.75 ± 9.63) of the Oswestry Disability Index was used to determine the sample size, as shown in Figure 3.1, 3.2 and 3.3

Table 2.
Estimated Mean (SD) Unadjusted Scores for the Different Treatment Groups and Times and Estimated Mean (95% Confidence Interval) Baseline-Adjusted Group Differences After Intervention as Given by the Mixed Linear Models^a

Variable	Mean Outcomes			Adjusted Mean Group Differences ^b			p ^c
	MCE Group (n=36)	GE Group (n=36)	GE Group (n=37)	MCE Group vs SE Group	SE Group vs GE Group	MCE Group vs GE Group	
Pain^d							
Current							
Baseline	3.31 (1.42)	3.61 (1.75)	3.30 (1.74)				
2 mo	1.76 (1.54)	2.34 (2.26)	2.73 (2.32)	0.27 (-0.73 to 1.27)	0.71 (-0.55 to 1.97)	0.97 (-0.08 to 2.03)	.39
1 y	2.01 (1.94)	2.70 (2.22)	2.66 (2.03)	0.39 (-0.65 to 1.44)	0.27 (-0.83 to 1.36)	0.66 (-0.34 to 1.66)	.42
Strongest							
Baseline	6.25 (1.99)	6.39 (2.32)	6.22 (2.03)				
2 mo	4.09 (2.08)	4.80 (2.41)	5.26 (2.74)	0.57 (-0.57 to 1.71)	0.63 (-0.74 to 2.01)	1.20 (-0.03 to 2.44)	.15
Disability^e							
Baseline	19.44 (8.38)	22.28 (11.22)	20.84 (9.43)				
2 mo	12.78 (7.62)	16.18 (10.88)	17.75 (9.63)	0.56 (-4.25 to 5.37)	3.02 (-2.44 to 8.47)	3.58 (-0.47 to 7.63)	.21
Trunk flexion^f							
Baseline	11.94 (10.86)	15.00 (10.86)	8.78 (10.86)				
2 mo	7.44 (10.86)	11.13 (10.86)	7.57 (10.86)	0.6 (-3.2 to 4.4)	2.7 (-1.3 to 6.6)	3.3 (-0.7 to 7.3)	.23
FABQ, physical activity^g							
Baseline	7.75 (5.35)	8.78 (5.82)	9.22 (5.03)				
2 mo	7.31 (4.22)	6.76 (5.37)	8.60 (5.14)	-1.58 (-4.00 to 0.84)	1.40 (-1.25 to 4.05)	-0.18 (-2.42 to 2.07)	.41
FABQ, work^h							
Baseline	13.19 (9.18)	14.46 (10.26)	13.53 (9.64)				
2 mo	11.86 (9.47)	12.72 (9.46)	12.44 (8.88)	-0.40 (-3.01 to 2.01)	0.65 (-2.70 to 4.00)	0.25 (-2.74 to 3.24)	.93

^a MCE group received low-level motor control exercises, GE group received high-level strength exercises, and GE group received general exercises.
^b Group-wise comparison of estimated mean posttest scores adjusted for baseline, control estimates. Positive value indicates greater improvement in time.

Figure 3. 1 Mean and standard deviation values used determine sample size.

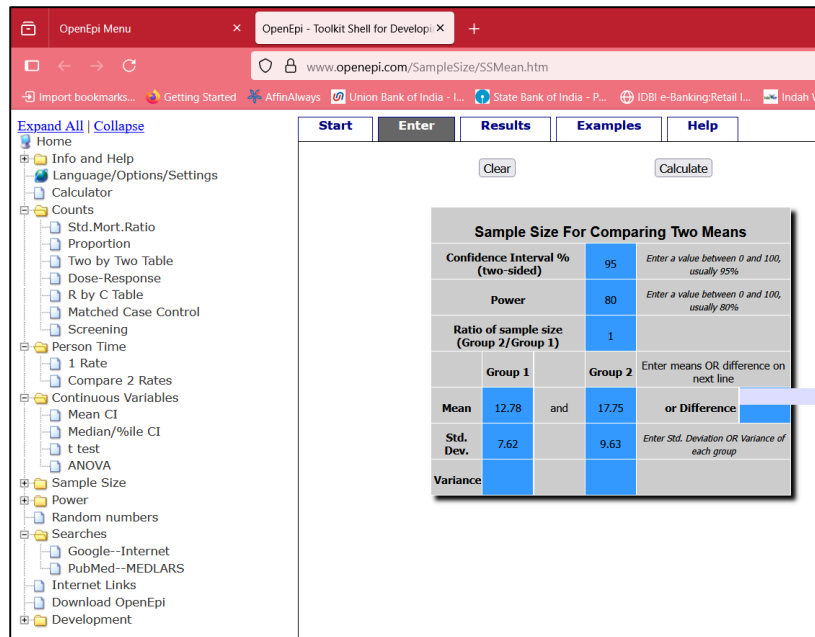


Figure 3. 2 Mean and standard deviation values keyed in openepiinfo software to determine sample size.

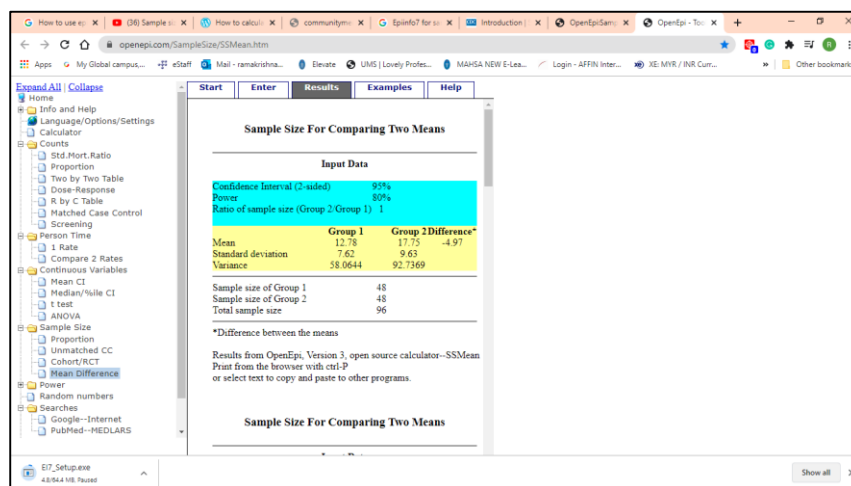


Figure 3. 3 Sample size determined by Openepi info using the Mean and standard deviation values provided.

Based on the calculation by openEpiinfo – online sample size calculator – a total of 96 samples (having 48 samples in each group) was determined.

3.2.4 Sampling Design and Grouping Allocation

- **Sampling Design**

In this research study, the researcher recruited the subjects using consecutive sampling, in which subjects who met the specific inclusion criteria were recruited for the study. Consecutive sampling is a non-probability sampling technique in which every subject who meets the eligibility criteria is included consecutively until the required sample size is achieved. It is widely used in clinical and healthcare research because it ensures that no eligible participant is omitted during the recruitment period (John W. Creswell, 2018).

Consecutive sampling is recommended in clinical research because it minimizes selection bias by ensuring that every eligible subject is approached (Acharya et al., 2013). It is also practical and feasible for hospital-based studies, as participants are presented in a natural time-bound sequence (Etikan, 2016).

- **Grouping Allocation**

Sequential Allocation: In this study, the participants were allocated to the control and experimental groups sequentially. The random allocation sequence was followed to ensure unbiased assignment of participants to study groups. This approach involved allocating participants into either the control group (Group 1) or the experimental group (Group 2). The allocation ratio was 1:1, ensuring an equal number of participants in each group. To enhance the reliability and integrity of the randomization process in group allocation of the participants, the grouping allocation was done by the physiotherapist working at MAHSA Physio Clinic following a fixed sequence:

- 1st eligible participant → Control group
- 2nd eligible participant → Experimental group
- 3rd eligible participant → Control group
- 4th eligible participant → Experimental group
- ...and so forth until the required sample size was achieved.

This method ensured an equal distribution of participants between groups but lacked the unpredictability of true randomization.

Allocation Concealment Mechanism: In this study, assignment of participants to groups was not influenced by the researcher, as it was done by an external person (physiotherapist of MAHSA Physio Clinic) who is not involved in the study. This method of sequential assigning participants to the control and experimental groups was followed as the patient flow with the specific diagnosis is from few specific clinics. As allocation followed a predictable alternating sequence, no allocation concealment procedures (such as sealed opaque envelopes or central randomization) were used.

Implementation: Clinicians from the clinic/hospital identified and diagnosed patients with CNSLBP, who were referred to MAHSA Physiotherapy Clinic. Upon referral to the physiotherapy department, each patient was received by the physiotherapist, who assigned them to a group according to the alternating sequence. The researcher conducted routine physiotherapy assessment along with the outcome measures and assigned the participant to the treatment group, assigned by the clinic physiotherapist.

3.3 ETHICAL CONSIDERATIONS

Ethical approval is considered crucial for any research involving humans as it ensures the rights of participants' safety, well-being, and integrity during the process of research (Beauchamp, 2019; World Medical Association, 2013).

3.3.1 Informed Consent

The core component of ethical consideration is the "INFORMED CONSENT", where the participants of the research are fully informed about the whole research process in writing, which includes:

- Purpose of the research study
- Procedures applied in the study (treatment)
- Risks and benefits of the study

- Right to withdraw from the study
- Privacy and confidentiality

The informed consent form explaining all the above which was provided to the participants in this research study, is provided in Appendix I.

3.3.2 Ethical Approval

The ethical approval for this research study was obtained from the University Research Review Committee (RRC) of MAHSA University, Malaysia (www.mahsa.edu.my), where the researcher is working. The Ethical approval number for this study is MAHSA/RRC-FHSS/10-17(25). The Ethical approval letter is provided in Appendix II

3.4 STUDY SETTINGS & PREPARATION FOR THE STUDY

The study was conducted in outpatient settings at two distinct physiotherapy clinics affiliated with MAHSA University, located in Kuala Lumpur and Bandar Saujana Putra. These locations were selected for their accessibility to individuals with CNSLBP and their integration with primary care facilities where such cases are managed. This dual-clinic setup enhanced the diversity of the sample population while maintaining consistency in intervention delivery. Both clinics had the necessary infrastructure to support the study's interventions.

A routine physiotherapy assessment using an assessment Form along with the measurement of research instruments was carried out by the researcher (Appendix III)

3.5 RESEARCH INSTRUMENTS / OUTCOME MEASURES

- **Pain Intensity:** Measured using the Numeric Pain Rating Scale (NPRS), a validated tool for assessing pain levels in adults. This unidimensional scale ranges from 0 to 10, where 0 represents no pain, and 10 represents the worst imaginable pain. The participants of this study were provided with the NPRS scoring sheet, and the participants rated their pain at baseline (pre-intervention) and after completing the 8-week intervention (post-intervention). The printed NPRS scoring sheet given to subjects is shown in Figure 3.4

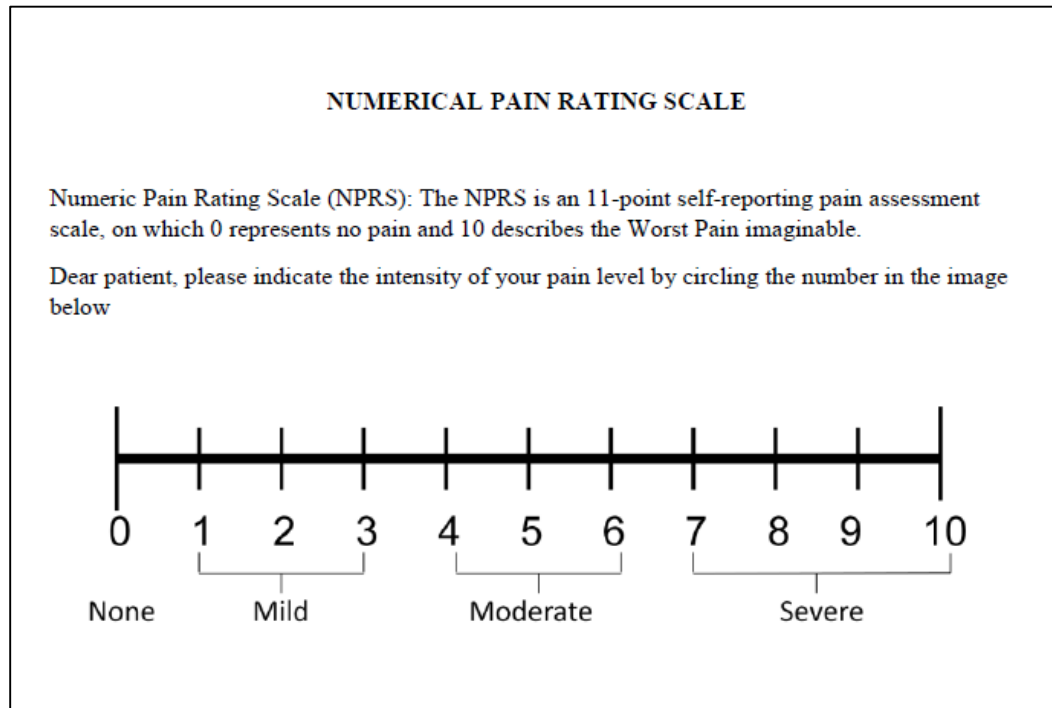


Figure 3. 4 Numerical Pain Rating Scale

- **Functional Activity:** Assessed using the Oswestry Disability Index (ODI), a widely recognized tool for evaluating functional activity/functional impairment due to LBP. The participants of this study were provided with the ODI scoring sheet. This questionnaire includes 10 sections, each with 6 response options scored from 0 to 5, where higher scores indicate greater disability. The total score is converted to a percentage, providing a clear representation of the level of functional disability. ODI assessments were conducted at baseline and after the 8-week intervention period. The outcome measure is provided in Appendix III.
- **Core muscle strength (CMS):** In this study, CMS was assessed using Stabilizer – Pressure Biofeedback device (Chattanooga) This biofeedback device is a reliable and accessible tool commonly used in physiotherapy practice (Figure 3.5).



Figure 3. 5 Stabilizer – Pressure Biofeedback device to measure Core Muscle Strength
manufactured by Chattanooga group

The assessment was conducted individually with each participant in a quiet, controlled environment to minimize distractions. Participants were instructed to lie in a prone position on a firm surface bed; the 3-chamber pressure cell of the Chattanooga pressure biofeedback system was placed horizontally under the abdomen, and the screws were tightened. The pressure cells were inflated to 40 mm/Hg using the provided pump. Once properly placed, the cuff was inflated to a baseline pressure of 70 mmHg (Figure 3.6).

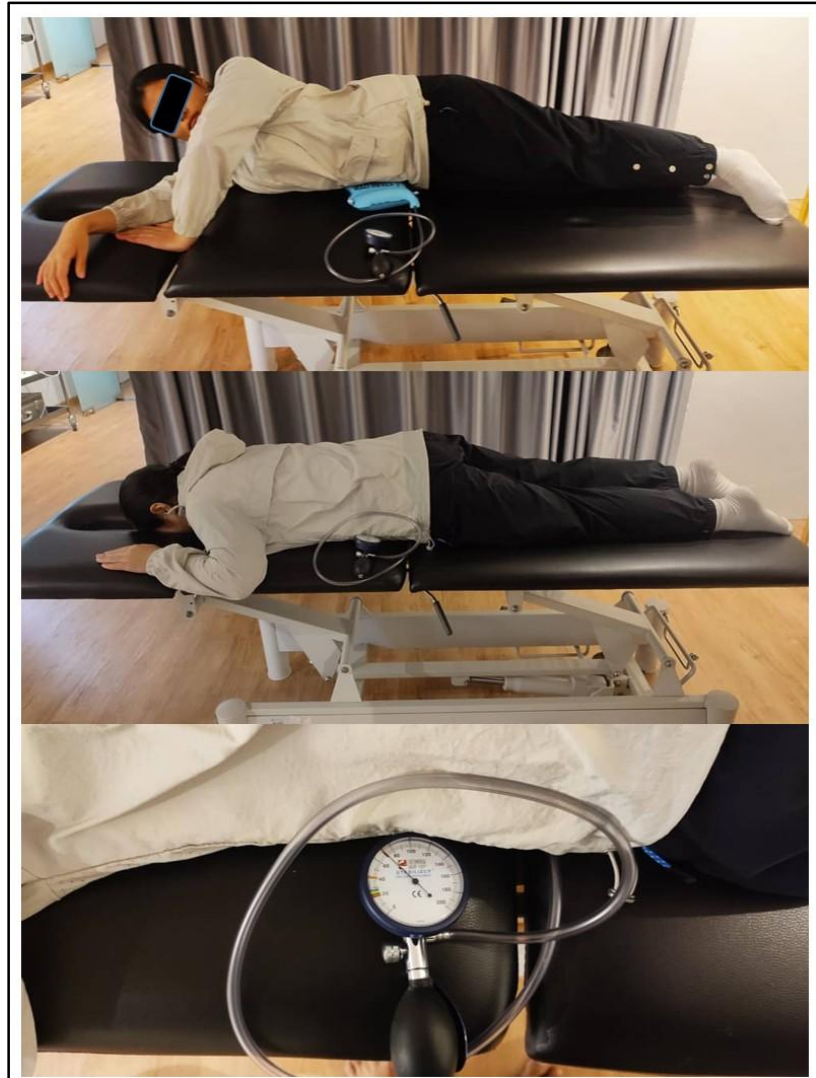


Figure 3. 6 Placement of Pressure Bio-Feedback cuff for core muscle strength readings

Participants were then asked to perform a gentle abdominal drawing-in maneuver, which involved pulling the lower abdomen inward toward the spine without any visible movement of the pelvis, hips, or ribcage. They were specifically instructed not to hold their breath, tilt the pelvis, or contract the gluteal or upper abdominal muscles. To ensure test reliability and prevent compensatory movements that could influence the readings, the examiner consistently provided verbal cues and visual monitoring throughout the procedure. Participants practiced the maneuver briefly before the actual measurement was taken, allowing them to familiarize themselves with the expected movement and reduce

the likelihood of error during the test. Each participant was asked to perform three repetitions of the abdominal drawing-in maneuver. During each repetition, the pressure reading on the stabilizer biofeedback was carefully observed on the gauge. A successful contraction was identified by a sustained pressure drop of more than 10 mmHg from the baseline of 70 mmHg, maintained for 10 seconds, as shown in Figure 3.7.

Any deviation above or below this range, or any observable compensatory movement, was noted as an incorrect performance. Between each repetition, a 30-second rest period was provided to avoid muscle fatigue and ensure consistent effort. The final reading for analysis was determined by considering the best of the three attempts that met all the test criteria without compensatory actions. This method enabled a fair assessment of core muscle engagement and control while minimizing the influence of fatigue and learning effects. All measurements were recorded by the researcher to maintain consistency across participants. The participants in this study were assessed with this measurement at baseline (pre-intervention) and after completing the 8-week intervention (post-intervention). The documentation of this outcome measure is provided in Appendix III.



Figure 3. 7 Readings in Pressure Bio-Feedback device during Abdominal Drawing In Maneuver (ADIM) reflecting Core muscle strength

3.6 INTERVENTIONS / PROCEDURE OF THE STUDY

The proposal of this research work was presented to the panel of State of the Art (SOTA) Seminar on 29th September 2016, and feedback was received in November 2016. The corrections recommended by the panel were implemented, and the revised synopsis of the received proposal, along with the actions taken report, was submitted to the Research and Development cell (RDC) during December 2016. The letter of Candidacy dated 7th March 2017 (Appendix No. IV) for the approval of research entitled, “Effects of Motor Control

Exercises on Pain, Functional Activity and Core Muscle Strength in CNSLBP” was received from RDC of Lovely Professional University (LPU). After obtaining approval for the research proposal from LPU, the research proposal was presented to the Research Review Committee (RRC) of MAHSA University, Malaysia, where the researcher is working and an ethical approval letter (dated 29 September 2017) obtained from RRC (Appendix No. II). The preliminary research works for the recruitment of subjects started after obtaining the ethical approval letter. Subject recruitment begins from 2nd October 2017 and the subjects were randomly allocated to the control and experimental groups. The Consort flow of the research methodology is provided in Figure 3.8, and this consort flowchart (Figure No. 3.8) was adopted from CONSORT 2025 Statement: updated guideline for reporting randomised trials (Hopewell et al., 2025).

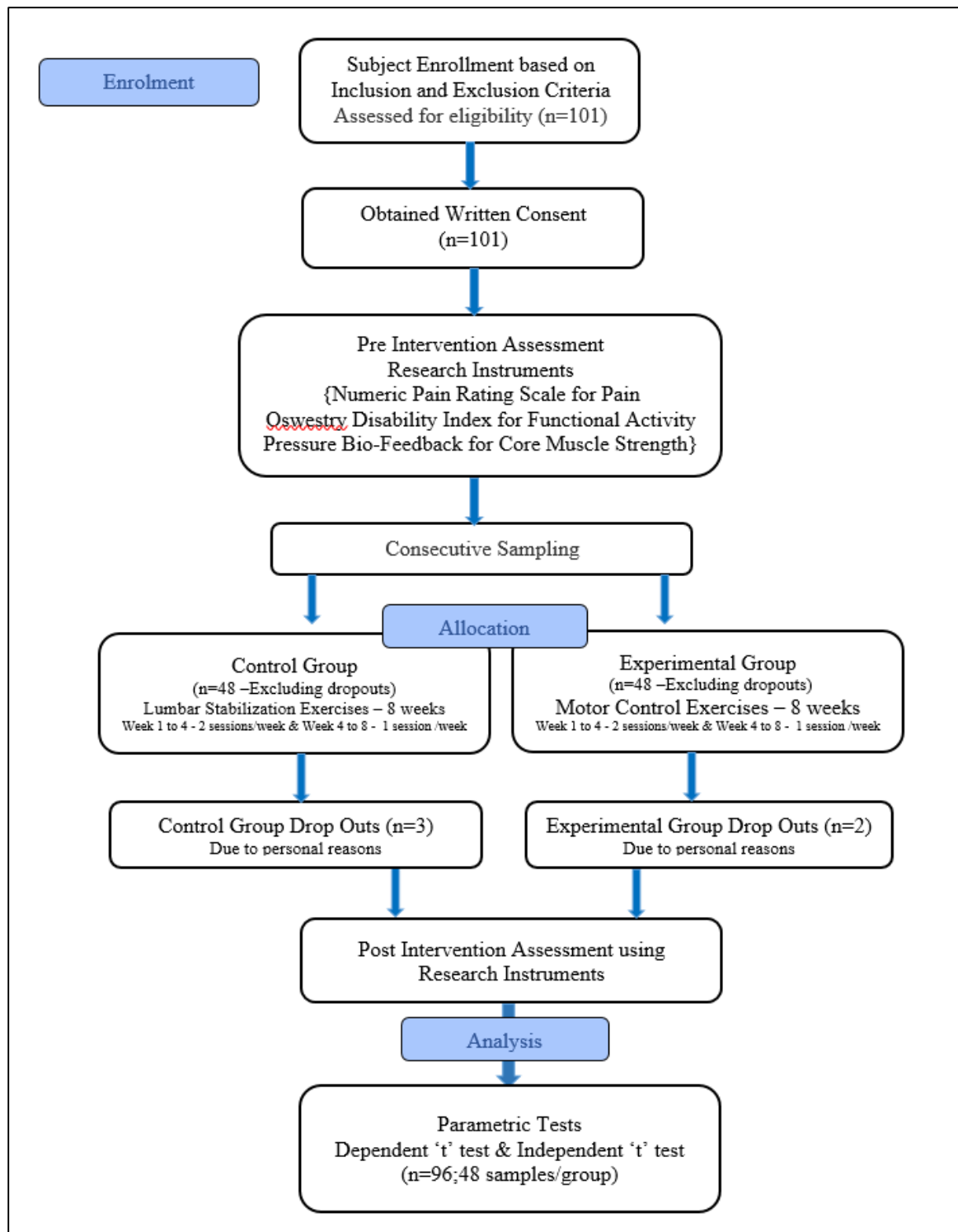


Figure 3. 8 CONSORT flow of the research work

3.6.1 Control Group

The control group received a standard lumbar stabilization exercise program, a commonly used intervention for managing CNSLBP. This program was also delivered over an 8-week period, comprising 12 sessions of 30 minutes each. Participants attended twice-weekly sessions during the first four weeks and once-weekly sessions during the subsequent four weeks. The focus of the lumbar stabilization exercises was to enhance core strength and spinal stability. The LSE exercise intervention was conducted by the principal researcher of this study, who is a trained physical therapist. This was done to ensure uniformity in instruction, correct exercise performance, and adherence to the intervention protocol by all the participants. These exercises used manual guidance and verbal cues to ensure proper technique aimed at activating the deep trunk muscles, including the transversus abdominis, multifidus, and obliques but without the use of real-time ultrasound biofeedback. Instead, therapists relied on palpation and visual observation to assess muscle engagement and provide corrective feedback.

Exercises in this group included abdominal hollowing, pelvic tilts, and bridging. As participants progressed, the complexity of exercises increased by introducing dynamic elements like the use of arm or leg movements while maintaining a stable core, followed by exercises on a gym ball along with the arm or leg movements. The researcher also emphasized controlled breathing and postural alignment during exercises to maximize their effectiveness. While the control group intervention lacked the precision of real-time biofeedback, it followed evidence-based protocols for lumbar stabilization. This allowed for a fair comparison between the experimental and standard approaches to managing CNSLBP. The findings provided valuable insights into the added benefits of biofeedback in improving motor control and reducing pain and disability. The details of the Lumbar Stabilization exercises prescribed for the subjects of the control group are provided in Tables 3.1 to 3.3 and in Figures 3.9 and 3.10

Table 3. 1 Lumbar stabilization exercises protocol for weeks 3 & 4

Week & Sessions	Exercise	Position	Instructions	Dosage (Reps/Sets/Hold)	Progression
Week 1 – 2 2 sessions / week	Transversus Abdominis (TrA) Activation	Supine lying position and Abdominal Drawing In Exercises	Gently draw in lower abdomen (“abdominal Drawing In Maneuver – ADIM) without breath-holding;	10 reps × 10 sec hold X 7 – 10 sets (30 minutes)	Progress to TrA contraction with unilateral pelvic bridging
	TrA strengthening	Supine lying position - ADIM exercises including unilateral pelvic bridging activity	Gently draw in lower abdomen and maintain contraction of TrA and lift unilateral pelvis while holding TrA contraction		Progress to TrA contraction with bilateral pelvic bridging
	TrA strengthening	Supine lying position and Abdominal Drawing In Exercises including pelvic bridging activity	Gently draw in lower abdomen and maintain contraction of TrA and lift bilateral pelvis while holding TrA contraction		Progress to Multifidus strengthening
	Multifidus Strengthening	Prone lying position and lifting upper trunk with elbow support and progress to hand support	Gently lift up the upper trunk with elbow and forearm support and later with hand support only		Progress to further strengthening of TrA

Table 3. 2 Progressive lumbar stabilization exercises protocol for weeks 3 & 4

Week & Sessions	Exercise	Position	Instructions	Dosage (Reps/Sets/Hold)	Progression
Week 3 – 4 2 sessions / week	TrA strengthening progression	Supine lying position and lifting upper trunk with elbow support without holding the breath	Gently lift up the upper trunk with elbow and forearm support	10 reps × 10 sec hold X 7 – 10 sets (30 minutes)	Progress to further stabilization exercises of Multifidus and TrA together
	TrA strengthening progression	Supine lying position and lifting upper trunk with upper limb stretched forward in front without holding the breath	Gently lift up the upper trunk without arm support as much as possible without bending the neck forward		
	Multifidus and TrA strengthening	Prone lying position and with feet and elbows in contact with ground (plank)	Gently lift up the whole body from the bed with the support of elbows and feet		
	Oblique's strengthening	Side lying position with body aligned in straight line	Gently lift up the body sideways with elbow and feet support		

Table 3. 3 Dynamic Lumbar Stabilization Exercises protocol for weeks 5 to 8

Week & Sessions	Exercise	Position	Instructions	Dosage (Reps/Sets/Hold)	Progression
Week 5 – 8 1 session / week	Multifidus and TrA strengthening	Four point kneeling position with arm, legs and trunk aligned accordingly	Gently straighten the right upper limb and left lower limb aligning to the trunk like a superman position	10 reps × 10 sec hold X 7 – 10 sets (30 minutes)	Progress to dynamic stabilization exercises using gym ball for further strengthening of Multifidus obliques and TrA together
	Multifidus, Oblique's and TrA strengthening	Sitting on a Gym ball and straightening the knee with trunk aligned accordingly	Gently straighten the right / left knee with maintaining an erect spine and without losing the balance		
		Leaning on a gym ball placed between trunk and wall.	Gently squat by pressing the gym ball using the trunk against the wall without losing balance		
		Four point kneeling position over a gym ball with arm, legs and trunk aligned accordingly	Gently straighten the right / left knee with maintaining an erect spine and without losing the balance		



Starting Position



Bilateral Pelvic Bridging Exercise



Unilateral Pelvic Bridging Exercise



Upper Trunk Raise with Elbow Support



Upper Trunk Raise without Elbow Support



Bilateral leg Raise



Prone on Elbows Exercise



Prone on Hands Exercise



Prone Planks Exercise

Figure 3. 9 Static Lumbar Stabilization Exercises prescribed for the subjects with Chronic Non-Specific Low Back Pain.

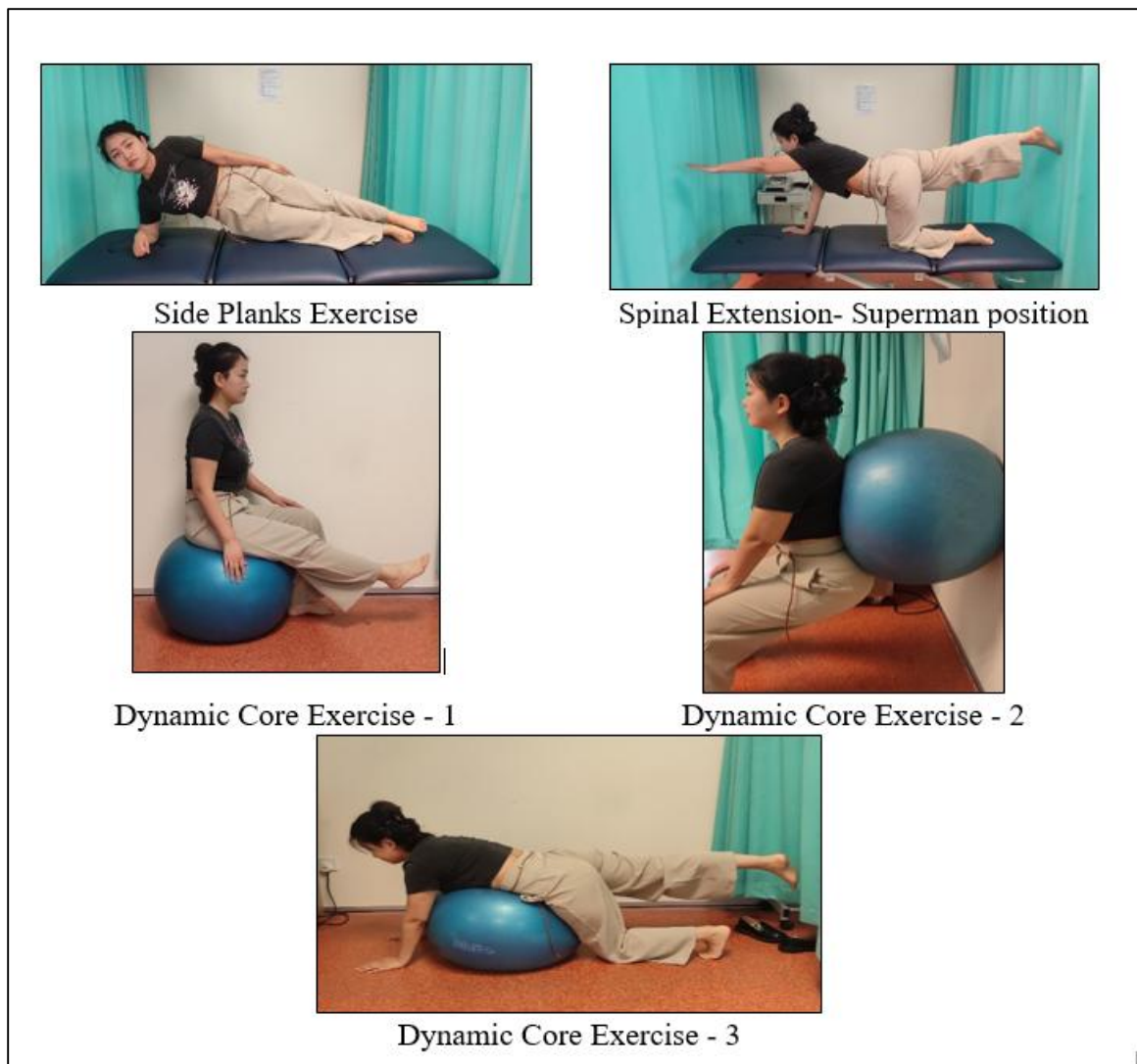


Figure 3. 10 Dynamic Lumbar Stabilization Exercises prescribed for the subjects with Chronic Non-Specific Low Back Pain (Brumitt et al., 2013)

3.6.2 Experimental Group

The experimental group participated in a tailored motor control exercise (MCE) program, supplemented by real-time ultrasound biofeedback. The intervention aimed to enhance motor control and alleviate pain and functional impairments associated with CNSLBP. This program was delivered in two progressive stages over an 8-week period, with participants attending 12 sessions (twice per week for the first four weeks, followed by once per week for the final four weeks). Each session lasted approximately 30 minutes.

The real-time ultrasound (RTUS) feedback intervention was administered by the principal researcher, who is trained in musculoskeletal ultrasound imaging and has completed structured training in the use of RTUS for rehabilitation purposes. To ensure consistency, all intervention sessions were conducted by the same researcher throughout the study following a protocol on therapeutic exercise for lumbopelvic stabilization using RTUS feedback.

The real-time ultrasound equipment used was a Full Digital Ultrasonic Diagnostic System (Version: V1. 3, PN NO.: WED-20-11050410E) manufactured by Shenzhen Well.D Medical Electronics Co. Ltd (Figure 3.11). Software version: V1.6.1.2 with standard musculoskeletal settings, and the Curvilinear Convex Array (C3-1/60R/3-5 MHz) probe, with a maximum detect depth of +/- 190 mm, was used to provide real-time feedback to the patient. A hypoallergenic, water-based ultrasound gel was used as a coupling medium. A frequency of 5 MHz was set to visualize the Transversus Abdominis muscle while using the above-mentioned equipment. The registration certificate of the Real Time Ultrasound equipment machine used in this study is provided in Appendix V



Figure 3. 11 Full Digital Ultrasonic Diagnostic System manufactured by Shenzhen Well.D Medical Electronics Co. Ltd used in this research

Participants were positioned in supine lying with a pillow under the knees with ultrasound probe placed in transverse orientation on the anterolateral aspect of the abdominal wall halfway between the iliac crest and inferior border of rib cage as shown in Figure 3.12 and the ultrasound probe moved until the best possible visualization of the lateral abdominal muscles as shown in Figure 3.13 and Figure 3.14 and once visualization of TrA achieved participants were instructed to do Abdominal Drawing in Maneuver exercise and to watch the ultrasound screen with therapist's guidance (researcher of this study) to receive real-time feedback about the contraction of their TrA.

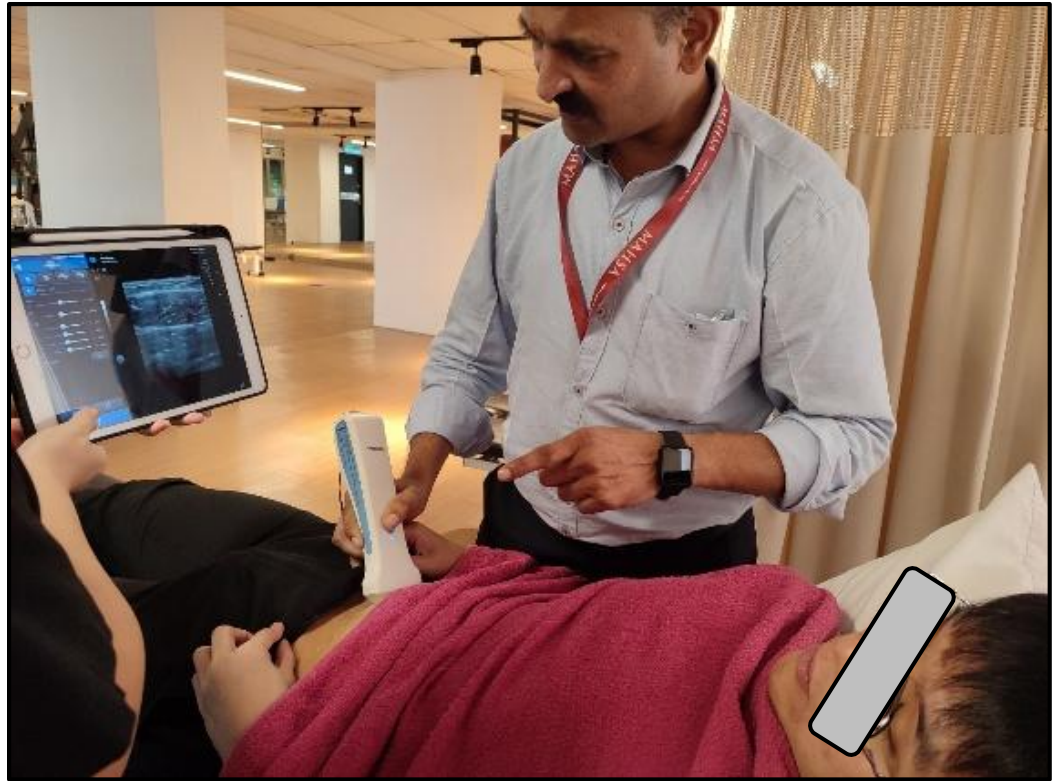


Figure 3. 12 Placement of Ultrasound Probe on the Lateral Abdominal Wall to have a better visualization of Transversus Abdominis contraction

The execution of the MCE program involved 2 stages, in which the duration of Stage 1 was the first 4 weeks (weeks 1 – 4), which comprises the cognitive and associative phases of MCE, whereas the Stage 2 is the next 4 weeks (weeks 5 – 8), which comprises the autonomous phase of MCE. Each participant progressed through the stages according to specific criteria that should have been met in each stage.



Figure 3. 13 Bio Feedback training for Transversus Abdominus Muscle using Real Time Ultrasound Bio Feedback

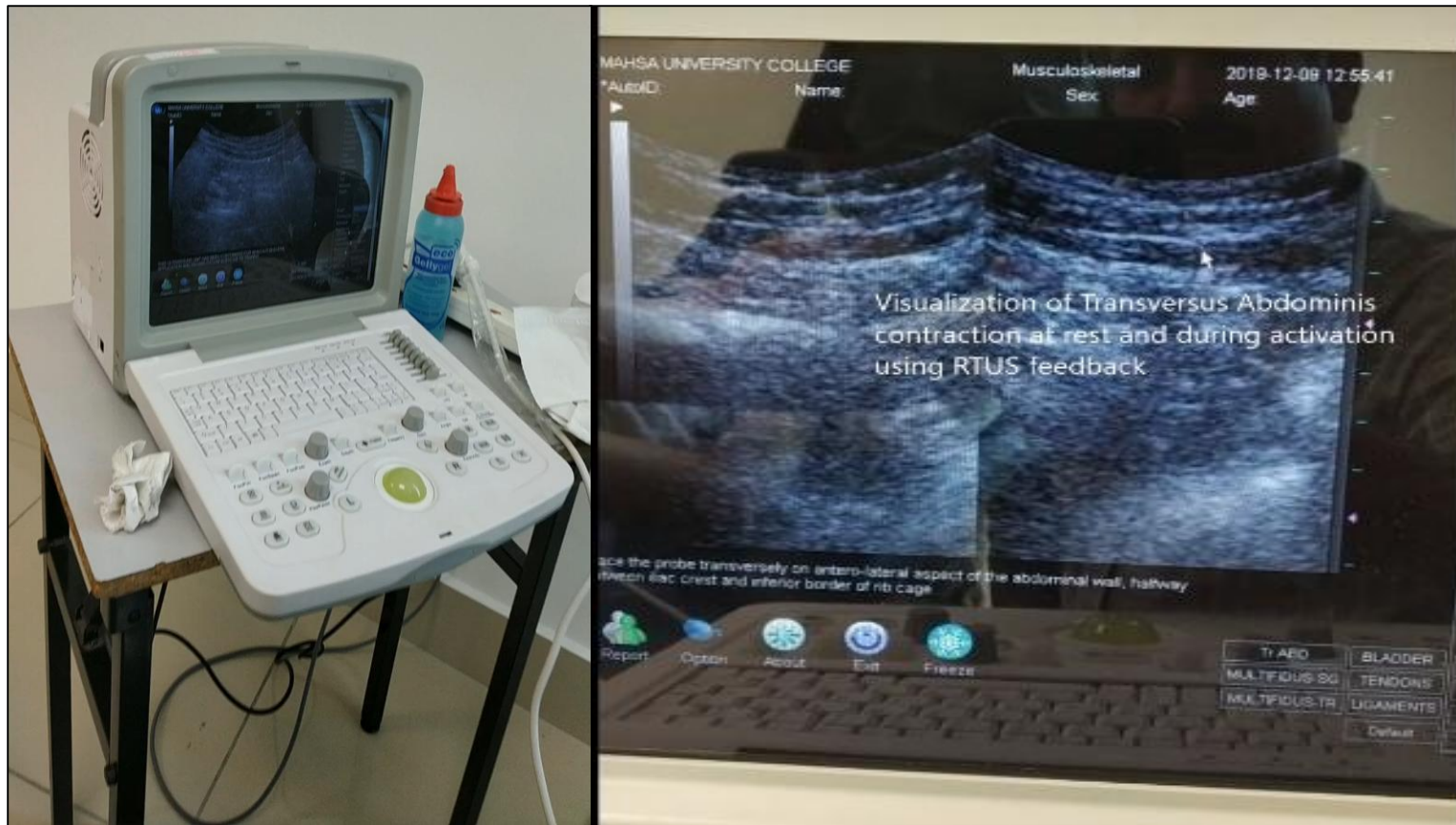


Figure 3. 14 Visualization of Transversus Abdominis contraction at rest and during muscle contraction using RTUS feedback

Stage 1 focused on the initial activation and coordination of the deep trunk muscles, particularly the TrA. Participants were instructed to isolate these muscles while reducing the over activity of superficial muscles, such as the rectus abdominis. This stage emphasized proper muscle recruitment to achieve stability and control of the lumbar-pelvic region. Real-time ultrasound biofeedback was used to guide participants, offering an immediate visual representation of their muscle activation patterns. This feedback allowed the physical therapist to provide precise corrections, ensuring proper technique during exercises. Participants also engaged in exercises targeting the pelvic floor muscles, breathing control, and postural alignment. Tasks included maintaining an isolated contraction of the transversus abdominis for 10 repetitions of 10 seconds each while maintaining normal respiration. Participants progressed to Stage 2 only after demonstrating mastery of Stage 1, defined as consistent activation of target muscles with proper technique.

Stage 2 involved integrating the achieved motor control into dynamic functional tasks. Exercises were advanced to include more complex movements requiring the coordination of trunk and limb muscles. Functional tasks included dynamic balancing, weight-shifting, and maintaining stability during multi-directional movements. The complexity of exercises increased progressively based on individual capabilities and progress. Real-time ultrasound biofeedback continued to provide guidance, ensuring precision in muscle activation. The integration of biofeedback was pivotal role in the success of the intervention. The immediate feedback allowed participants to visualize and correct muscle activation errors, fostering motor learning and reinforcing proper movement patterns. This interactive approach increased participants' engagement and adherence to the program. The exercises prescribed with the RTUS biofeedback to the subjects of experimental group provided are provided in Tables 3.4 and 3.5.

Table 3. 4 Motor Control Exercises Protocol administered with Real-Time Ultrasound Feedback for stage -I

Week & Sessions	Exercise	Position & Probe Placement	Instructions	Dosage (Reps/Sets/Hold)	Progression
Week 1 – 4 2 sessions / week	Transversus Abdominis (TrA) Activation	Supine lying with pillow under knees & ultrasound probe placed transversely on lateral wall of the lower abdomen	Gently draw in lower abdomen (“abdominal Drawing In Maneuver – ADIM) without pelvic tilt/ breath-holding; observe TrA thickening on RTUS	10 reps × 10 sec hold	Progress to Mastering TrA contraction
	Mastering isolated TrA Muscle contraction	Supine lying with pillow under knees & ultrasound probe placed transversely on lateral wall of the lower abdomen	Gently draw in lower abdomen and maintain contraction of TrA for 5-7 seconds without breath-holding; observe TrA thickening on RTUS	X 7 – 10 sets (30 – 45 Minutes)	Progress to combination of Transversus Abdominis Muscle contraction along with pelvic floor muscle contraction

Table 3. 5 Motor Control Exercises Protocol administered with Real-Time Ultrasound Feedback for stage -II

Week & Sessions	Exercise	Position & Probe Placement	Instructions	Dosage (Reps/Sets/Hold)	Progression
Week 5 – 8 1 session / week	TrA Contraction	Supine hook-lying & ultrasound probe placed transversely on midpoint of lower abdomen and on lateral wall of the lower abdomen	ADIM along with an action of controlling the urine flow which enhance contraction of pelvic floor muscle and observe TrA thickening on RTUS	10 reps × 10 sec hold	Progress to Semi Fowlers position
		Semi-Fowlers position & ultrasound probe placed on lateral wall of the lower abdomen	ADIM and maintain contraction of TrA and lifting each lower limb while maintaining TrA contraction	X 7 – 10 sets (30 – 45 Minutes)	Progress to Fowlers position and include upper limb activity
		Fowler's Position & ultrasound probe placed on lateral wall of the lower abdomen	ADIM and maintain contraction of TrA and including upper limb activity such as holding a ball and passing it between hands while mainlining TrA contraction.		To continue ADIM exercise to maintain core muscle strength

Changes to Outcomes Post-Trial Commencement

No major changes to the primary or secondary outcome measures were reported after the trial commenced. Both NPRS and ODI remained the standard tools for assessing pain and functional disability throughout the study. Minor procedural adjustments were made to enhance data collection accuracy. Some participants in the experimental group required additional guidance during baseline assessments to ensure they understood how to use the real-time ultrasound biofeedback. This was necessary to align participants with the study protocol. Adherence to the session schedule was initially not systematically monitored but was incorporated during the trial to better assess the intervention's practical feasibility and consistency. These procedural updates did not alter the defined outcomes but aimed to enhance the quality and reliability of the collected data.

3.7 STATISTICAL ANALYSIS

The SPSS 27 version of the software was used for computing the statistics of this study. The significance level for the study was set at 0.05, with a 95% confidence interval. The homogeneity of the data and normality were analyzed using the Shapiro-Wilk and Kolmogorov-Smirnov tests, along with skewness and kurtosis tests. The within-group analysis was conducted using a paired t-test, and the between-group analysis was conducted using an Independent t-test.

CHAPTER IV

RESULTS

CHAPTER OVERVIEW

This chapter presents the procedures and techniques employed to analyze the data collected for the study. Data analysis serves as a critical bridge between the raw information obtained through the research instruments and the interpretation of results in relation to the research objectives and hypotheses. The analysis process involves organizing, cleaning, and systematically examining the dataset to identify patterns, trends, and relationships that address the research questions. Both descriptive and inferential statistical methods are applied, as appropriate, to summarize the data and test the formulated hypotheses. Statistical analyses are conducted using SPSS (version 27), ensuring accuracy, reliability, and replicability of results. The findings derived from these analyses are presented in tabular, graphical, and narrative formats in the subsequent sections, forming the empirical foundation for the discussion in the following chapter.

The collected data were cleaned and stored in Excel sheets. The data were screened for data entry errors, natural variation, and special cases. There were no outliers, so no changes to the master chart were needed. 96 subjects accounted for the study results. The samples were randomized into the two groups with a 1:1 ratio. The data were initially assessed for baseline homogeneity using the demographic data collected on Age group and Gender. Then, a distribution analysis was performed to assess normality, and, following this, the statistical tests were selected for the study. The selected three outcome measures were subjected to within-group analyses to assess the extent of changes produced by each intervention and to between-group analyses to compare the effects and test the study hypothesis.

4.1 DESCRIPTIVE ANALYSIS

The normality of the data was tested using both the Kolmogorov-Smirnov and Shapiro-Wilk tests.

Table 4. 1 Statistical test of normality Kolmogorov-Smirnov and Shapiro-Wilk tests

Variable	Tests of Normality					
	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Pain Intensity (NPRS)	0.176	96	0.000	0.929	96	0.000
Disability (ODI)	0.101	96	0.017	0.961	96	0.006
Core Muscle Strength (PBF)	0.171	96	0.000	0.941	96	0.000

The results of both the Kolmogorov-Smirnov and Shapiro-Wilk tests indicated that all three outcome measures—Numerical Pain Rating Scale (NPRS), Oswestry Disability Index (ODI), and Core Muscle Strength (CMS) — pre-post differences significantly deviated from normality ($p < 0.05$). Hence the data was again tested for normality using the skewness and Kurtosis and the results of those were shown in Table 4.2.

Table 4. 2 Statistical test of normality using Skewness and Kurtosis

Variable	Skewness	SE Skewness	Z- Skewness	Kurtosis	SE Kurtosis	Z- Kurtosis	Normality
Pain Intensity (NPRS)	-0.21	0.25	-0.84	-1.09	0.49	-2.23	Normal
Disability (ODI)	0.39	0.25	1.57	-0.74	0.49	-1.52	Normal
Core Muscle Strength (PBF)	0.36	0.25	1.48	-0.91	0.49	-1.88	Normal
NPRS = Numerical Pain Rating Scale; ODI = Oswestry Disability Index; CMS = Core Muscle Strength: SE- Standard Error							

From the above table, it was observed that the skewness values of the variables NPRS = Numerical Pain Rating Scale; ODI = Oswestry Disability Index; CMS = Core Muscle Strength fall between -1 and $+1$ and kurtosis values between -2 and $+2$, which are generally considered acceptable for normality. Hence, the researcher decided to assess skewness and kurtosis to evaluate the approximate normality of the data and proceed with using parametric tests for all 3 outcome measures.

Table 4. 3 Demographic Data of Participants

Variables	Control Group	Experimental Group	Total
Number of participants	48	48	96
Age (Mean $\pm$ SD)	42.12 $\pm$ 4.62	42.33 $\pm$ 5.09	42.22 $\pm$ 4.83
Gender (Mode, %)	Male (27, 56.3%)	Male (30, 62.5%)	Male (57, 59.4%)
	Female (21, 43.7%)	Female (18, 37.5%)	Female (39, 40.6%)

Table 4.3 presents the comparative analysis of demographic data between the control and experimental groups. Figure 4.1 describes the age distribution of subjects, where the subjects were categorized into four groups: 35–40 years, 41–45 years, 46–50 years, and 51–55 years. In the control group, there were 19 participants aged 35–40 years, 16 aged 41–45 years, 12 aged 46–50 years, and 1 aged 51–55 years. In the experimental group, 23 participants were aged 35–40 years, 12 were aged 41–45 years, 10 were aged 46–50 years, and 3 were aged 51–55 years. The chi-square test yielded a p-value of 0.545 (2.134), indicating no significant difference in age distribution between the two groups.

Regarding the gender distribution, the control group consisted of 27 males and 21 females, whereas the experimental group had 30 males and 18 female participants, as shown in Figure 4.2.

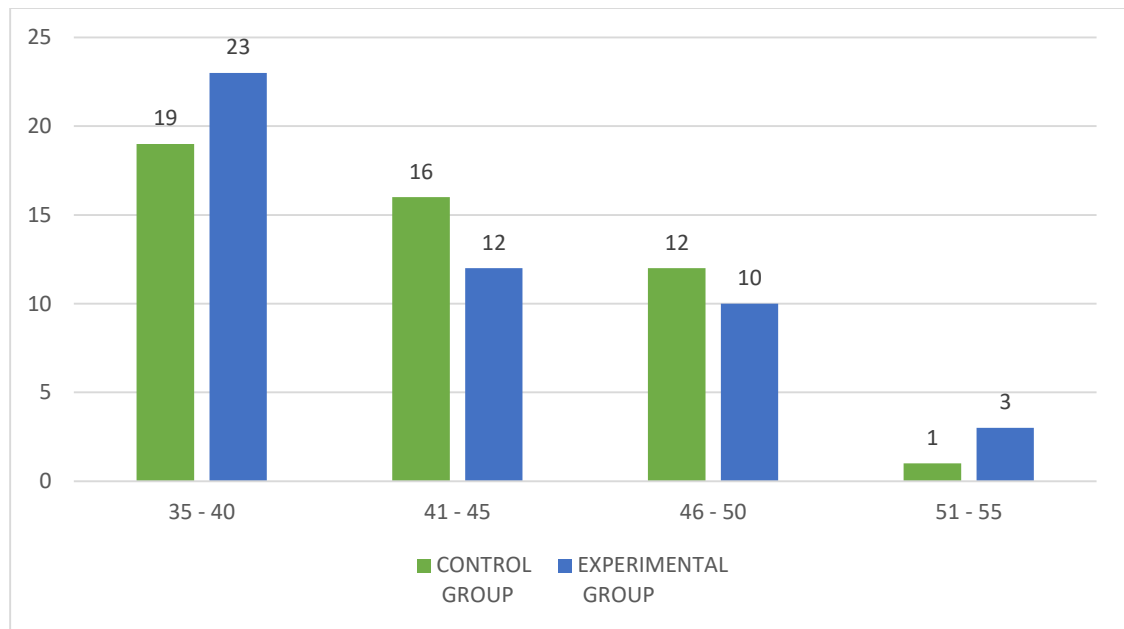


Figure 4. 1 Age wise distribution of samples between control and experimental group

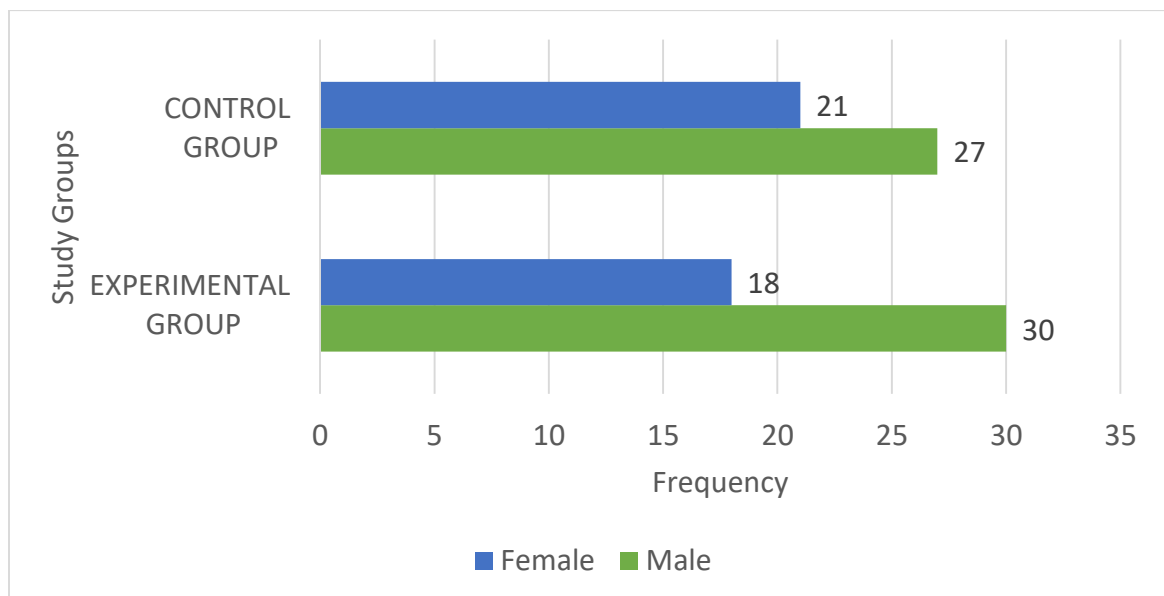


Figure 4. 2 Gender distribution of samples between control and experimental groups

4.2 INFERENCE STATISTICS

Test selection for inferential statistics was done based on the nature of the data and distribution analysis. This study used parametric statistical methods to analyze pain intensity using the Numeric Pain Rating Scale (NPRS; 0-10 cm), Functional Activity (Disability level) using the Oswestry Disability Index (ODI; 0-100%), and Core Muscle Strength using Pressure Bio-Feedback (PBF; mm/Hg). All the variables were considered under ratio-level data as they have an absolute zero point in their measurement. Also, as the skewness values fall between -1 and $+1$ and the kurtosis values fall between -2 and $+2$, which are generally considered acceptable for normality, parametric tests were chosen to analyze and interpret the data.

Table 4.4 presents the within-group pre–post comparison of pain intensity, disability, and core muscle strength for both the control and experimental groups following their respective interventions. The analysis demonstrates statistically significant improvements across all outcome measures in both groups ($p < 0.001$). However, the magnitude of change and effect sizes indicate a substantially greater clinical response in the experimental group receiving motor control exercises compared to the control group receiving lumbar stabilization exercises.

Table 4. 4 Impact of interventions on Pain intensity, Functional Activity and Core Muscle Strength within control and experimental group

Out- come	Group	Pre-test (M ± SD)	SEM	Post-test (M ± SD)	SEM	Mean Diff (M ± SD)	SE M	95% CI-DIFF	t- value (df=47)	p-value	Cohen's d
NPRS	CON	7.79 ± 0.92	0.13	3.44 ± 1.11	0.16	4.35 ± 1.30	0.19	3.98 to 4.73	23.27	<.001	3.36
	EXP	7.75 ± 0.79	0.11	0.71 ± 0.65	0.94	7.04 ± 0.97	0.14	6.76 to 7.32	50.47	<.001	7.29
ODI	CON	67.49 ± 10.61	1.53	34.02 ± 9.16	1.32	33.46 ± 11.28	1.63	30.19 to 36.74	20.55	<.001	2.97
	EXP	69.40 ± 10.14	1.46	11.71 ± 9.59	1.38	57.69 ± 14.06	2.03	53.61 to 61.77	28.42	<.001	4.10
PBF	CON	7.88 ± 2.28	0.33	15.21 ± 2.81	0.41	-7.33 ± 1.46	0.21	-7.76 to - 6.91	-34.72	<.001	-5.01
	EXP	8.42 ± 2.57	0.37	22.62 ± 2.51	0.36	14.21 ± 2.52	0.36	-14.94 to -13.48	-39.10	<.001	-5.64
NPRS - Numeric Pain Rating Scale; ODI - Oswestry Disability Index; PBF - Pressure Bio-Feedback											
M - Mean; SD – Standard Deviation; SEM – Standard Error Mean; CI DIFF – Confidence Interval Difference (Lower-Upper)											
CON= Control, EXE= Experimental, *Statistically significant difference at $p<0.05$											

Pain Intensity (NPRS): Both groups demonstrated a statistically significant reduction in pain intensity following the intervention period. In the control group, mean pain scores decreased from 7.79 ± 0.92 at baseline to 3.44 ± 1.11 post-intervention ($t(47) = 23.27$, $p < 0.001$), representing a large effect size (Cohen's $d = 3.36$). In contrast, the experimental group showed a markedly greater reduction, with pain scores decreasing from 7.75 ± 0.79 to 0.71 ± 0.65 ($t(47) \approx 50.47$, $p < 0.001$), with an extremely large effect size (Cohen's $d = 7.29$). Figure 4.3 illustrates the mean pain intensity scores for both control and experimental groups at pre-test and post-test, with standard error bars indicating variability.

From a clinical perspective, the reduction observed in the experimental group exceeds commonly accepted thresholds for clinically meaningful improvement in pain intensity (≥ 2 -point change on NPRS), suggesting that motor control exercises produced not only statistically significant but also clinically substantial pain relief compared to conventional lumbar stabilization exercises.

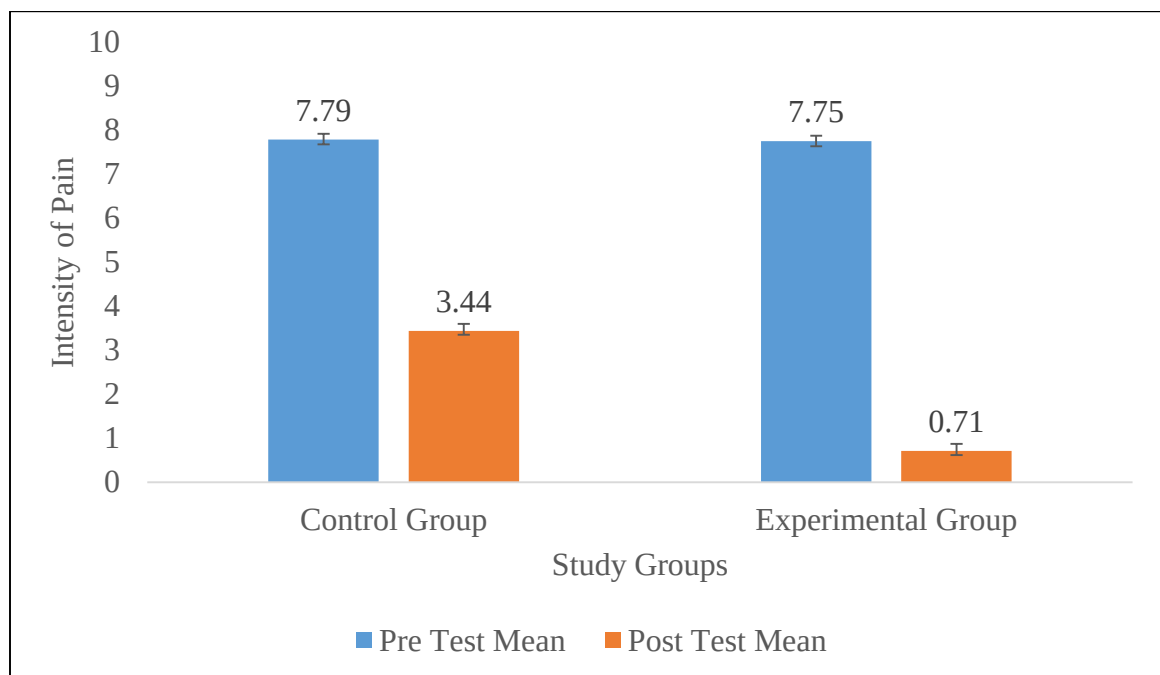


Figure 4.3 Mean values of pre- and post-test of control and experimental groups with standard error for Pain Intensity

Functional Activity (ODI): A similar pattern was observed for functional activity. The control group demonstrated a significant reduction in ODI scores from 67.49 ± 10.61 to 34.02 ± 9.16 ($t(47) = 20.55$, $p < 0.001$), corresponding to a large effect size ($d = 2.97$). The experimental group exhibited a more pronounced improvement in functional activity, with ODI scores decreasing from 69.40 ± 10.14 to 11.71 ± 9.59 ($t(47) = 28.42$, $p < 0.001$), yielding a very large effect size ($d = 4.10$). Figure 4.4 shows the mean percentage of functional activity for both control and experimental groups at pre- and post-test, with small standard error bars indicating low variability.

Importantly, the post-intervention ODI score in the experimental group reflects a transition from severe disability to minimal disability, indicating a substantial restoration of functional activity. This magnitude of change exceeds the minimum clinically important difference for ODI (approximately 10–12 points), reinforcing the clinical effectiveness of motor control exercises in improving functional outcomes in CNSLBP.

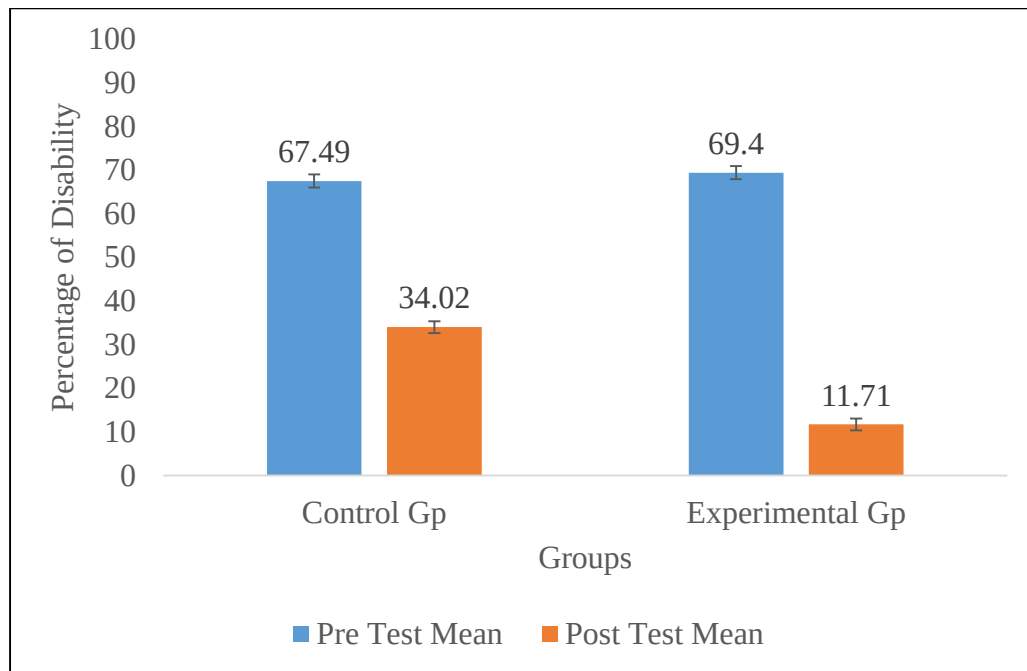


Figure 4. 4 Mean values of pre and post-test of control and experimental groups with standard error for Disability

Core Muscle Strength (PBF): Core muscle strength improved significantly in both groups, as indicated by increases in pressure biofeedback values indicating enhanced neuromuscular control and trunk stability. The control group improved from 7.88 ± 2.28 to 15.21 ± 2.81 mmHg ($t(47) = -34.72$, $p < 0.001$), while the experimental group improved from 8.42 ± 2.57 to 22.62 ± 2.51 mmHg ($t(47) = -39.10$, $p < 0.001$). Both groups exhibited very large effect sizes ($d = -5.01$ and $d = -5.64$, respectively). Figure 4.5 illustrates the mean core muscle strength (mmHg) for the control and experimental groups at pre-test and post-test, with standard error bars.

Although both interventions were effective in enhancing core muscle activation, the experimental group demonstrated a greater improvement, suggesting that motor control exercises may be more effective in facilitating deeper activation and coordination of stabilizing musculature. This improvement is clinically relevant, as increased core muscle function is associated with improved spinal stability and reduced risk of recurrence in chronic low back pain populations.

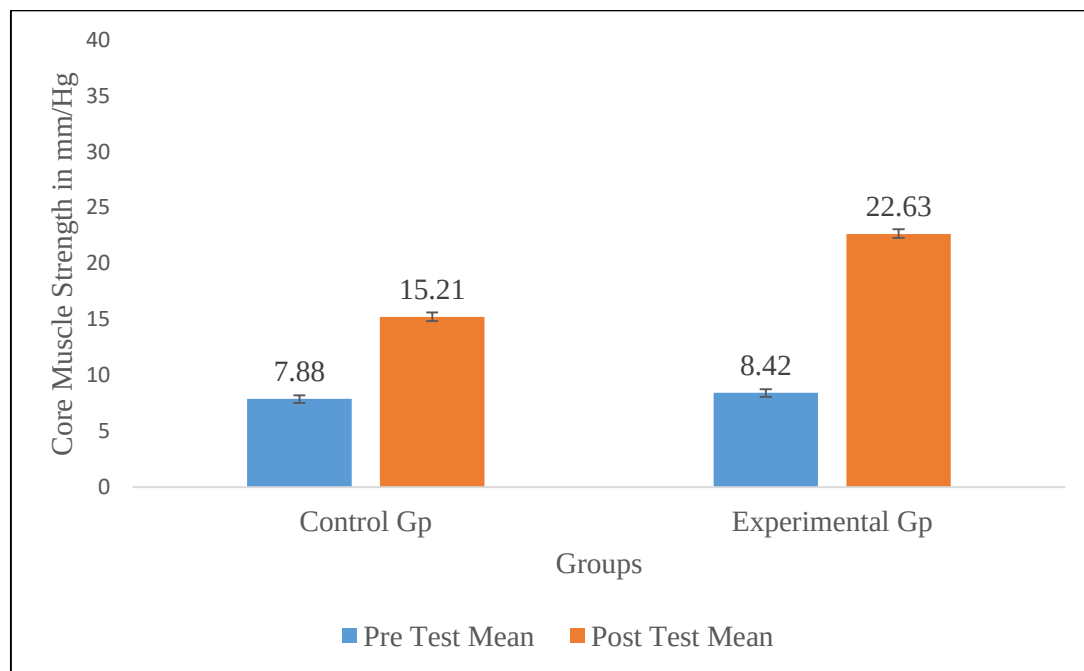


Figure 4. 5 Mean values of pre and post-test of control and experimental groups with standard error for Core Muscle Strength

Overall Summary within-group analysis indicates that both interventions were effective in improving pain, disability, and core muscle strength over time. However, the magnitude of improvement consistently favored the motor control exercise group across all outcome measures. The substantially larger effect sizes observed in the experimental group suggest a superior therapeutic benefit, highlighting motor control exercises as a potentially more effective intervention for CNSLBP in comparison to lumbar stabilization exercises.

Table 4. 5 Impact of interventions on Pain intensity, Functional Activity and Core Muscle Strength between control and experimental groups

Out- come	Groups	M ± SD	SEM	Mean Diff (M)	SEM	95% CI (Diff)	t-value (df=47)	p-value	Cohen's d
NPRS	Control	4.35 ± 1.30	0.19	-2.69	0.23	-3.15 to -2.22	-11.52	<.001	-2.35
	Experimental	7.04 ± 0.97	0.14						
ODI	Control	33.46 ± 11.28	1.63	-24.23	2.60	-29.39 to -19.06	-9.31	<.001	-1.90
	Experimental	57.69 ± 14.06	2.03						
PBF	Control	7.33 ± 1.46	0.21	-6.88	0.42	-7.7 to- 6.04	-16.36	<.001	-3.34
	Experimental	14.21 ± 2.52	0.36						

NPRS - Numeric Pain Rating Scale; ODI - Oswestry Disability Index; PBF - Pressure Bio-Feedback, M - Mean; SD – Standard Deviation; SEM – Standard Error Mean; CI DIFF – Confidence Interval Difference (Lower-Upper), *Statistically significant difference at $p<0.0$

Table 4.5 presents the between-group comparison of post-intervention outcomes for pain intensity (NPRS), functional activity (ODI), and core muscle strength (PBF) between the control group (lumbar stabilization exercises) and the experimental group (motor control exercises). An independent-samples t-test was conducted to determine differences between groups, and 95% confidence intervals were used to evaluate the precision and robustness of the observed effects.

Overall, the findings indicate that motor control exercises produced superior therapeutic outcomes compared to conventional lumbar stabilization exercises, with consistently larger effect sizes observed across all variables.

Pain Intensity: A statistically significant difference in post-intervention pain intensity was observed between the control and experimental groups ($t(94) = -11.52, p < 0.001$). The experimental group demonstrated a substantially greater reduction in pain compared to the control group. Figure 4. 6 shows the comparison of pain intensity improvement between control and experimental groups. The mean difference between groups was -2.69 points (95% CI: -3.15 to -2.22), indicating a clear and precise effect in favor of the experimental intervention. The confidence interval does not cross zero, confirming the statistical robustness of the finding. The large effect size (Cohen's $d = -2.35$) further supports a strong clinical impact of MCE in reducing pain intensity compared to LSE.

Clinically, this finding suggests that motor control exercises are substantially more effective in reducing pain severity in individuals with CNSLBP. The magnitude of the effect indicates not only statistical significance but also strong clinical relevance, as the improvement exceeds the minimum threshold for meaningful pain reduction.

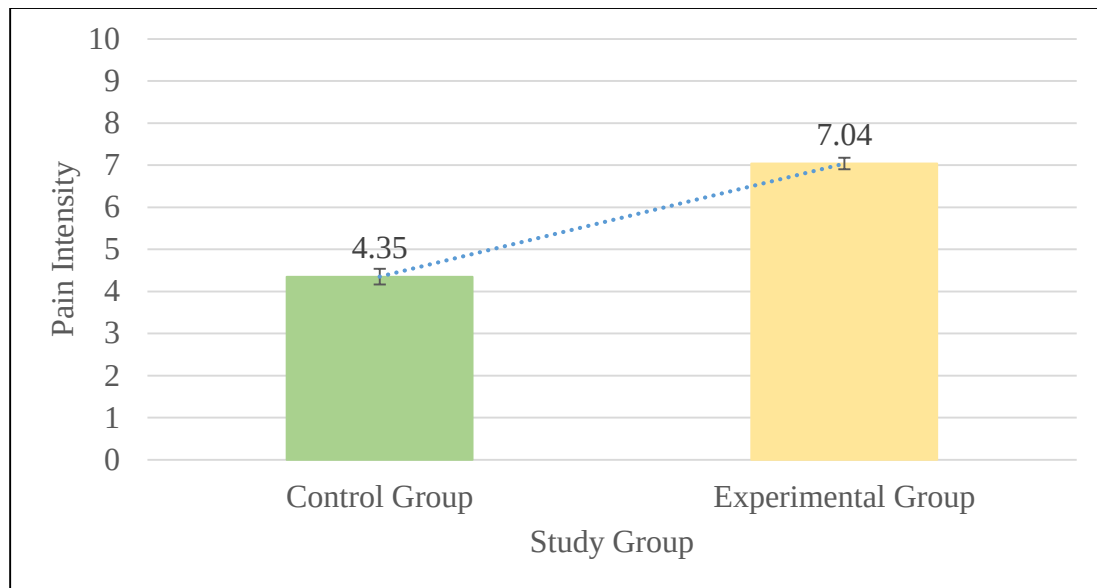


Figure 4. 6 Comparison of improvement in Pain intensity between control and experimental groups

Functional activity: A significant between-group difference was also observed in functional activity outcomes ($t(94) = -9.31, p < 0.001$). Participants in the experimental group achieved significantly greater improvement in functional activity than those in the control group. The mean difference was -24.23 points (95% CI: -29.39 to -19.06), indicating a large and clinically meaningful reduction in disability in favor of the experimental group. Figure 4.7 shows a clear difference in disability scores between the control and experimental groups after the intervention.

Importantly, the confidence interval is narrow and does not include zero, demonstrating high precision of the estimated effect. The effect size was large (Cohen's $d = -1.90$), suggesting a strong superiority of motor control exercises in improving functional ability. Clinically, this magnitude of improvement represents a shift from moderate/severe disability to minimal disability, highlighting the functional relevance of the intervention.

From a clinical perspective, this indicates that motor control exercises lead to superior improvements in functional activity enabling better performance of daily activities and reduced activity limitation. The observed difference suggests that motor control

training may be more effective in restoring functional independence in chronic low back pain populations.

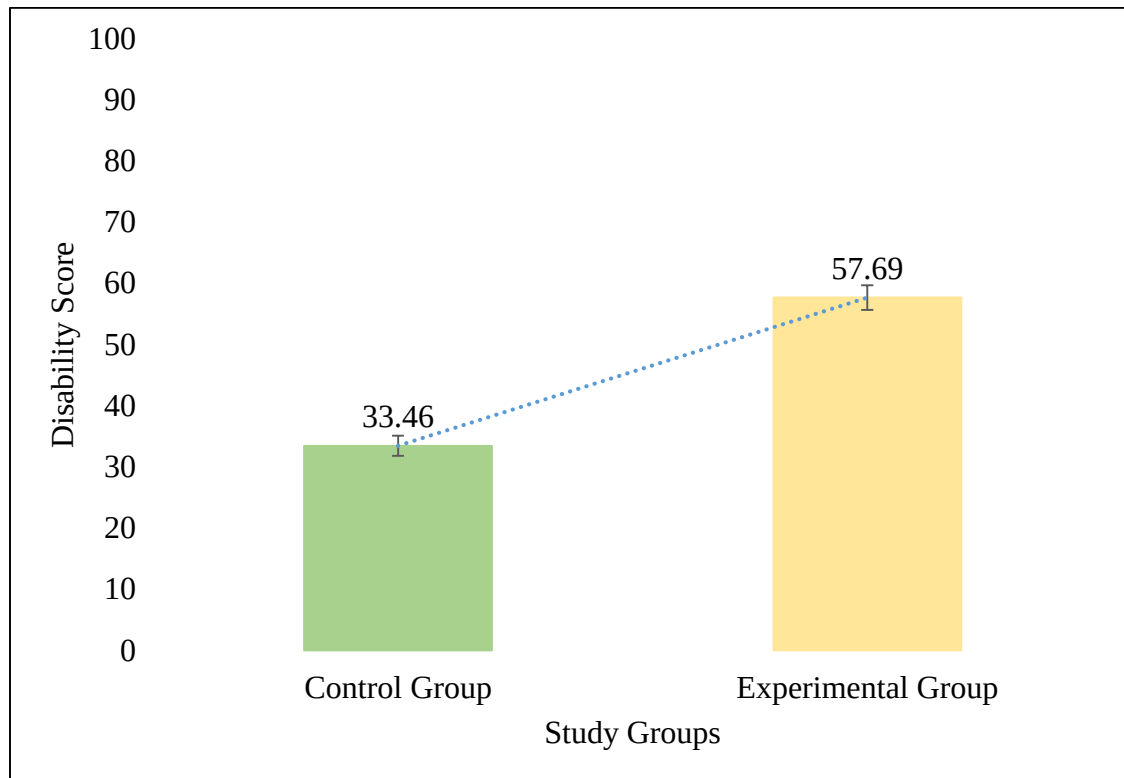


Figure 4. 7 Comparison of improvement in Disability between control and experimental groups

Core Muscle Strength: A statistically significant difference in core muscle strength was observed between the two groups ($t(94) = -16.36$, $p < 0.001$), with the experimental group demonstrating greater improvement. The mean difference was -6.88 mmHg (95% CI: -7.70 to -6.04), indicating a strong and precise between-group effect in favor of motor control exercises. Figure 4.8 illustrates a clear improvement in core muscle strength in both groups, with a more pronounced increase in the experimental group.

The confidence interval remains entirely below zero, confirming statistical reliability and consistency of the treatment effect. The effect size was large (Cohen's $d = -3.34$), indicating a very strong intervention effect on core muscle activation and trunk

stability. From a clinical perspective, this improvement suggests enhanced neuromuscular control and spinal stability, which are critical factors in reducing the risk of recurrence CNSLBP.

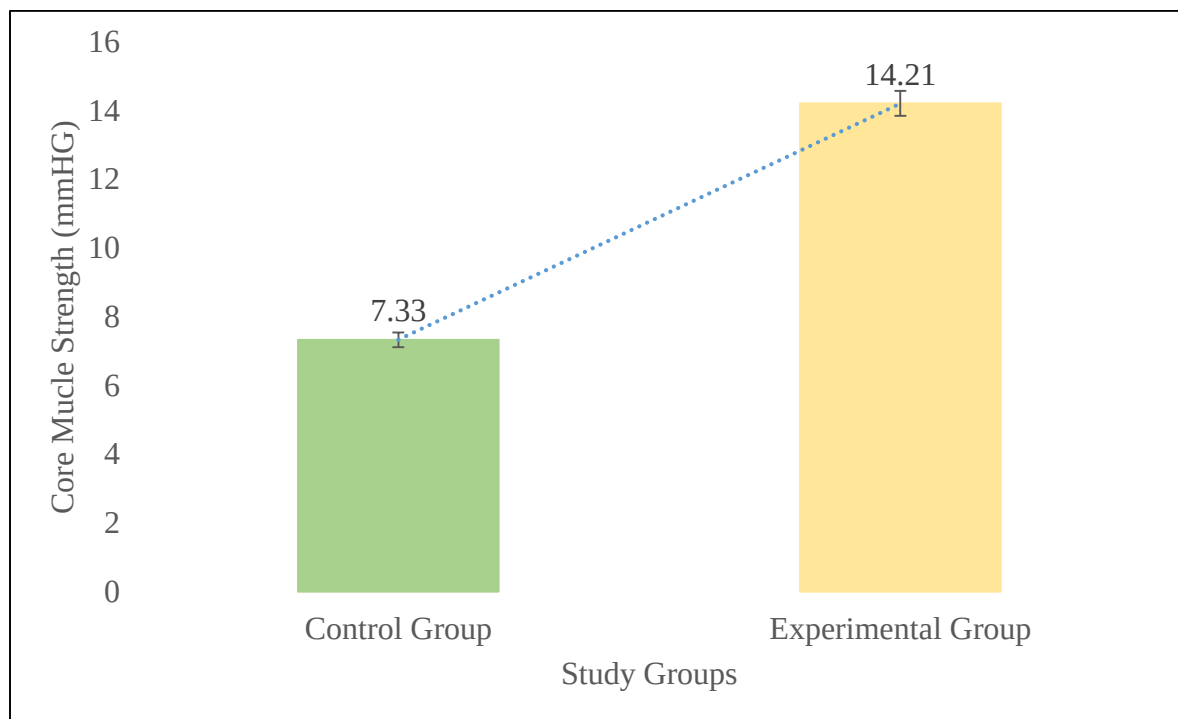


Figure 4. 8 Comparison of improvement in Core Muscle Strength between control and experimental groups

Overall Summary: Between-Group analysis demonstrates that motor control exercises produced significantly greater improvements than lumbar stabilization exercises across all outcome measures. The confidence intervals for all variables did not cross zero, indicating robust and precise treatment effects. Additionally, the consistently large effect sizes across pain, disability, and core muscle strength confirm the clinical superiority of motor control exercises in managing CNSLBP.

CHAPTER V

DISCUSSION

CNSLBP remains one of the most pervasive musculoskeletal disorders globally, significantly impacting quality of life and functional activity. The complexity of CNSLBP lies in its multifactorial origins and the absence of clear pathological findings. Over the last 10 years, core muscle-strengthening exercises have been a cornerstone of conservative management, aiming to enhance trunk stability and motor control. Concurrently, research has increasingly explored the integration of feedback modalities such as visual, auditory, and biofeedback in these exercise programmes to optimize neuromuscular activation and particularly tailor interventions to individual patient needs.

Core muscle training was considered the major intervention tool in the current study because the deep trunk muscles, such as the transversus abdominis and lumbar multifidus, play a crucial role in maintaining spinal stability and coordinating trunk movement. It has been shown that these muscles are often impaired in patients with CNLSBP, leading to spinal dysfunction and pain perpetuation. Exercise programs focused on retraining these muscle groups have demonstrated positive results in reducing pain and improving function in such individuals. Targeted exercises aiming at spinal segmental control have been found to improve muscle morphology and patient-reported outcomes over general exercises, though protocol variability remains challenging for clinical standardization (Hodges PW, Richardson, 1996 & 1997)

5.1 OVERVIEW OF FINDINGS

This study evaluated the comparative effects of MCE and LSE on pain, functional activity, and core muscle strength in individuals with CNSLBP. The findings demonstrated statistically and clinically significant improvements in both groups; however, the MCE group consistently achieved superior outcomes across all primary variables.

Compared with existing the literature, the magnitude of improvement observed in this study is notably higher than that reported in most recent systematic reviews. For example, a 2023 systematic review reported moderate-quality evidence supporting MCE for reducing pain and disability, but with generally small-to-moderate effect sizes across pooled trials (Capel-Alcaraz et al., 2023). Similarly, a Cochrane-based synthesis concluded that while exercise therapy is beneficial for CNSLBP, no single exercise modality consistently demonstrates large superiority over others (Saragiotto et al., 2016)

However, more recent 2024–2025 network meta-analyses suggest that motor control and stabilization-based interventions rank among the most effective exercise approaches for improving pain and disability, particularly in patients with movement-control deficits (Zhao et al., 2025). The stronger effects observed in this study may therefore reflect improved treatment specificity, stricter exercise progression, and greater emphasis on neuromuscular retraining compared with heterogeneous protocols reported in the literature.

Importantly, these findings support a shift in conceptual understanding of CNSLBP away from purely biomechanical dysfunction toward a sensorimotor control impairment model, in which deficits in movement coordination and cortical motor planning play a central role in symptom persistence.

5.2 IMPACT OF MOTOR CONTROL EXERCISE ON PAIN

The present study demonstrated that MCE produced substantially greater pain reduction compared to LSE. This finding aligns with recent evidence indicating that motor control–based interventions are moderately effective in reducing pain, although effect sizes vary widely depending on patient characteristics and intervention design.

Recent systematic reviews confirm that exercise therapy provides clinically meaningful pain reduction in CNSLBP; however, MCE appears to be more effective in subgroups with impaired motor control and lumbar instability (Niederer et al., 2020;). In

contrast, general stabilization programs tend to produce more variable outcomes due to differences in exercise dosage, progression, and patient adherence.

A key point of contrast with earlier literature is that older trials often reported minimal or short-term pain benefits from MCE alone (O'Sullivan et al., cited in multiple systematic reviews), whereas newer meta-analyses demonstrate more consistent effects when interventions include progressive motor learning, feedback integration, and task-specific retraining.

Comparative studies have reported mixed findings regarding the effectiveness of motor control exercises compared with other interventions. Costa et al. (2009) observed that motor control exercise led to short-term improvements in global perceived recovery and activity levels; however, it did not demonstrate a significant effect on pain reduction, with a mean difference of 0.9 points (95% CI: -0.01 to 1.8) in pain intensity (Costa et al., 2009). In contrast, the present study demonstrated a more pronounced reduction in pain within the Motor Control Exercise group. This discrepancy may be explained by differences in the specific exercise protocol applied or variations in participant characteristics between studies.

The greater pain reduction observed in the Motor Control Exercise group in this study may also be explained by underlying neuromuscular mechanisms supported in the literature. Motor control exercises are designed to selectively activate and retrain the deep trunk-stabilizing muscles, particularly the TrA and lumbar multifidus, which are often dysfunctional in individuals with chronic low back pain. By improving the timing and coordination of these muscles, rather than focusing solely on muscle strength, these exercises enhance spinal segmental stability and reduce excessive mechanical stress on pain-sensitive structures. This restoration of normal motor control strategies has been proposed as a key mechanism contributing to pain reduction and functional improvement (Van Dieën et al., 2019a).

The superior pain reduction in the present study can be interpreted through multiple mechanisms (Van Dieën et al., 2019b):

1. Improved neuromuscular coordination – restoring timing of deep stabilizers reduces aberrant spinal loading.
2. Reduced mechanical irritation – improved segmental control limits micro-instability during movement.
3. Central pain modulation – repeated safe movement exposure reduces threat perception and cortical pain amplification.
4. Exercise-induced hypoalgesia – activation of descending inhibitory pathways contributes to analgesic effects.

These mechanisms are strongly supported by contemporary neurophysiological models of chronic pain, which emphasize that pain reduction is primarily mediated through central rather than purely peripheral adaptations.

5.3 IMPACT OF MOTOR CONTROL EXERCISE IN IMPROVING FUNCTIONAL ACTIVITY

Disability outcomes improved significantly in both groups, but the MCE group demonstrated superior functional restoration. This finding is consistent with recent systematic reviews reporting that stabilization and motor control interventions improve disability more effectively than general exercise, particularly in patients with movement dysfunction phenotypes (Frizziero et al., 2021).

Both groups exceeded the established MCID for the ODI, which ranges from 6 to 12 points depending on the population and methodology used (Macedo, Maher, Latimer, & McAuley, 2009). However, compared with the existing literature, the magnitude of disability improvement in this study is higher than the typically reported pooled effects. Most meta-analyses describe small-to-moderate improvements, whereas the current study demonstrated large functional gains. This discrepancy may be explained by:

- Higher intervention fidelity (closely supervised progression)

- Emphasis on deep muscle activation quality rather than repetition volume
- Integration of motor learning principles (feedback, correction, repetition)

Importantly, disability in CNSLBP is now understood as a biopsychosocial construct, not merely a reflection of physical impairment. Therefore, the superior improvements observed in the MCE group may also reflect:

- Increased movement confidence
- Reduced fear-avoidance behavior
- Improved self-efficacy in performing daily tasks

These psychosocial mechanisms are increasingly emphasized in recent literature as key mediators of functional recovery in chronic pain populations.

In contrast, LSE primarily improves general trunk endurance, which may not directly translate into improved task-specific motor performance, explaining the relatively smaller functional gains

5.4 IMPACT OF MOTOR CONTROL EXERCISE ON CORE MUSCLE STRENGTH

Both interventions improved core muscle strength; however, MCE demonstrated significantly greater gains. This aligns with recent meta-analytic findings indicating that motor control and core stabilization exercises improve lumbar muscle activation patterns and paraspinal muscle function more effectively than general exercise (Shanbehzadeh et al., 2022).

The improvements in CMS are particularly noteworthy when compared with normative values for healthy individuals, which range from 2 to 10 mmHg with a median of 9 mmHg (Crasto et al., 2019). The superior core-strength improvements in the MCE group align with the theoretical framework underlying this intervention. MCE's specifically target the TrA muscle through the abdominal drawing-in maneuver, which has

been shown to be more effective at activating this deep stabilizing muscle compared to general core strengthening techniques (Akbari et al., 2008).

When compared with previous literature, the results of this study suggest a more pronounced improvement than typically reported. Earlier studies often emphasize modest increases in muscle thickness or endurance without substantial functional translation. In contrast, more recent evidence highlights that the primary adaptation in MCE is neuromuscular efficiency rather than hypertrophy.

The physiological mechanisms underlying these improvements include:

- Restoration of feedforward activation of transversus abdominis and multifidus
- Improved intermuscular coordination between deep and superficial trunk muscles
- Cortical reorganization of motor planning areas due to repetitive motor learning
- Enhanced proprioceptive feedback integration, improving postural control

Thus, the improvement in “core strength” observed in this study should be interpreted as a functional neuromotor adaptation, not merely an increase in muscular force production. This interpretation is consistent with contemporary literature, which emphasizes that spinal stability depends more on timing and coordination than on maximal voluntary contraction strength.

5.5 MOTOR CONTROL TRAINING WITH REAL-TIME ULTRASOUND FEEDBACK

In this study, the researcher incorporated RTUS feedback mechanisms into core-strengthening interventions, which can enhance patient engagement and improve motor control. The integration of RTUS imaging and biofeedback in this study represents a significant methodological advancement and may partly explain the superior outcomes observed in the MCE group.

Similar to the current study, previous clinical trials have reported controversial results: exercise regimens combined with biofeedback did not yield significantly superior

outcomes in pain reduction and functional improvement compared to exercises alone (Öztürk et al., 2024).

Visual feedback using RTUS or augmented reality systems, coupled with surface electromyography, enhances patients' ability to perceive and adjust muscle activation during exercises (Lancere et al., 2023). Previous research demonstrated the utility of biofeedback in chronic LBP, showing improved neuromuscular control and pain outcomes supporting the integration of biofeedback systems as used in our study (Lazaridou et al., 2023).

Porwal et al (2023). illustrated that pressure biofeedback effectively enhances abdominal muscle activation during trunk stabilization exercises, a principle directly mirrored in our protocol design and patient outcomes (Porwal et al., 2023). The RTUS biofeedback approach also tends to enhance adherence by enabling patients to receive immediate feedback, boosting motivation; however there is no conclusive evidence that one type of feedback is superior to another (Zadrapova et al., 2022).

Auditory feedback supplements this by providing cues for muscle contraction timing and intensity, supporting neuromuscular re-education; however, this has not been researched so far to our knowledge. While promising, the efficacy of these modalities requires further evaluation, given occasional findings that visual feedback may modify pain perception without necessarily improving muscle function directly (Heinrich et al., 2020).

Biofeedback devices, including pressure biofeedback units and electromyographic biofeedback, offer objective data on muscle activation, facilitating tailored rehabilitation. Pressure biofeedback helps patients learn to contract deep stabilizer muscles effectively by providing real-time pressure changes linked to transversus abdominis activation (Lima et al., 2012).

Through RTUS biofeedback, patients demonstrated faster acquisition of correct activation patterns, which increases the exercise accuracy and improves engagement and adherence. These improvements likely reflect enhanced sensory-motor integration during

early learning phases. However, long-term functional outcomes depend on whether these patterns are internalized and retained without external feedback. The findings of this study align well with the existing literature advocating the use of motor control exercises (MCE) and biofeedback (BF) in the management of CNSLBP. Therefore, RTUS biofeedback should be understood as an augmentation tool that accelerates neuroplastic adaptation, rather than an independent mechanism of recovery.

5.6 STRENGTHS OF THE STUDY

One of the standout strengths of this study lies in its rigorous design and methodological framework. The randomization is widely regarded as the gold standard for evaluating clinical interventions, primarily because, in this study the researcher minimized the biases such as selection and allocation bias. Randomizing participants to intervention and control groups ensured that confounding variables were evenly distributed, providing a more accurate representation of the intervention's true effect.

The study carefully defined inclusion and exclusion criteria, which ensured a homogeneous sample of CNSLBP patients. By excluding individuals with specific pathologies, such as infections, tumors, or radiculopathy, the study targeted those who would benefit most from conservative interventions such as MCE's and biofeedback (BF). This careful patient selection increased the internal validity of the study and strengthened the applicability of the results to similar clinical populations.

The intervention protocol was meticulously designed based on contemporary evidence and clinical guidelines mentioned in the review of the literature. It included a combination of motor control retraining exercises and biofeedback, both of which have shown promise individually in past studies. Integrating these interventions into a structured, supervised program allowed for consistent implementation and real-time monitoring of patient performance and compliance.

The use of biofeedback in particular represents a progressive approach to CNSLBP management. Real-time feedback helped patients gain greater awareness of their posture and muscle activation, addressing one of the most commonly identified barriers to effective

rehabilitation in this population — poor motor control and neuromuscular coordination. Including this technique made the intervention both innovative and evidence-based.

The high levels of participant adherence and retention added to the study's credibility. Maintaining participant engagement in exercise trials, especially in chronic pain populations, can be challenging. The fact that the majority of participants completed the study with good compliance highlights the feasibility and acceptability of the intervention program in clinical practice.

5.7 LIMITATIONS OF THE STUDY

A randomized controlled trial was not feasible due to ethical considerations, as withholding the intervention from a control group would have resulted in unequal access to potentially beneficial treatment in a private clinical setup. Also, due to logistical and operational constraints within the study setting, random assignment of participants was not feasible.

Although the sample size was statistically calculated and considered sufficient to test the primary hypothesis, the study is still constrained by a relatively modest sample size typical of controlled clinical trials. While the study was adequately powered to detect significant differences in primary outcomes, a larger sample would have enhanced statistical power, particularly for detecting subtler effects in secondary outcomes and for conducting robust subgroup analyses (e.g., severity-based stratification, age groups, or duration of CLBP).

Another important limitation is the selective study center. Conducting the study specific physiotherapy center restricts the external validity and generalizability of the findings. Variations in patient demographics, clinical practices, therapist expertise, and healthcare infrastructure across different regions may influence the effectiveness of interventions such as Motor Control Exercises (MCE) with biofeedback and Lumbar Stabilization Exercises (LSE). Therefore, multi-center randomized controlled trials are recommended to strengthen the generalizability and confirm the reproducibility of the findings across diverse clinical settings.

The follow-up period was relatively short, focusing primarily on immediate post-intervention outcomes. Given that chronic low back pain (CLBP) is a long-term, recurrent condition, the sustainability of treatment effects remains uncertain. The absence of medium- and long-term follow-up (e.g., 6-month or 12-month assessments) limits the ability to determine whether observed improvements are maintained, attenuated, or require booster sessions over time.

Additional limitations include:

- Potential performance bias due to therapist involvement: As the intervention was delivered under the supervision of the primary researcher (a trained physiotherapist), there is a possibility of therapist-related bias, including enhanced motivation, attention, or unintentional influence on participant performance, which may not reflect routine clinical practice conditions.
- Limited control of external physical activity and co-interventions: Participants' engagement in additional physical activities, self-exercises, or concurrent treatments outside the study protocol may not have been fully controlled, potentially influencing outcomes.
- Absence of objective biomechanical or imaging-based outcomes: The study primarily relied on clinical and functional outcome measures. The inclusion of objective assessments (e.g., muscle activation patterns, ultrasound-based morphological changes, or electromyography) could have strengthened mechanistic interpretation of the intervention effects.
- Adherence monitoring limitations: Although participants were instructed to follow the intervention protocol, precise quantification of adherence and home-exercise compliance may not have been fully captured, potentially influencing the interpretation of treatment efficacy.
- No subgroup or sensitivity analysis was performed: The study did not conduct subgroup analyses (e.g., based on age, pain duration, or baseline severity) or

sensitivity analyses to test the robustness of the findings. This limits the ability to explore differential treatment effects and assess the stability of the results under varying analytical assumptions.

- Certain potential confounding variables, such as lifestyle habits, physical activity levels, occupational demands, medication use, sleep quality, psychological factors, previous exercise or physiotherapy experience, and adherence to the prescribed exercises, may have influenced pain perception, functional behaviour, and recovery among participants with chronic non-specific low back pain. These factors were not completely controlled or objectively quantified throughout the study and, therefore, may have contributed to variations in treatment response and potentially influenced the observed outcomes.

5.8 CLINICAL IMPLICATIONS

The findings of this study carry important clinical implications for the management of CNSLBP. First and foremost, the study confirms that MCE's combined with biofeedback represent a practical and effective non-pharmacological intervention for reducing pain and disability in this patient population. These results provide physiotherapists and rehabilitation professionals with evidence to support the integration of MCE and BF into routine clinical practice.

Given the high prevalence and economic burden of CNSLBP globally, interventions that improve function and quality of life without the adverse effects associated with medication or invasive procedures are invaluable. This study highlights the feasibility of implementing structured exercise programs with biofeedback in outpatient settings, potentially reducing healthcare utilization and improving patient self-management. The study underscores the importance of individualized, supervised exercise therapy. The tailored nature of MCE allows clinicians to address specific motor control deficits, while biofeedback ensures that patients perform exercises correctly, enhancing

neuromuscular retraining. This approach aligns well with current clinical guidelines that advocate for patient-specific, active interventions in LBP management.

The integration of biofeedback technology offers a practical way to engage patients actively in their rehabilitation. By providing real-time feedback on muscle activation and posture, BF can help overcome common challenges like poor exercise technique and low body awareness, often seen in CNSLBP patients. This could lead to better treatment adherence and more sustained clinical benefits.

5.9 RECOMMENDATIONS FOR FUTURE RESEARCH

While this study provides valuable insights into the effectiveness of MCE combined with RTUS biofeedback, it also highlights several important directions for future investigation.

One critical area requiring further research is the long-term efficacy and sustainability of MCE with biofeedback. Future longitudinal studies with extended follow-up periods of 6 months, 1 year, or longer are needed to determine whether the short-term improvements in pain, function, and motor control are maintained over time. Such studies should also investigate whether maintenance or booster sessions are necessary to prevent relapse and sustain therapeutic gains in the long term.

Furthermore, future studies should investigate dose–response relationships, including optimal training frequency, session duration, and overall intervention intensity required to achieve and maintain clinical benefits. Understanding the minimum effective dose would improve treatment efficiency and clinical decision-making.

The traditional concept of isolating and strengthening individual “core muscles” is increasingly being challenged in contemporary rehabilitation science. Current evidence is shifting toward a motor control and task-oriented training paradigm, emphasizing coordinated movement strategies rather than isolated muscle activation. Therefore, future research should directly compare task-specific functional training that replicates real-life activities with biofeedback-assisted motor control training to determine which approach yields superior functional outcomes and motor learning retention.

Furthermore, future studies should consider incorporating real-time ultrasound (RTUS) assessment of abdominal muscle thickness, particularly the transversus abdominis and other deep trunk muscles, alongside functional and clinical outcome measures. Serial measurement of muscle thickness before and after the intervention could provide an objective indication of changes in muscle morphology and activation associated with motor control exercise. This would further strengthen the understanding of the physiological mechanisms underlying the effectiveness of MCE with RTUS biofeedback in individuals with chronic non-specific low back pain and help establish a more comprehensive relationship between changes in muscle characteristics, pain, functional activity, and core muscle strength.

Future studies could investigate the effectiveness of motor control exercises using real-time ultrasound (RTUS) biofeedback in women following Caesarean section, particularly focusing on the activation and recovery of the deep trunk muscles. RTUS could be used both to assess changes in muscle thickness and to provide visual biofeedback during targeted training. This may help determine whether RTUS-guided MCE can improve deep trunk muscle function and contribute to better functional recovery following Caesarean delivery.

Future research should consider incorporating a biopsychosocial model of rehabilitation when investigating chronic non-specific low back pain. In addition to physical impairments, factors such as psychological status, pain-related beliefs, fear-avoidance, stress, coping strategies, and social or occupational factors could be addressed alongside exercise-based interventions. This may provide a more comprehensive understanding of the multifactorial nature of chronic low back pain and potentially improve long-term functional outcomes.

Another important direction is the systematic evaluation of different types, intensities, and delivery modes of biofeedback technology. While this study utilized pressure-based biofeedback, emerging modalities such as electromyography (EMG) biofeedback, real-time ultrasound imaging, and wearable inertial or kinematic sensor-based

systems may provide different or superior therapeutic effects. Head-to-head comparative trials are required to determine the most effective, efficient, and patient-friendly biofeedback modality for clinical practice.

Future studies could examine whether smoking status influences the response to motor control exercise combined with RTUS biofeedback in individuals with chronic non-specific low back pain. Comparing smokers and non-smokers in terms of changes in pain, functional activity, and core muscle strength may provide valuable information regarding the potential influence of smoking-related factors on rehabilitation outcomes and treatment responsiveness.

Future studies should also adopt multi-center and multi-population designs involving participants from diverse demographic, geographical, cultural, and socioeconomic backgrounds. This would enhance the external validity and generalisability of findings while also identifying potential contextual and implementation-related barriers that may influence clinical application in real-world settings.

In addition, future research should incorporate cost-effectiveness analyses to evaluate the economic feasibility of advanced biofeedback systems in routine rehabilitation settings. This is particularly important for informing healthcare policy and resource allocation in both high- and low-resource environments.

Finally, future research should explore patient adherence, motivation, and behavioural factors influencing engagement with biofeedback-based rehabilitation programmes. Qualitative or mixed-methods studies may provide deeper insights into patient experience, acceptability, and long-term compliance, which are critical for successful implementation in clinical practice.

CHAPTER VI

CONCLUSION

This study demonstrates that Motor Control Exercises augmented with real-time ultrasound biofeedback yield superior outcomes in CNSLBP compared to conventional Lumbar Stabilization Exercises. The addition of biofeedback appears to enhance neuromuscular control by facilitating accurate muscle activation, resulting in greater reductions in pain intensity, improved functional activity, and increased core muscle strength.

The statistically significant improvements observed across all outcome measures in the experimental group suggest that biofeedback is not merely adjunctive but mechanistically relevant, likely influencing both motor relearning and pain modulation pathways. These findings reinforce the premise that targeted, feedback-driven interventions can address underlying motor control deficits more effectively than traditional approaches.

Overall, integrating real-time biofeedback into MCE represents a clinically meaningful advancement in CNSLBP rehabilitation, promoting precision in movement, individualized correction, and sustained functional gains. Future research should focus on long-term efficacy, optimization of training parameters, and the development of standardized clinical protocols to support broader implementation.

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APPENDICES

APPENDIX I – INFORMED CONSENT

Informed Consent Form for the Research Study: “Effects of Motor Control Exercises On Pain, Functional Activity, and Core Muscle Strength In Chronic Non-Specific Low Back”
Conducted by Ramakrishnan G V, Lecturer, School Of Physiotherapy, MAHSA University

This informed consent form is for men and women who attend MAHSA Physiotherapy Clinic located at MAHSA Avenue, Kuala Lumpur and Jalan Dato Hamzah, Klang, Selangor, and who we are invited to participate in research on Chronic Non-Specific Low Back Pain.

The title of research project is, **“Effects of Motor Control Exercises on Pain, Functional Activity and Core Muscle Strength in Chronic Non-Specific Low Back Pain”**

Name of the Researcher: Ramakrishnan G V

Phone Number: +60122601998

E-mail: ramakrishnan@mahsa.edu.my

This Informed Consent Form has two parts:

Part I - Information Sheet – Page 1 to 3 (to share information about the research with you)

Part II - Certificate of Consent – Page 4 (for signatures if you agree to take part)

You will be given a copy of the full Informed Consent Form

PART I – INFORMATION SHEET

Myself Ramakrishnan G V, conducting a research on effects of Motor Control Exercises on Chronic Non-Specific Low Back Pain. I am inviting you to be part of this research. Before you decide, you can talk to anyone you feel comfortable with about the research. Kindly go through the information provided in this information sheet. There may be few words that you do not understand, If so, please ask me for clarification and I will explain. If you have questions later, you can ask me.

Purpose of this Research Study: Chronic Non-Specific Low Back Pain is one of the major problem faced by many people due to poor postural habits and lack of exercise. The objective of this study is to compare the effects of Motor Control Exercises (MCE) and Lumbar Stabilization Exercises (LSE) on pain, functional activity, and core muscle strength in individuals with chronic non-specific low back pain. The reason for doing this research is to find out which of the prescribed exercise is more helpful in decreasing pain, improving physical function and core muscle strength in patients suffering from Chronic Non-Specific Low Back Pain.

Type of Research Intervention: In this research, the participants will be randomly assigned to one of the two groups. Participants of experimental group will be receiving Motor Control Exercises and participants of control group will be receiving Lumbar Stabilization Exercises over an 8-week period.

Participant selection: For this research, I'm inviting the participants who has been diagnosed with Chronic Non-Specific Low Back Pain by a General Practitioner and with the following inclusion & exclusion criteria.

INCLUSION CRITERIA

Patients clinically diagnosed by Physician as Chronic non-specific low back pain with at least 12 weeks of duration

Age group between 35-55 years

Both male and female subjects

EXCLUSION CRITERIA

Patients on current medical treatments in any form

Patients who underwent physiotherapy treatment in the past 3 months

Patients with radiating pain to lower limbs

Patients with any other series illness to any parts of the body

Patients who are mentally challenged

Patients with spinal stenosis, spondylolisthesis, spondylitis, spondylolysis

Patients with spinal deformities

Patients with a medical history of metabolic / cardiovascular / neurological disease

Voluntary Participation: Your participation in this research is entirely voluntary. It is your choice whether to participate. Regardless of your decision, all the services you receive at this clinic will remain unchanged. If you choose not to participate in this research project, you will receive the standard treatment routinely offered at this clinic for Chronic Non-Specific Low Back Pain, and we will provide you with more information about it. You may change your mind and withdraw from the study at any time, even if you initially agreed to participate.

Procedure / Protocol of Treatment & Its Duration: Upon participating in this study, the researcher will be asking you to provide demographic details such as name, age, gender, medical history, and any relevant background information. A routine physiotherapy assessment will be done, including pain measurement using Numeric Pain Rating Scale, Physical function assessment using Oswestry Disability Index and Core Muscle strength using pressure Biofeedback.

Participants assigned to the experimental group will receive Motor Control Exercises, while those in the control group will receive Lumbar Stabilization Exercises. Both groups will undergo treatment for a period of eight weeks. From weeks 1 to 4, two treatment sessions per week will be scheduled, and from weeks 5 to 8, one session per week will be scheduled. Each session will last approximately 60 to 75 minutes.

At the end of 8 weeks of physiotherapy treatment as per the protocol, participants will be reassessed using the Numeric Pain Rating Scale, Physical function assessment using Oswestry Disability Index and Core Muscle strength using pressure Biofeedback. Later, the collected data will be analysed using appropriate statistical methods.

Risks/ Side Effects: There are no risks associated to this study as these exercises are non-invasive and prescribed to selective participants who are suffering from Chronic Non-Specific Low Back Pain diagnosed by a general practitioner. The Motor Control Exercises & Lumbar Stabilization exercises prescribed in this study are designed to be safe and are commonly used in clinical and rehabilitation settings. However, participants may experience temporary muscle soreness, fatigue, or mild discomfort as a result of engaging in physical exercises. These potential side effects are generally considered mild and transient.

Benefits: *If you participate in this research, you will have the following benefits:*

- The physiotherapy treatment will be given free of charge during the research period.
- Improvement in pain levels, physical function, and core muscle strength
- Enhanced understanding of effective exercise strategies for low back pain management
- Data collected from your participation will contribute to the body of scientific knowledge surrounding CNSLBP and its management.

- Your contribution will help researchers and healthcare professionals gain deeper insights into the potential benefits of core strengthening exercises, which can inform future treatment strategies.

Reimbursements: There is no incentives for participating in this research. However, during the research period, the car parking charges will be waived. You will not be given any other money or gifts to take part in this research.

Confidentiality: The participant information that is collected from this research project will be kept confidential. Information about you that will be collected during the research will be put away and no-one but the researcher will be able to see it. Any information about you will have a number on it instead of your name. Only the researcher will know what your number and It will not be shared with or given to anyone.

Sharing the Results: The knowledge that I get from doing this research will be shared with you through meeting before it is made widely available to the public. Confidential information will not be shared. After these meetings, I will publish the results in order that other interested people may learn from my research.

Right to Refuse or Withdraw: You do not have to take part in this research if you do not wish to do so and refusing to participate will not affect your treatment at this clinic in any way. You will still have all the benefits that you would otherwise have at this clinic. You may stop participating in the research at any time that you wish without losing any of your rights as a patient here. Your treatment at this clinic will not be affected in any way.

Whom to Contact: *If you have any questions now / later or even after the study has started, you may contact me through phone call / WhatsApp/ Email*

Name: Ramakrishnan G V,

Hand Phone Number +60122601998 / Email: ramakrishnan@mahsa.edu.my

THANKYOU

PART II – CERTIFICATE OF CONSENT

STUDY TITLE: *Effects of Motor Control Exercises on Pain, Functional Activity and Core Muscle Strength in Chronic Non-Specific Low Back Pain*

Name of the Researcher: Ramakrishnan G V

Please tick the box if you agree with the statements below:

1. I have read and understood the information sheet provided by the researcher for this study. []
2. I have had the opportunity to ask questions about this study and these have been answered to my satisfaction. []
3. I understand that my participation is voluntary and that I am free to withdraw from the study at any time without giving any reason, without my medical care or legal rights being affected. []
4. I understand that relevant sections of any of my medical notes and data collected during the study will be kept confidential and will only be used for the purpose of this study. []
5. I give my written consent to take part in this study []

Name of the Participant:

Signature of the Participant:

Date:

APPENDIX II – ETHICAL APPROVAL LETTER



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UNIVERSITY

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BE MORE

Ref: MAHSA/RRC-FHSS/10-17(25)

29 September 2017

Researcher Name: Mr. Ramakrishnan G. Venkatachalam
Department of Physiotherapy, Faculty of Health & Sport Sciences, MAHSA University

Dear Mr. Ramakrishnan G. V.,

Research Proposal Review (Ref no: FAHS/PT/2017/07-19)

Title: Effects of motor control exercises on pain, functional activity and core muscle strength in chronic non-specific low back pain

The abovementioned project has been reviewed by the University Research Review Committee (RRC), MAHSA University on 18 July 2017. I am pleased to inform you that your project has been **approved** by the RRC. Since your research is approved, you may proceed with your research as planned in your research proposal.

Thank you.

Yours sincerely,

.....
Dato' Prof. Dr. Rozaidah Bt Talib
Deputy Vice Chancellor – Research & Innovation,
MAHSA University

Cc: Dean, Faculty of Health & Sport Sciences

APPENDIX III – PHYSIOTHERAPY ASSESSMENT FORM



MAHSA PHYSIOTHERAPY CLINIC

MAHSA Avenue, Block C Level 1
Jalan Ilmu, Off, Jln Profesor Diraja Ungku Aziz,
59100 Kuala Lumpur, Wilayah Persekutuan Kuala Lumpur

PHYSIOTHERAPY ASSESSMENT FORM	
Demographic Data Name: Age: Sex: Occupation:	Date of Assessment: Referred By:
Chief Complaints:	
On Observation:	
On Palpation:	
On Examination:	
Special Tests (if any):	Outcome Measures:
Physiotherapist Impression:	
Problem List:	
Short Term Goals:	Long Term Goals:
Next follow up assessment on:	
Assessed By Name of the Physiotherapist: Signature of the Physiotherapist:	

PAIN INTENSITY - NUMERICAL PAIN RATING SCALE

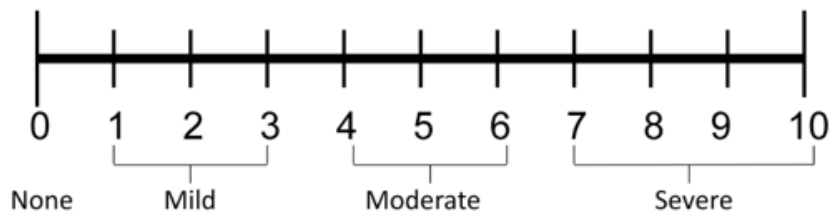
Numerical Pain Rating Scale – Pre Test Assessment

Patient Name:

Date of Assessment:

Numeric Pain Rating Scale (NPRS): The NPRS is an 11-point self-reporting pain assessment scale, on which 0 represents no pain and 10 describes the Worst Pain imaginable.

Dear patient, please indicate the intensity of your pain level by circling the number in the image below



Assessed By:

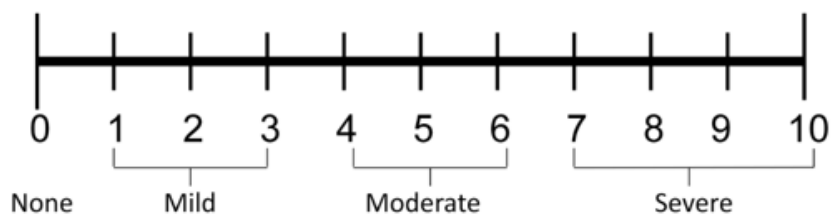
Numerical Pain Rating Scale – Post Test Assessment

Patient Name:

Date of Assessment:

Numeric Pain Rating Scale (NPRS): The NPRS is an 11-point self-reporting pain assessment scale, on which 0 represents no pain and 10 describes the Worst Pain imaginable.

Dear patient, please indicate the intensity of your pain level by circling the number in the image below



Assessed By:

DISABILITY - OSWESTRY DISABILITY INDEX

Oswestry Disability Index - Pre/Post Test Assessment

Patient Name:

Date of Assessment:

Oswestry Disability Index / Oswestry Low Back Pain Disability Questionnaire is an important tool that is used to measure a patient's permanent functional disability. The test is considered the 'gold standard' of low back functional outcome tools

Instructions

This questionnaire has been designed to give us information as to how your back or leg pain is affecting your ability to manage in everyday life. Please answer by checking ONE box in each section for the statement which best applies to you. We realise you may consider that two or more statements in any one section apply but please just shade out the spot that indicates the statement which most clearly describes your problem.

Section 1 – Pain intensity

- ☐ I have no pain at the moment
- ☐ The pain is very mild at the moment
- ☐ The pain is moderate at the moment
- ☐ The pain is fairly severe at the moment
- ☐ The pain is very severe at the moment
- ☐ The pain is the worst imaginable at the moment

Section 2 – Personal care (washing, dressing etc)

- ☐ I can look after myself normally without causing extra pain
- ☐ I can look after myself normally but it causes extra pain
- ☐ It is painful to look after myself and I am slow and careful
- ☐ I need some help but manage most of my personal care
- ☐ I need help every day in most aspects of self-care
- ☐ I do not get dressed, I wash with difficulty and stay in bed

Section 3 – Lifting

- ☐ I can lift heavy weights without extra pain
- ☐ I can lift heavy weights but it gives extra pain
- ☐ Pain prevents me from lifting heavy weights off the floor, but I can manage if they are conveniently placed eg. on a table
- ☐ Pain prevents me from lifting heavy weights, but I can manage light to medium weights if they are conveniently positioned
- ☐ I can lift very light weights
- ☐ I cannot lift or carry anything at all

Section 4 – Walking*

- ☐ Pain does not prevent me walking any distance
- ☐ Pain prevents me from walking more than 2 kilometres
- ☐ Pain prevents me from walking more than 1 kilometre
- ☐ Pain prevents me from walking more than 500 metres
- ☐ I can only walk using a stick or crutches
- ☐ I am in bed most of the time

Section 5 – Sitting

- ☐ I can sit in any chair as long as I like
- ☐ I can only sit in my favourite chair as long as I like
- ☐ Pain prevents me sitting more than one hour
- ☐ Pain prevents me from sitting more than 30 minutes
- ☐ Pain prevents me from sitting more than 10 minutes
- ☐ Pain prevents me from sitting at all

Section 6 – Standing

- ☐ I can stand as long as I want without extra pain
- ☐ I can stand as long as I want but it gives me extra pain
- ☐ Pain prevents me from standing for more than 1 hour
- ☐ Pain prevents me from standing for more than 3 minutes
- ☐ Pain prevents me from standing for more than 10 minutes
- ☐ Pain prevents me from standing at all

Section 7 – Sleeping

- ☐ My sleep is never disturbed by pain
- ☐ My sleep is occasionally disturbed by pain
- ☐ Because of pain I have less than 6 hours sleep
- ☐ Because of pain I have less than 4 hours sleep
- ☐ Because of pain I have less than 2 hours sleep
- ☐ Pain prevents me from sleeping at all

Section 9 – Social life

- ☐ My social life is normal and gives me no extra pain
- ☐ My social life is normal but increases the degree of pain
- ☐ Pain has no significant effect on my social life apart from limiting my more energetic interests eg, sport
- ☐ Pain has restricted my social life and I do not go out as often
- ☐ Pain has restricted my social life to my home
- ☐ I have no social life because of pain

Section 8 – Sex life (if applicable)

- ☐ My sex life is normal and causes no extra pain
- ☐ My sex life is normal but causes some extra pain
- ☐ My sex life is nearly normal but is very painful
- ☐ My sex life is severely restricted by pain
- ☐ My sex life is nearly absent because of pain
- ☐ Pain prevents any sex life at all

Section 10 – Travelling

- ☐ I can travel anywhere without pain
- ☐ I can travel anywhere but it gives me extra pain
- ☐ Pain is bad but I manage journeys over two hours
- ☐ Pain restricts me to journeys of less than one hour
- ☐ Pain restricts me to short necessary journeys under 30 minutes
- ☐ Pain prevents me from travelling except to receive treatment

Summation of Score Points

Total Score: _____ Points

Percentage Score: _____

Percentage Score: _____ %

$$\left(\frac{\text{TOTAL SCORE}}{\text{TOTAL POSSIBLE SCORE}} \right) \times 100$$

Assessed By: _____

Scoring instructions

For each section the total possible score is 5; if the first statement is marked the section score = 0; if the last statement is marked, it = 5. If all 10 sections are completed the score is calculated as follows:

Example: 16 (total scored)

$$50 \text{ (total possible score)} \times 100 = 32\%$$

If one section is missed or not applicable the score is calculated:

16 (total scored)

$$45 \text{ (total possible score)} \times 100 = 35.5\%$$

Minimum detectable change (90% confidence): 10% points (change of less than this may be attributable to error in the measurement)

Interpretation of scores

0% to 20%: minimal disability:	The patient can cope with most living activities. Usually no treatment is indicated apart from advice on lifting sitting and exercise.
21%-40%: moderate disability:	The patient experiences more pain and difficulty with sitting, lifting and standing. Travel and social life are more difficult and they may be disabled from work. Personal care, sexual activity and sleeping are not grossly affected and the patient can usually be managed by conservative means.
41%-60%: severe disability:	Pain remains the main problem in this group but activities of daily living are affected. These patients require a detailed investigation.
61%-80%: crippled:	Back pain impinges on all aspects of the patient's life. Positive intervention is required.
81%-100%:	These patients are either bed-bound or exaggerating their symptoms.

CORE MUSCLE STRENGTH – PRESSURE BIOFEEDBACK

Core Muscle Strength - Pressure Biofeedback - Pre Test Assessment

Patient Name:

Date of Assessment:

The Transversus Abdominis muscle function is assessed using Chattanooga Stabilizer Pressure Biofeedback system by is typically taking the monitoring pressure fluctuations on a pressure biofeedback device while the patient performs specific muscle contractions or maneuvers like abdominal drawing-in exercises.

Baseline Pressure	Measured Pressure Value	Difference of Pressure

Assessed by:

Core Muscle Strength - Pressure Biofeedback - Post Test Assessment

Patient Name:

Date of Assessment:

The Transversus Abdominis muscle function is assessed using Chattanooga Stabilizer Pressure Biofeedback system by is typically taking the monitoring pressure fluctuations on a pressure biofeedback device while the patient performs specific muscle contractions or maneuvers like abdominal drawing-in exercises.

Baseline Pressure	Measured Pressure Value	Difference of Pressure

Assessed by:

APPENDIX IV – LETTER OF CANDIDACY



School of Research Degree Programmes

LPU/RDP/EC/170307/48

Dated: 7th March 2017

G V Ramakrishnan
2/123, Kumudham Nagar
Vilankurichi Post Coimbatore
Tamil Nadu, India

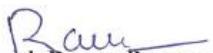
Dear Student,

Subject: Letter of Candidacy for Ph.D.

We are pleased to inform you that the Department Doctoral Board has approved your candidacy for the Ph.D. Programme on 29th September 2016(Thursday) by accepting your research proposal entitled: "EFFECTS OF MOTOR CONTROL EXERCISES ON PAIN,FUNCTIONAL ACTIVITY AND CORE MUSCLE STRENGTH IN CHRONIC NON-SPECIFIC LOW BACK PAIN." under the supervision of Dr. Arun B., Programme Leader, Mahsa University .

As a Ph.D candidate, you are required to abide by the conditions, rules and regulations laid down for Ph.D. Programme of the University, and amendments, if any, made from time to time.

We wish you the very best and in case you have any query related to your Programme, please do not hesitate to contact School of Research Degree Programmes.


HOS (Research Degree Programmes)

Jalandhar-Delhi G.T.Road, Phagwara, Punjab (India) - 144411

Ph : +91-1824-444594 Fax : +91-1824-240830 E-mail : drp@lpu.co.in website : www.lpu.in

APPENDIX V – REAL TIME ULTRASOUND MACHINE REGISTRATION CERTIFICATE

		No. Siri: Serial No.: 030428
ASAL ORIGINAL		
PIHAK BERKUASA PERANTI PERUBATAN	 	MEDICAL DEVICE AUTHORITY
PIHAK BERKUASA PERANTI PERUBATAN MEDICAL DEVICE AUTHORITY AKTA PERANTI PERUBATAN 2012 (AKTA 737) MEDICAL DEVICE ACT 2012 (ACT 737) SIJIL PENDAFTARAN PERANTI PERUBATAN MEDICAL DEVICE REGISTRATION CERTIFICATE Seksyen 5(1) Akta 737 Section 5(1) of Act 737		
No. Pendaftaran: Registration No.:	GB669571355019	Tarikh Sah Laku Pendaftaran: Registration Validity Date: 22/07/2019 – 21/07/2024
Sijil ini adalah dengan ini dikeluarkan kepada: <i>This Certificate is hereby issued to:</i>		
REHAMED HEALTHCARE SDN BHD		
yang beralamat di: of:	NO.12 GROUND FLOOR, JALAN SETIAWAN OFF JALAN TUN RAZAK 50400 KUALA LUMPUR, MALAYSIA 50400 KUALA LUMPUR	
bagi mengesahkan peranti perubatan seperti yang dinyatakan dalam Lampiran 1 adalah berdaftar di bawah Seksyen 5(1) Akta 737. <i>to confirm that the medical device as detailed out in Attachment 1 is registered under Section 5(1) of Act 737.</i>		
Pendaftaran ini diberikan tertakluk kepada peruntukan-peruntukan di bawah Akta 737 dan peraturan-peraturan yang dibuat dibawahnya serta syarat-syarat seperti di Lampiran 2. <i>This registration is granted subject to the provisions under Act 737 and its subsidiary legislations and the conditions as in Attachment 2.</i>		
	 AHMAD SHARIFF BIN HAMBALI Ketua Eksekutif Chief Executive Pihak Berkuasa Peranti Perubatan Medical Device Authority	

LAMPIRAN 1
Attachment 1



No. Pendaftaran: GB669571355019
Registration No.:

Berikut-butir peranti perubatan yang didaftarkan
Particulars of the registered medical device

Nama Peranti Perubatan **ACHIEVO V2U SOUND SYSTEM**
Medical Device Name

Kelas **CLASS B** Brand **V2U**
Class

Kelompok **SYSTEM**
Group

Nama dan alamat pembuat: **SHENZHEN WELL.D MEDICAL ELECTRONICS CO., LTD.**
Name and address of manufacturer: **WELL.D PARK, QINGLAN 3 RD., NATIONAL BIOPHARMACEUTICAL INDUSTRIAL BASE**
PINGSHAN NEW AREA
SHENZHEN

APPENDIX

No.	NAME AS PER DEVICE LABEL	IDENTIFIER	BRIEF DESCRIPTION OF ITEM
1.	V2U Sound Real Time Ultrasound	WED - 160	User-friendly Ultrasound Work-Station Managing System Produces real time visual biofeedback of the muscle movementAccessories: Ultrasound gel, ProbesFeatures: calculation software packages, patient data managing system, tissue harmonic imaging, Dicom 3.0
2.	Convex Probe	103-01SP	3.5MHz Convex Probe
3.	Linear Probe	103-02SP	7.5MHz Linear Probe

APPENDIX VI – DATA COLLECTION TABLE

OUTCOME MEASURE

PAIN (NPRS) /DISABILITY (ODI) /CORE MUSCLE STRENGTH (PBF)

PATIENT NO.	PRE-TEST	POST-TEST	DIFFERENCE
	(BASELINE)	(AFTER 8 WEEKS)	

APPENDIX VII – RESEARCH PROJECT OUTPUT

ORAL PRESENTATION					
S. No.	Topic	Conference Name	Place	Date	Mode
1	Effects of Motor Control Exercises in Chronic Non-Specific Low Back Pain	57 th Annual conference -Indian Association of Physiotherapists	Bangalore India	1 st and 2 nd February 2019	Face to Face
2	Motor Control Exercises With Real-Time Ultrasound Feedback For Managing Pain And Disability Among Patients With Chronic Non-Specific Low Back Pain	Mahsa International Conference on Advances in Life Science and Engineering (Mi-CALSE 2023) - MAHSA University	Bandar Saujana Putra, Selangor, Malaysia.	13 & 14 October 2023	Face to Face

PAPER PUBLICATION					
S. No.	TOPIC	JOURNAL NAME	MONTH & YEAR OF PUBLICATION	SJR	INDEXING
1	Motor Control Exercises With Real-time Ultrasound Feedback for Managing Pain and Disability Among Patients with Chronic Non-specific Low Back Pain	Malaysian Journal of Medicine and Health Sciences	May 2025 Volume: 21 Issue: 3 Page Number: 287 - 294	0.153	Scopus

CONFERENCE PRESENTATION CERTIFICATE

	57th ANNUAL CONFERENCE INDIAN ASSOCIATION OF PHYSIOTHERAPISTS IAPCONBANGALORE 2019 
CERTIFICATE	
This certificate of appreciation is awarded to Dr./Mr./Ms./Mss.....<u>RAMAKRISHNAN G.V.</u>..... Presented paper/poster titled.....<u>Effects of Motor Control Exercises in Chronic Non-specific Low Back Pain</u>..... under category of <u>PG student/ Clinician/ Academician/ Scholar</u> in 57TH Annual Conference of Indian Association of Physiotherapists.	
Date: February 1st and 2nd 2019 Venue: Palace Ground, Bangalore, Karnataka.	
 Dr. Sanjiv K Jha, (P.T) President Executive Central Committee, IAP	 Prof. Ifthikar Ali, (P.T) Organizing Chairman
 Dr. A Suresh Babu Reddy, PhD (PT) Organizing Secretary	 Dr. Pravin Aaron, DPT (LLU-USA) Chairperson-Scientific Committee
	 Dr. Pearlson K, PT Co-ordinator-Scientific Committee



MAHSA
UNIVERSITY



MACS
MAHSA ACADEMIC SOLUTIONS

**THIS CERTIFICATE OF APPRECIATION
IS PROUDLY PRESENTED TO**

RAMAKRISHNAN VENKATACHALAM

for his/her contribution as

PAPER PRESENTER

for the research paper entitled

**MOTOR CONTROL EXERCISES WITH REAL-TIME ULTRASOUND FEEDBACK FOR MANAGING
PAIN AND DISABILITY AMONG PATIENTS WITH CHRONIC NON-SPECIFIC LOW BACK PAIN**

at the

**MAHSA INTERNATIONAL CONFERENCE ON ADVANCES IN LIFE
SCIENCE AND ENGINEERING (MI – CALSE 2023)**

held on 13th & 14th of October, 2023

at

MAHSA UNIVERSITY, MALAYSIA

Organised by the

**CENTRE FOR PRE-UNIVERSITY STUDIES
& CENTRE FOR EDUCATION AND LANGUAGES**

DR. NUR FAUWIZAH AZAHAR
Conference Chair, MI-CALSE 2023,
MAHSA University, Malaysia

MASITAH BINTI MAT
Director, Centre for Pre-University
Studies, MAHSA University, Malaysia

DR. ANTONY V. SAMROT
Director, Research and Innovation,
MAHSA University, Malaysia

RESEARCH PAPER PUBLISHED

Malaysian Journal of Medicine and Health Sciences (eISSN 2636-9346)

ORIGINAL ARTICLE

Motor Control Exercises With Real-time Ultrasound Feedback for Managing Pain and Disability Among Patients With Chronic Non-specific Low Back Pain

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ABSTRACT

Introduction: Non-specific Low Back Pain (NSLBP) is the fifth leading cause of absenteeism from workplace and its considered quite challenging to treat in physical-therapy because of the nature of recurrence. Among the wide range of exercises, identifying the most suitable patient-centric exercise is crucial in relieving symptoms. This study aims to assess the changes following administering motor control exercises (MCE) providing appropriate biofeedback, on pain and functional activity among patients with chronic NSLBP. **Materials and methods:** This quasi-experimental study with consecutive sampling had a control and experimental group with forty-eight participants in each group. The control group received lumbar stabilization exercises (LSE) and experimental group received MCE with real-time ultrasound (RTUS) biofeedback for a period of 8 weeks. The subjects were measured for pain and functional activity using Numeric Pain Rating Scale (NPRS) and Oswestry Disability Index (ODI). **Results:** Results of within group analysis of NPRS and ODI scores revealed that there was a significant difference in both groups which means both interventions were effective. However, between-group analysis revealed that from baseline homogeneity, there was a significant difference between two groups at the end of intervention with experimental group subjects displaying less pain and disability compared to the control group. **Conclusion:** This study concluded that MCE administered with RTUS biofeedback was significantly more effective than LSE in reducing pain and functional disability in patients with chronic NSLBP. Enhanced motor control precision through biofeedback may help physiotherapists to tailor interventions more effectively, making it a valuable addition to physical-therapy protocols for chronic NSLBP. *Malaysian Journal of Medicine and Health Sciences* (2025) 21(3): 287-294. doi:10.47836/mjmh.21.3.33

Keywords: Non-specific low back pain, Numeric pain rating scale, Oswestry disability index, Motor control exercises, RTUS biofeedback

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INTRODUCTION

Non-Specific Low Back Pain (NSLBP) is identified as a major health issue worldwide. As the cause of pathology remains unidentified, this condition poses a serious challenge to the treating physical therapist both in clinical decision-making and treatment delivery. An experienced physical therapist should analyze the pain algorithm with in-depth anatomical knowledge and wise clinical decision-making to bring about a faster prognosis.

NSLBP is defined as low back pain not attributable

to a recognizable, known specific pathology such as osteoporosis, infection, fracture, or inflammation (1). NSLBP can be acute, sub-acute or chronic based on duration of the ailment and it accounts for 65% of visits to a physical therapist (2). The lifetime prevalence of NSLBP is as high as 84% with chronic LBP being the commonest (3). The economic burden and the global disability caused by this condition cannot be underestimated (4). NSLBP is reported as a self-limiting condition, in which the majority of cases recover in three to four months with or without treatment and only around 10% are challenging cases that do not respond to treatment much and need intense physical therapy and are challenging to the professionals (5).

Management of NSLBP mainly depends on individual variability in pain behavior, high probability of recurrence, lack of treatment generalizability, and so on

(6). NICE guidelines recommends non-pharmacological management and physical therapy treatment as first-line approach for NSLBP rather than analgesics and imaging (7). It emphasizes the importance on staying active and doing exercises as a part and parcel of any treatment protocol to prevent further damage to the underlying tissues and helps in faster recovery (8). Individual muscle exercises have always been taught in many musculoskeletal conditions by physiotherapists. There are controversial claims for its advantages and disadvantages. As a breakthrough in physiotherapy management of NSLBP, a study revealed that considering NSLBP as a single condition (homogenous event) will not lead to identifying the appropriate and effective intervention and hence there is a need for subgrouping them to aid clinical decision-making (9). Hence identifying an appropriate intervention based on reliable tools categorising the sub-group of ailment is mandatory. In this study, chronic NSLBP was considered as the main sub-group, as there is poor evidence for exercises in acute NSLBP management already (10,11). Having opted for exercise as an intervention, there is no clear determination as of now to state which type of exercises are effective in the management of Chronic NSLBP. Some suggestions range from a home exercise program to supervised exercises, then to progress with the structured exercise regimen. However, there is no clear consensus to state if these interventions differed in their effect (12, 13). Chronic NSLBP can be categorized into movement impairment (MI) and movement control impaired (MCI) subjects.

It is well accepted that NSLBP is due to the lack of stability in spinal musculature (14, 15, 16) and patients have impairments in the control of deep trunk muscles especially the transversus abdominis, which is responsible for maintaining the coordination and stability of the spine (17). Based on the above principle Motor Control Exercises (MCE) were developed with the aim of restoring the coordination, control and capacity of the trunk muscles (18). MCE involves the training of isolated contraction of deep trunk muscles with integration of these deep muscles contraction into more complex static dynamic and functional tasks (19, 20). MCE intervention involves the coordination and optimal control of global trunk muscles as well (21, 22).

Motor control theories emphasize learning for normal movement patterns to occur. However, learned abnormal movements become an issue in terms of chronic NSLBP patients, and consecutively unlearning becomes tougher and poses a big challenge for the physiotherapist. Re-learning or re-education of the normal motor strategy is essential in the management of chronic NSLBP. The anticipatory recruitment of trunk muscles particularly the Transversus Abdominis (TrA) and the multifidus is found to be the basis for any trunk or limb movement. These two muscles contract before the limb muscles move and thereby stabilize the motion

segments (23, 24). This anticipatory contraction is lost in NSLBP patients and as a result, the entire movement gets distorted. When it comes to lumbar stabilization exercises or core stabilization exercises using the motor control retraining concept, there have been so many conflicting results in the past that promote more research with specific objectives and specified populations (25, 26). This might be mainly due to a lack of proper execution of the exercise as it is very difficult to contract these deeply seated muscles. Voluntary contraction of these muscles needs more precision and practice and it takes a lot of understanding from the patient who is already in pain. If there was a biofeedback mechanism to exactly provide the patient with guidance, it might be easier for the patients to enhance or correct their performance.

The novelty of applying MCE using non-invasive Real-time ultrasound imaging (RTUS) feedback for NSLBP patients highlights on the key aspect of providing real time feedback to both the patients and the physiotherapists. Activation of TrA and multifidus has always been challenging which is easily met with RTUS. Apart from this, the precise targeting of deep muscle contraction, improvement in motor learning, objective monitoring and progress tracking are the advantages of this RTUS. The visual biofeedback also helps in engagement of patients in performing the exercises and provides continued motivation to the doer.

This research aims to assess the effectiveness of Motor Control Exercises (MCE) combined with biofeedback in reducing pain and improving functional activity in patients with chronic non-specific low back pain (NSLBP). The study will compare these outcomes with the traditional lumbar stabilization program typically administered to such patients.

The objectives of this research are as follows

- To evaluate the effects of Motor Control Exercises on pain reduction in patients with Chronic Non-Specific Low Back Pain.
- To evaluate the effects of Motor Control Exercises on improving functional activity in patients with Chronic Non-Specific Low Back Pain.

MATERIALS AND METHODS

The study is a Quasi-experimental study with a control group and experimental group with an allocation ratio of 1:1 with 48 subjects in each group. The subjects were selected if they were clinically diagnosed by the Physician as Chronic Non-Specific Low Back Pain (CNSLBP) from the outpatient department of two medical clinics and through consecutive sampling method, 96 subjects were finalised for the study and were allocated randomly into either of the groups – Control group and Experimental group by a random table method. The primary researcher was not aware of the process of randomization and came to know the

group only on the day of first session of intervention. The study was approved by The University Research Review Committee of MAHSA University (Ethical approval number MAHSA/RRC-FHSS/10-17(25)). All the subjects were briefed about the research process and an informed consent was obtained.

Subjects with a history of CNSLBP affecting their functional activity and between the age group of 35 and 55 years of both genders were included in the study. Subjects who were clinically diagnosed by a Physician as CNSLBP for a duration of 12 weeks at least were included in the study.

Subjects with a history of radiating pain to either of the limbs, tingling sensation, paraesthesia in any of the lower limbs, recent spinal fracture, spinal stenosis, spondylolisthesis, spondylitis, spondylolysis, spinal deformities were excluded from the study. Subjects with unstable medical condition like severe hypertension, uncontrolled diabetes, cardiovascular disorders, neurological deficit and mental instability were excluded from the study.

After the subjects were randomly allocated into the respective groups, a pre-test measurement for pain and functional activity were done using Numeric Pain Rating Scale (NPRS) and Oswestry Disability Index (ODI). NPRS is a unidimensional measure of pain intensity in adults that examines the responsiveness pain characteristics with a 11 point numeric scale with 0 at one end and 10 at other end, where zero represents no pain and ten represents worst possible pain (27). ODI is a patient-completed questionnaire which gives a subjective percentage score of level of function (disability) in activities of daily living in those rehabilitating from low back pain (28). Various parameters of pain are measured with each item consisting of 6 statements with a score of zero to five, where zero stands for least disability and five greatest disability. The total score is taken as percentage.

The experimental Group received MCE that was individualized and taught by a specially trained physical therapist according to a protocol on therapeutic exercise for lumbopelvic stabilization using RTUS feedback. The ultrasound equipment used was Full Digital Ultrasonic Diagnostic System (Version: V1. 3, PN NO.: WED-20-11050410E) manufactured by Shenzhen Well.D Medical Electronics Co. Ltd. Software version: V1.6.1.2 with standard musculoskeletal settings and the Curvilinear Convex Array (C3-1/60R/3-5 MHz) probe having a maximal detect depth of penetration upto +/- 190 mm was used to provide real-time feedback to patient. Hypoallergenic water-based ultrasound gel was used as a coupling medium for ultrasound. A frequency of 5 MHz was set to visualize the Transversus Abdominis (TrA) muscle while using the above-mentioned equipment.

Participants were positioned in supine lying with a pillow under the knees with ultrasound probe placed in transverse orientation on the anterolateral aspect of the abdominal wall (29) halfway between the iliac crest and inferior border of rib cage as shown in Figure 1(a) and the ultrasound probe moved until the best possible visualization of the lateral abdominal muscles as shown in Figure 1(b) and once visualization of TrA achieved participants were instructed to do Abdominal Drawing in Maneuver exercise and to watch the ultrasound screen with therapist's guidance to receive real-time feedback about the contraction of their TrA.

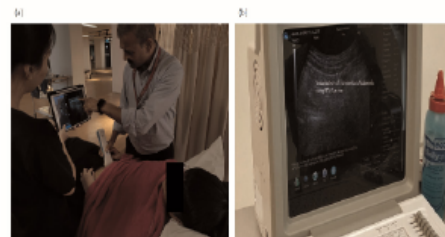


Figure 1: Ultrasound probe placement and visualization of abdominal muscles in Figures 1(a) and 1(b). (a) Placement of Ultrasound Probe in the lateral abdominal wall. (b) Real time ultrasound Imaging of the Abdominal Wall at rest visualizing Transversus Abdominis, External and Internal Oblique.

The execution of MCE program involved 2 stages in which the duration of Stage 1 was the first 4 weeks (weeks 1 – 4) which comprises the cognitive and associative phases of MCE whereas the Stage 2 is the next 4 weeks (weeks 5 – 8) which comprised the autonomous phase of MCE (21). Each participant progressed through the stages according to specific criteria that should have been met in each stage.

In Stage-1 training, the coordinated activity of the trunk muscles, including independent activation of the transversus abdominis, was initiated, and reducing over activity of specific superficial muscles was done in an individualized manner with RTUS feedback. These exercises were supplemented with exercises for the pelvic floor muscles, breathing control, and control of spinal posture and movement. The specific muscles that were trained depended on the initial assessment. RTUS biofeedback that was directly fed into the patient's attention which was used to enhance the learning of the tasks of transversus abdominis training. The stage 1 training (Weeks 1 – 4) of TrA muscle was continued until the patients were able to maintain the isolated contractions of TrA muscle for ten repetitions of ten seconds each while maintaining normal respiration. When this level of competence was achieved, patients were considered ready to progress to the next stage. In Stage 2 (weeks 5 – 8), the patients were positioned in fowlers position and the activation of TrA muscle

from static to dynamic position through the movement of hips and knees making the static into dynamic tasks in functional positions. The exercise program involved increasing the complexity by changing the fowlers position from low to semi fowlers position and the exercises progressed with functional tasks (like holding a ball, changing a ball from hand to hand) while attempting to maintain the TrA contraction and these exercises targeting coordination of trunk and limb movement, maintenance of optimal trunk stability, and improvement of posture and movement patterns.

Participants received 12 sessions of treatments for 30 minutes over eight weeks (Two sessions per week in the first Four weeks & and One session in the second Four weeks). Control group participants received Lumbar stabilization exercises for the same specific period as mentioned above for motor control exercises. The subjects were trained without the Real-time ultrasound biofeedback, using manual guidance and auditory feedback alone by the therapist. A post-test was taken for both outcome measures at the end of eight weeks.

Statistical analysis

The SPSS 25 version of software was used for computing the statistics of this study. The significance level for the study was fixed at 0.05 with a confidence interval of 95%. Chi square analysis was done to analyze the baseline homogeneity between the demographic data of the subjects. The homogeneity of data and normal distribution were analyzed through the Shapiro-wilk test and Kolmogorov-Smirnov test. The within-group analysis of parametric score was done through Paired t-test and between group was done and between group analysis was done through an Independent t-test.

RESULTS

There were 96 subjects who accounted for the study results. The demographic data were analyzed for the baseline homogeneity. The data were distributed normally as per Kolmogorov-Smirnova and Shapiro-Wilk test and represented in Table I.

Table I: Statistical test of normality

Outcome Measure	Kolmogorov-Smirnov ^a			Shapiro-Wilk		
	Statistic	Degree of freedom	Significance	Statistic	Degree of freedom	Significance
Numerical Pain Rating Scale	1.98	96	0.197	2.942	96	0.105
Oswestry Disability Index	2.14	96	0.207	3.457	96	0.166

The demographic data of the subjects - distribution of age, sex, duration of ailment, presence of radiating symptoms, and side of predominance of pain was

assessed and presented in Table II for group differences and the results showed that groups were homogenous in all the criteria except the duration of ailment where the subjects in the experimental group were more chronic than the control. Hence, any changes that occurred in the dependent variable should be mostly because of the independent variable. Figure 2(a) shows the gender distribution of samples within control and experimental groups and Figure 2(b) shows the age distribution of samples within control and experimental groups for this study.

Table II: Analysis of the demographic data

Criteria	Control Group	Experimental Group	Significance
Age			
35-40	19	23	Chi-square = 2.134 P = 0.545
41-45	16	12	
46-50	12	10	
51-55	01	03	
Sex			
Male	30	27	Chi-square = 0.3887 P = 0.5330
Female	18	21	
Duration of ailment	14.5	18.72	t-test t=7.276 P=0.024
Radiating symptoms			
Yes	11	14	Chi-square = 0.486 P = 0.485
No	37	34	
Side predominance			
Right	6	7	Chi-square = 0.537 P = 0.764
Left	5	7	
Central/bilateral	37	34	

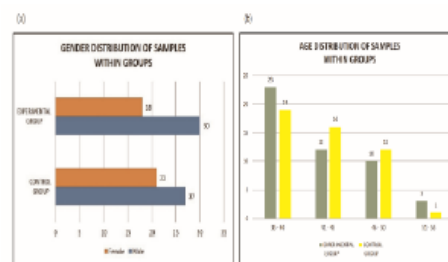


Figure 2: Demographic characteristics of samples within control and experimental groups in Figures 2(a) and 2(b). (a) Gender distribution of samples within groups. (b) Age distribution of samples within groups.

The primary outcome measures were analyzed for both within-group differences and between-group differences using parametric tests respectively. The within-group analysis of the ODI and NPRS scores revealed that there was a significant difference (at $P < 0.05$) between the temporal variables in both groups which means both interventions were effective in reducing pain and functional activity (Table III). Figure 3(a) displays Pre and Post test mean for Numerical Pain Rating Scale and Oswestry Disability Index within groups and

Figure 3(b) Mean difference for Numerical Pain Rating Scale and Oswestry Disability Index between control and experimental groups. However, the between-group analysis using independent t-test revealed that from a baseline homogeneity, there was a remarkable difference between the control and experimental groups as shown in Table IV. At the end of the intervention with experimental group subjects displaying less pain and disability compared to the control group with a significant difference (at $P < 0.05$) which showed that experimental group is more effective in reducing pain and improving functional activity when compared with control group. Figures 4A and 4B display the difference of mean values of NPRS and ODI between control and experimental groups.

Table III: Within-group analysis of the outcome measures

Outcome Measure / Group	Test	N	Mean	Standard Deviation	t-value	P value
NPRS-Control Group	PRE TEST	48	7.79	0.922	-23.27*	0.001
	POST TEST	48	3.44	1.109		
NPRS-Experimental Group	PRE TEST	48	7.75	0.786	-50.470*	0.001
	POST TEST	48	0.71	0.651		
ODI-Control Group	PRE TEST	48	67.49	9.162	-20.549	0.013
	POST TEST	48	34.02	10.606		
ODI-Experimental Group	PRE TEST	48	69.40	10.138	-28.422*	0.001
	POST TEST	48	11.71	9.594		
Total				96		

Notes: *NPRS – Numerical Pain Rating Scale; *ODI – Oswestry Disability Index

*Statistically significant difference at $P < 0.05$

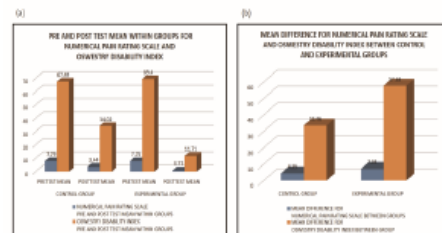


Figure 3: Mean for outcome measures within groups and Mean difference between groups in Figures 3(a) and 3(b). (a) Pre and Post test mean for Numerical Pain Rating Scale and Oswestry Disability Index within groups. (b) Mean difference for Numerical Pain Rating Scale and Oswestry Disability Index between control and experimental groups.

Table IV: Between-group analysis of the outcome measures

Out- come Measure / Test	Groups	N	Mean	Standard Deviation	t-test	P-value
NPRS- PRE TEST	Control Group	48	7.79	0.92	0.238	0.812
	Experi- mental Group	48	7.75	0.79		
NPRS- POST TEST	Control Group	48	3.44	1.11	14.70*	0.001
	Experi- mental Group	48	0.71	0.65		
ODI- PRE TEST	Control Group	48	67.49	9.162	1.124	0.644
	Experi- mental Group	48	69.40	10.138		
ODI- POST TEST	Control Group	48	34.02	10.606	28.15*	0.001
	Experi- mental Group	48	11.71	9.594		
	Total			96		

Notes: *NPRS – Numerical Pain Rating Scale; *ODI – Oswestry Disability Index

*Statistically significant difference at $P < 0.05$

DISCUSSION

Chronic NSLBP has remained a major health issue with a high prevalence (30). While continuous research had always been conducted to overcome this problem, there was still a significant gap in engaging the core muscles and helping patients understand the importance of activating the TrA and multifidus. It was mainly because the exercise was not always willingly performed by the patients or even if done was not done targeting the exact group of muscles needed (31). Hence this study was conducted with among 96 subjects between the age group of 35 and 55 years of both genders who had complaints of low back pain for 12 weeks duration. The study compared the lumbar stabilization exercises against the motor control exercises with RTUS feedback for a period of eight weeks. The results of the study showed that both the groups performed well in both outcome measures. However, the subjects in the experimental group showed a better improvement than the control group participants in the standing, weight lifting, and walking component of the ODI. This is in line with the meta-analysis of the previous study that judged that MCT (motor Control Training) was effective in reducing the pain and disability associated with chronic back pain among community dwelling adults (32). This is due to the fact that the MCE can reduce the

over activity (33) of certain group of muscles and also at the same time reduce the muscle fatigue (34) thereby maintaining the properties of the contractile structure (35). The integration of biofeedback with the performance of exercise has helped the participants achieve the activation of the target muscle more precisely in the experimental group. This techno-assisted exercise has proven results in adaptive functions of core muscles with a proportional increase in type I fibers (36). The ability to observe and correct the muscle activation patterns in real time ensures that exercises are optimized for each patient, addressing specific imbalances or dysfunctions contributing to CNSLBP (37). The study displays high coherence in the conductance of the research because of the interactive element that increased the motivation of the participants and adherence to the rehabilitation program. This approach allows clinicians to dynamically assess a patient's performance and adjust the rehabilitation plan accordingly (38).

The novelty of the current is the incorporation of real-time ultrasound feedback into motor control exercises which is a distinct feature. The precision achieved through real-time ultrasound feedback allows for a more tailored and individualized rehabilitation approach. This adaptability ensures that the exercises evolve with the patient's progress and changing needs, making the intervention more responsive and effective over time. The study may contribute to a deeper understanding of muscle activation patterns in individuals with CNSLBP by utilizing RTUS. Researchers and clinicians can gain insights into how specific muscles respond to various exercises and how these patterns correlate with pain reduction and functional improvements.

CONCLUSION

This study concludes that motor control training when provided along with real-time ultrasound biofeedback is an effective intervention tool in managing pain a disability associated with chronic NSLBP. Future studies should concentrate on providing pain counselling along with MCT in countering other ailments associated with chronic NSLBP.

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Title of the work: Innovative Motor Control Training with Real-Time Ultrasound Feedback Compared to Lumbar Stabilization in Chronic Non-Specific Low Back Pain

Name of authors: G.V. Ramakrishnan, and Dr. Suresh Mani

Summary of Graphical Abstract: This study compared Motor Control Exercises (MCE) with Real-Time Ultrasound feedback to Lumbar Stabilization Exercises (LSE) in patients with Chronic Non-Specific Low Back Pain. Over 8 weeks, MCE with ultrasound feedback led to greater reductions in pain, disability, and improved core muscle strength, highlighting the effectiveness of feedback-based motor retraining in managing low back pain

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**EFFECTS OF MOTOR CONTROL EXERCISES ON PAIN,
FUNCTIONAL ACTIVITY AND CORE MUSCLE
STRENGTH IN CHRONIC NON-SPECIFIC
LOW BACK PAIN**

Thesis Submitted for the Award of the Degree of

DOCTOR OF PHILOSOPHY

in

Physiotherapy

By

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