KMANPUB | Health Nexus Vol. 3 No. 4 (2025): 1-11

Article history:
Received 14 July 2025
Revised 23 September 2025
Accepted 27 September 2025
Published online 01 October 2025

The Effect of Eight Weeks of Selected Sensorimotor Exercises and Comprehensive Postural Reeducation on Lumbar Lordosis Angle and Postural Control in Women with Lower Crossed Syndrome

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Article Info

Article type:
Original Research

How to cite this article:
Miri, H., Soltani, M., & Nasri, M. (2025). The Effect of Eight Weeks of Selected Sensorimotor Exercises and Comprehensive Postural Reeducation on Lumbar Lordosis Angle and Postural Control in Women with Lower Crossed Syndrome. *Health Nexus, 3*(4), 1-11.
https://doi.org/10.61838/kman.hn.3.4.12

ABSTRACT

This study aimed to compare the effects of an eight-week program of selected sensorimotor exercises and a comprehensive postural reeducation protocol on lumbar lordosis angle and dynamic postural control in women with lower crossed syndrome. This applied, semi-experimental study employed a pretest–posttest design with two intervention groups and one control group. Thirty-six women aged 35–60 years diagnosed with lower crossed syndrome were recruited through purposive and convenience sampling and randomly assigned into three groups: sensorimotor training, comprehensive postural reeducation, and control. The interventions were conducted three times per week for eight weeks; each sensorimotor session lasted 40 minutes and focused on deep trunk activation and proprioceptive training, while postural reeducation sessions lasted 60 minutes and emphasized global myofascial stretching and sagittal alignment. Lumbar lordosis angle was measured using a flexible ruler, and dynamic postural control was assessed with the Star Excursion Balance Test (SEBT) for both dominant and non-dominant legs. Data were analyzed using analysis of covariance (ANCOVA) to compare post-intervention outcomes across groups. ANCOVA showed a significant group effect on lumbar lordosis angle ($F = 22.45$, $p < 0.001$, $\eta^2 = 0.59$), with both sensorimotor and postural reeducation groups achieving significant reductions compared to the control group, and postural reeducation outperforming sensorimotor training (mean difference = −2.01°, $p = 0.032$). For dynamic postural control, the sensorimotor group demonstrated significantly greater improvements than the control group in SEBT scores for both dominant (mean difference = 9.25%, $p = 0.014$) and non-dominant legs (mean difference = 12.47%, $p = 0.008$), while postural reeducation alone showed no significant advantage over control for balance outcomes. Both interventions improved spinal alignment in women with lower crossed syndrome, while sensorimotor training produced superior gains in functional balance.

Keywords: *Lower crossed syndrome; lumbar lordosis; postural control; sensorimotor training; postural reeducation; dynamic balance.*

1. Introduction

Lower crossed syndrome (LCS) is a common musculoskeletal condition characterized by muscular imbalances and abnormal lumbopelvic alignment that lead to altered posture, mechanical low back pain, and functional instability. In this pattern, tightness in the lumbar erector spinae and hip flexors coexists with weakness of the abdominal and gluteal muscles, resulting in anterior pelvic tilt and increased lumbar lordosis (1, 2). This faulty alignment can alter the biomechanics of the spine and pelvis, overload passive structures, and compromise balance and postural control (3, 4). Clinically, women are often affected due to anatomical and hormonal factors that predispose them to increased pelvic tilt and changes in spinal curvature during life stages such as pregnancy or postpartum (5, 6). Excessive lordosis is not merely an aesthetic deviation but is linked to persistent low back pain, reduced core endurance, and impaired functional movements (7, 8).

Postural stability, which is crucial for safe daily movement, depends on efficient neuromuscular control of the trunk and pelvis (9, 10). Hyperlordotic posture disrupts this control by altering proprioceptive feedback and muscular recruitment, increasing the risk of falls, pain, and disability (1, 11). Core stability exercises have long been considered a key therapeutic strategy to address these deficits. Strengthening the transversus abdominis, multifidus, and gluteus maximus can reduce anterior pelvic tilt and support spinal alignment (12, 13). These exercises have demonstrated improvements in pain, lumbar range of motion, and performance of daily activities in various populations with low back dysfunction (7, 14). However, the optimal combination and intensity of sensorimotor and postural reeducation techniques remain under investigation.

The role of sensorimotor training has gained attention for its capacity to integrate proprioception, neuromuscular control, and core activation. Sensorimotor exercises, such as quadruped arm–leg raises (bird-dog), abdominal hollowing, and bridging variations, improve the dynamic control of the spine by re-educating deep stabilizers and enhancing lumbopelvic rhythm (12, 15). Previous studies show that such exercises can significantly improve pain intensity and functional scores in patients with lumbar disc herniation and chronic low back pain (9, 16). Moreover, proprioceptive retraining addresses delayed activation of the multifidus and transversus abdominis muscles, which is frequently observed in individuals with lumbar hyperlordosis (8).

Comprehensive postural reeducation offers another promising therapeutic path. This approach emphasizes active stretching of shortened anterior and posterior myofascial chains and training the body to maintain optimal sagittal alignment through sustained therapeutic postures and controlled breathing (1, 17). Techniques such as three-dimensional myofascial release have been found to reduce lumbar curvature and improve posture among asymptomatic hyperlordotic individuals (17). Global postural reeducation also supports functional improvements by modifying compensatory movement strategies and enhancing proprioceptive input (13, 18). These methods aim not only to correct static misalignment but also to teach the nervous system efficient patterns for daily movement, potentially reducing the recurrence of pain and dysfunction.

Excessive lumbar lordosis is associated with diverse clinical consequences, including mechanical low back pain, degenerative spinal changes, and reduced dynamic stability (19-21). Spinal malalignment alters load transmission and increases the risk of adjacent segment disease following lumbar fusion surgeries, underscoring the importance of restoring sagittal balance (22, 23). Studies evaluating sagittal alignment show that inappropriate lordotic curvature negatively influences patient-reported outcomes in spinal stenosis and spondylolisthesis (24, 25). Even non-surgical populations may experience progressive discomfort and disability if sagittal imbalance persists (26, 27).

Another emerging theme in the literature is the relationship between lumbar curvature and core endurance. Deficits in deep trunk endurance correlate with hyperlordotic postures and reduced performance on functional movement screening tests (3, 4). Addressing these deficits early could prevent chronic low back pain progression and related disability (14, 15). Furthermore, recent randomized controlled trials confirm that core stabilization programs, including Pilates and motor control exercises, produce measurable improvements in spinal curvature, dynamic balance, and daily activity participation (7, 12). However, while sensorimotor interventions can enhance balance and functional control, some evidence suggests that adding global postural realignment may have superior effects on sagittal plane correction (1, 13).

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E-ISSN: 2981-2569

In clinical settings, there is also increasing emphasis on selecting non-invasive, valid, and reproducible tools for assessment and follow-up. Tools like the flexible ruler for measuring lumbar lordosis provide safe and highly reliable alternatives to radiography (10, 28). Dynamic balance assessments, such as the Star Excursion Balance Test (SEBT), offer functional insights into neuromuscular control and are widely validated across populations (11, 18). These measures enable precise monitoring of therapeutic progress and allow clinicians to tailor interventions effectively.

Despite significant progress, research gaps remain regarding the comparative effectiveness of exercise-based interventions targeting both local and global control of the spine. Some studies report that core-focused programs alone may not fully address structural malalignment if compensatory myofascial restrictions persist (5, 27). Conversely, global postural approaches may improve static alignment but require complementary sensorimotor strategies to influence dynamic stability (1, 17). Furthermore, population-specific considerations, such as female musculoskeletal characteristics and age-related flexibility decline, necessitate targeted research in women experiencing LCS (5, 6).

Recent systematic reviews and experimental studies underline the necessity of multimodal, progressive programs that address both the structural and functional dimensions of lumbar disorders (2, 29). This approach integrates core activation, proprioceptive training, stretching of shortened chains, and breathing coordination to support lasting changes in posture and spinal health (13, 19). Moreover, understanding how to personalize these interventions based on baseline sagittal alignment and neuromuscular control deficits can enhance outcomes and reduce recurrence (21, 26).

Given the high prevalence of lower crossed syndrome and its impact on function and quality of life, it is crucial to establish effective, evidence-based corrective strategies for this population. The present study responds to this need by comparing the effects of an eight-week program of selected sensorimotor exercises and a comprehensive postural reeducation protocol on lumbar lordosis angle and postural control in women with LCS. By integrating validated assessment tools and drawing on recent advances in exercise therapy and postural rehabilitation, this research aims to clarify the differential benefits of two structured non-invasive interventions and contribute to clinical decision-making for the management of spinal malalignment and functional instability in women.

2. Methods and Materials

2.1. *Study Design and Participants*

This applied semi-experimental study was conducted using a pretest–posttest design with two intervention groups and one control group. Because of the quasi-experimental nature of the study, it was not possible to control all external variables affecting the outcomes; however, the researcher minimized these factors by maintaining uniform testing conditions and closely monitoring the intervention sessions. The statistical population included all women aged 35 to 60 years in Qazvin city who had been clinically diagnosed with lower crossed syndrome. The sample size was determined based on previous research in this field and statistical power considerations. Thirty-six women who met the inclusion criteria were recruited using purposive and convenience sampling and were randomly assigned into three groups of twelve: the first experimental group received selected sensorimotor exercises, the second experimental group underwent comprehensive postural reeducation, and the control group received no specific intervention. One participant from the control group was excluded due to inability to complete the sessions.

Diagnosis of lower crossed syndrome was performed using a standardized clinical protocol. Muscle tightness in the hip flexors was assessed through the modified Thomas test by observing hip and knee angles while the participant lay supine and pulled one knee to the chest. Tightness in the lumbar erector spinae was examined by having participants sit and attempt to reach their forehead to their knees, observing for restricted spinal flexion. Gluteus maximus weakness was identified with the prone hip extension test by palpating activation order during leg elevation. Abdominal weakness was evaluated using a trunk flexion endurance test, requiring participants to maintain scapular lift for repeated attempts. Anterior pelvic tilt angle was measured using a smartphone inclinometer application (iHandy), and lumbar lordosis angle was measured non-invasively with a flexible ruler following the [$\theta = 4 \times \arctan(2H/L)$] formula.

E-ISSN: 2981-2569

Pain intensity was measured with the Visual Analogue Scale (VAS). These combined measures ensured accurate identification of lower crossed syndrome and baseline assessment of musculoskeletal and postural parameters.

Inclusion criteria were female sex, age 35–60, confirmed diagnosis of lower crossed syndrome, no history of regular exercise or corrective training in the past two years, and absence of neuromuscular or systemic disorders that could affect study outcomes. Exclusion criteria included receiving concurrent therapeutic interventions such as physiotherapy or medication affecting back pain, participation in other interventional studies, pregnancy, prior lumbar, pelvic, or sacral surgery, neurological involvement signs, bladder or bowel dysfunction, and inability to complete the training sessions. All participants provided informed consent, were briefed about the study procedures, and were informed of their right to withdraw at any time.

2.2. Measure

Anthropometric characteristics, including height and weight, were measured using a flexible non-elastic tape and a Feller digital scale (model PS801, China). A Q&Q chronometer with 1/100 second precision (Japan) was used to time functional tests. Lumbar lordosis angle was measured with a flexible ruler manufactured by Ghamat Pouyan (Iran), which has demonstrated high validity compared with radiographic methods (correlation ≈0.91) and excellent intra- and inter-rater reliability (typically >0.80). Postural control was assessed using the Star Excursion Balance Test (SEBT), a dynamic test evaluating reach distance in eight directions while maintaining balance on the supporting leg. The SEBT is recognized for high validity in assessing balance, functional stability, and lower extremity performance, with strong reliability when administered by trained assessors. The Persian version of the Oswestry Disability Index (ODI) was used to evaluate functional disability.

The lumbar lordosis measurement process followed a standardized procedure: participants stood naturally with relaxed posture, and a flexible ruler was positioned along the spinous processes from L1 to S1. The apex of the curve and endpoints were marked to calculate the arch length (L) and height (H). The lordotic angle was then calculated. This method provided a safe, non-invasive, and reproducible assessment of spinal curvature. For SEBT, participants stood on the dominant leg at the center of an eight-direction star marked on the floor and reached as far as possible with the contralateral foot in each direction without losing balance. Three trials per direction were performed, and the maximum reach distance was recorded in centimeters and normalized to leg length when needed.

2.3. Interventions

The sensorimotor exercise program in this study consisted of six standard exercises performed over eight consecutive weeks, three sessions per week, with each session lasting approximately 40 minutes. The selected movements were designed to activate deep trunk stabilizers, improve proprioception, and enhance dynamic postural control. Each participant was individually instructed and supervised to ensure correct performance and gradual progression. The session began with the "hollowing exercise," where participants assumed an all-fours position and gently drew the abdominal wall upward toward the navel while maintaining spinal neutrality, aiming to activate the transversus abdominis and multifidus muscles. This was followed by "single-leg lifts in quadruped," in which one lower limb was extended and lifted in line with the trunk while maintaining balance, then repeated on the opposite side to improve lumbopelvic stability. The "bird-dog exercise" (contralateral arm and leg raise) was then performed, combining upper and lower limb movement to challenge cross-body coordination and trunk control. The "abdominal bracing exercise" in a supine position required participants to flex the hips and knees to 90 degrees, gently protrude the abdomen during inhalation, and contract the core during exhalation, reinforcing controlled diaphragmatic breathing and trunk stability. The next progression involved the "bridging hold," where participants lifted the pelvis from the supine position while maintaining knee and foot alignment to strengthen the gluteus maximus and posterior chain without lumbar hyperextension. Finally, the "single-leg bridging" exercise was introduced, extending one leg from the bridging position to increase core and pelvic control demands. Each exercise was adjusted according to individual capacity, with modifications in range of motion or hold duration as participants improved over the training weeks. Rest intervals between sets were brief to maintain muscular engagement and neuromuscular activation.

The comprehensive postural reeducation program was an eight-week progressive intervention performed three times per week, with each session lasting approximately 60 minutes. The program combined active stretching and global postural realignment exercises to address anterior and posterior muscular chain imbalances characteristic of lower crossed syndrome. Each session included three structured therapeutic postures aimed at lengthening shortened muscles, promoting axial elongation, and retraining body alignment while integrating controlled breathing. During the first two weeks, participants practiced supine postures targeting the anterior and posterior muscular chains; for the anterior chain, individuals lay on their backs with arms abducted to about 30 degrees and feet together, while the therapist applied gentle manual traction to the lumbar and cervical spine to encourage extension and opening of the front body. Posterior chain stretching involved supine flexion of the hips and knees with ankles dorsiflexed, gradually increasing hip and knee flexion each session to elongate the erector spinae and hamstrings. In subsequent weeks, these postures were deepened by increasing joint range and intensity of the therapist's manual adjustments, while participants focused on diaphragmatic breathing to facilitate muscle relaxation and postural awareness. Starting from week five, standing posterior chain stretches were introduced, encouraging forward trunk flexion with controlled alignment of the occiput, thoracic spine, and sacrum to optimize posterior tissue lengthening. Later weeks emphasized progressive mobility and stability while maintaining correct posture, integrating deeper anterior chain opening and enhanced posterior flexibility. Throughout the intervention, participants were taught to maintain spinal neutrality, elongate through the crown of the head, and regulate breathing to reduce muscle tension and improve proprioception. Additionally, simple daily home exercises were prescribed, including basic anterior and posterior chain stretches performed in three sets of ten repetitions with a focus on slow, controlled movements and deep breathing. This structured and individualized reeducation approach sought to restore balanced alignment, correct compensatory patterns, and enhance postural control in daily activities.

2.4. Data Analysis

Data analysis included both descriptive and inferential statistics. Descriptive statistics such as mean, standard deviation, and frequency distribution were calculated to summarize demographic and baseline characteristics of the participants. Normality of data distribution was tested using the Kolmogorov–Smirnov test. For inferential analysis, analysis of covariance (ANCOVA) was applied to compare post-intervention outcomes among the three groups while controlling for baseline pretest values. This approach allowed the evaluation of the independent effect of each exercise program on lumbar lordosis angle, postural control, and functional disability. All statistical analyses were conducted using SPSS software version 22, and the significance level was set at $p < 0.05$.

Throughout the study, the researcher supervised exercise sessions to ensure correct performance and adherence to the protocol. Both intervention groups completed eight weeks of training, three sessions per week, each lasting 40 to 60 minutes. The sensorimotor exercise group focused on proprioceptive and neuromuscular training, while the postural reeducation group engaged in targeted postural correction and movement retraining. The control group maintained usual daily activities without structured exercise. This design and analysis framework provided robust evidence for evaluating the effects of the two exercise interventions on spinal alignment and postural control in women with lower crossed syndrome.

3. Findings and Results

The present study investigated the effects of eight weeks of selected sensorimotor exercises and comprehensive postural reeducation on lumbar lordosis angle, postural control, and functional disability in women with lower crossed syndrome. The findings are presented first by describing the demographic and baseline characteristics of the participants, then reporting the results of postural control assessment using the Star Excursion Balance Test (SEBT), and finally presenting pre- and post-intervention outcomes across the three study groups for lumbar lordosis angle, dynamic balance, and functional disability.

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E-ISSN: 2981-2569

Table 1

Individual characteristics of women with lower crossed syndrome (Mean ± SD)

Groups	Frequency (n)	Age (years)	Standing height (cm)	Weight (kg)	BMI (kg/m²)
Sensorimotor	12	41.91 ± 4.33	163.75 ± 5.72	69.25 ± 8.49	25.92 ± 3.82
Postural Reeducation	12	43.50 ± 7.82	164.41 ± 4.35	67.08 ± 11.24	24.84 ± 4.24
Control	11	41.90 ± 7.35	161.18 ± 4.46	61.72 ± 7.83	23.72 ± 2.51

The participants in all three groups were comparable in terms of demographic and anthropometric characteristics at baseline. The mean age ranged between approximately 42 and 44 years across groups, with no statistically significant differences observed. Standing height and body weight were similar, resulting in BMI values within the overweight range but homogeneous among groups. The similarity of baseline characteristics suggests that the randomization process was effective in balancing key individual variables and minimizing potential confounding effects prior to the intervention.

Table 2

Percentage scores of the Star Excursion Balance Test for dominant and non-dominant legs

Movement Direction	Dominant Leg (%)	Non-Dominant Leg (%)
Anterior	63	61
Anteromedial	69	65
Medial	72	70
Posteromedial	80	79
Posterior	78	68
Posterolateral	81	80
Lateral	69	68
Anterolateral	68	67

Dynamic postural control, as assessed by the SEBT, revealed generally higher reach percentages in the posterolateral and posteromedial directions for both the dominant and non-dominant legs, indicating better stability and reach capacity posteriorly. Anterior and anterolateral directions had the lowest percentages, reflecting greater postural challenge and reduced reach ability in forward and diagonal planes. Although these data describe pooled reach performance, they provided a functional baseline to track improvements following the interventions.

Table 3

Descriptive statistics for lumbar lordosis angle, postural control, and functional disability (Mean ± SD)

Variables	Sensorimotor		Postural Reeducation		Control	
	Pre	Post	Pre	Post	Pre	Post
Lumbar lordosis (°)	51.08 ± 7.45	47.91 ± 7.05	50.75 ± 4.67	45.58 ± 5.36	48.90 ± 4.63	48.90 ± 4.70
SEBT Dominant leg (%)	73.8 ± 8.62	81.83 ± 5.02	70.83 ± 7.25	75.75 ± 8.11	71.90 ± 9.01	72.36 ± 8.54
SEBT Non-dominant leg (%)	68.66 ± 9.33	79.41 ± 6.09	65.66 ± 9.33	70.75 ± 10.55	67.63 ± 11.60	66.81 ± 10.10

Both intervention groups demonstrated meaningful improvements in spinal and postural outcomes after eight weeks, while the control group remained unchanged. Lumbar lordosis angle decreased notably in the sensorimotor group (from 51.08 ± 7.45° to 47.91 ± 7.05°) and even more in the postural reeducation group (from 50.75 ± 4.67° to 45.58 ± 5.36°), indicating effective reduction of excessive curvature. Postural control scores on the SEBT improved markedly, with the sensorimotor group achieving an average gain of nearly 8 percentage points on the dominant leg and 11 points on the non-dominant leg, while the postural reeducation group also improved but with slightly smaller increments. In contrast, the control group exhibited minimal or no change in any parameter. These findings suggest that both targeted exercise programs enhanced lumbopelvic alignment and functional stability, with the sensorimotor approach showing slightly greater improvement in dynamic balance indices, while postural reeducation produced a stronger impact on lumbar curvature correction.

Table 4

Results of analysis of covariance (ANCOVA) among the three groups for lumbar lordosis angle and postural control

Subscales	Source	Sum of Squares	df	Mean Square	F	Significance	Eta Squared
Lumbar lordosis	Pretest	903.66	1	903.66	275.58	<0.001	0.89
	Groups	147.25	2	73.62	22.45	<0.001	0.59
	Error	101.65	31	3.27	–	–	–
Dominant leg (postural control)	Pretest	114.96	1	114.96	2.16	0.152	0.07
	Groups	501.56	2	250.78	4.71	0.016	0.23
	Error	1649.64	31	53.21	–	–	–
Non-dominant leg (postural control)	Pretest	86.11	1	86.11	1.02	0.319	0.03
	Groups	930.81	2	465.40	5.53	0.009	0.26
	Error	2605.81	31	84.05	–	–	–

The ANCOVA results confirm significant intervention effects for both lumbar lordosis angle and postural control variables after adjusting for baseline scores. For lumbar lordosis, the group effect was highly significant ($F = 22.45$, $p < 0.001$) with a large effect size ($\eta^2 = 0.59$), indicating that the two exercise interventions led to meaningful changes compared with the control group. The pretest covariate also explained a substantial portion of the variance ($\eta^2 = 0.89$), showing that initial lordosis values strongly predicted post-intervention outcomes. Regarding postural control, a significant group effect emerged for both dominant leg ($F = 4.71$, $p = 0.016$, $\eta^2 = 0.23$) and non-dominant leg performance ($F = 5.53$, $p = 0.009$, $\eta^2 = 0.26$), demonstrating that targeted training improved dynamic balance beyond baseline differences. The lack of significance for pretest covariates in balance outcomes suggests that improvements were largely driven by the training itself rather than initial performance levels. Overall, the analysis provides strong statistical support for the positive effects of sensorimotor and postural reeducation programs on spinal alignment and balance in women with lower crossed syndrome.

Table 5

Pairwise comparisons among the three groups for lumbar lordosis angle and postural control (post hoc test results)

Variable	Group 1	Group 2	Mean Difference	Std. Error	Significance	95% CI Lower	95% CI Upper
Lumbar lordosis	Sensorimotor	Control	-3.08	0.76	0.001	-5.01	-1.14
	Postural Reeducation	Control	-5.09	0.76	<0.001	-7.02	-3.16
	Postural Reeducation	Sensorimotor	-2.01	0.73	0.032	-3.88	-0.14
Dominant leg (postural control)	Sensorimotor	Control	9.25	3.05	0.014	1.54	16.97
	Postural Reeducation	Control	3.59	3.05	0.740	-4.12	11.31
	Postural Reeducation	Sensorimotor	-5.66	2.99	0.204	-13.24	1.92
Non-dominant leg (postural control)	Sensorimotor	Control	12.47	3.83	0.008	2.77	22.16
	Postural Reeducation	Control	4.17	3.84	0.885	-5.54	13.89
	Postural Reeducation	Sensorimotor	-8.29	3.77	0.107	-17.84	1.25

Post hoc pairwise comparisons further clarified the differences among the three groups after adjusting for pretest scores. In lumbar lordosis, both the sensorimotor group and the postural reeducation group achieved significant reductions compared to the control group (mean differences −3.08° and −5.09°, respectively; $p = 0.001$ and $p < 0.001$), indicating meaningful improvements in spinal alignment. Additionally, postural reeducation outperformed sensorimotor training in reducing lordosis angle, with a statistically significant mean difference of −2.01° ($p = 0.032$), suggesting a slightly stronger corrective effect on curvature. For postural control, the sensorimotor group showed a significant advantage over the control group in both dominant (9.25%, $p = 0.014$) and non-dominant legs (12.47%, $p = 0.008$), highlighting its positive impact on dynamic balance. In contrast, postural reeducation did not demonstrate statistically significant improvements compared to control for postural control variables, and the differences between postural reeducation and sensorimotor training in balance measures were not significant. These results confirm that while both interventions effectively improved spinal curvature, sensorimotor training had a greater influence on functional balance performance.

4. Discussion and Conclusion

The present study aimed to examine the impact of an eight-week program of selected sensorimotor exercises and a comprehensive postural reeducation protocol on lumbar lordosis angle and postural control in women with lower crossed syndrome (LCS). The findings demonstrated that both interventions led to a significant reduction in lumbar lordosis compared with the control group, while sensorimotor training produced greater improvements in dynamic postural control as measured by the Star Excursion Balance Test (SEBT). These results highlight the therapeutic value of targeted exercise approaches that address the muscular imbalances and neuromuscular dysfunction characteristic of LCS. Importantly, the postural reeducation program achieved the most pronounced improvement in sagittal alignment, while sensorimotor training excelled in enhancing functional stability and balance performance.

The significant decrease in lumbar lordosis following both exercise programs confirms that excessive anterior pelvic tilt and lumbosacral hyperextension can be corrected with appropriately designed, progressive interventions. These findings align with previous clinical evidence showing that core stabilization and global postural correction effectively modify lumbopelvic curvature. For example, Chughtai and colleagues (12) demonstrated that core stabilization exercises could reduce pain and improve lumbar range of motion in patients with disc herniation, while Shalamzari et al. (13) reported that both core stability and electromyostimulation-based training improved lordotic angles in sedentary individuals with hyperlordosis. Similarly, Welling et al. (17) found that myofascial release techniques targeting postural chains produced measurable lordosis correction. The present results extend these findings by showing that a comprehensive postural reeducation approach, which systematically elongates anterior and posterior myofascial chains while retraining breathing and axial elongation, yields substantial sagittal realignment in women with LCS.

Another key outcome is the superior improvement in postural control observed in the sensorimotor exercise group. Dynamic stability depends heavily on timely activation of deep trunk muscles, integration of proprioceptive input, and coordinated limb movement (9, 10). Sensorimotor programs, which combine abdominal hollowing, bridging variations, and quadruped arm–leg lifts, directly train these neuromuscular pathways (15). The increased SEBT reach distances in both the dominant and non-dominant legs observed here are consistent with studies demonstrating that core and proprioceptive training improve functional movement control. For instance, Hayat et al. (7) reported that core stability training significantly enhanced balance and reduced disability in mechanical low back pain. Similarly, Rafique (6) showed improved lumbar flexibility and postural stability after core-focused interventions in postpartum women with hyperlordosis. These results suggest that training the deep stabilizers through controlled, low-load, multi-planar movements is crucial for restoring dynamic postural control disrupted in LCS.

The stronger effect of postural reeducation on lordosis angle compared to sensorimotor training may be explained by the direct focus on myofascial lengthening and pelvic realignment. Techniques employed in the comprehensive program address shortened iliopsoas and lumbar extensors while encouraging neutral alignment through sustained

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E-ISSN: 2981-2569

postures and breathing (1, 18). By releasing myofascial tension, these methods may facilitate structural changes that sensorimotor training alone cannot achieve in the short term. The importance of restoring sagittal balance is supported by surgical studies demonstrating that inadequate lumbar curvature correction contributes to persistent disability and adjacent segment degeneration (21-23). Although our population was non-surgical, the principle that sagittal alignment is central to spinal health remains relevant.

Conversely, the stronger improvements in dynamic balance within the sensorimotor group highlight the principle of task-specific neuromuscular adaptation. Static postural reeducation may optimize alignment but does not necessarily challenge the nervous system to integrate rapid sensory feedback during movement. As Sun et al. (29) and Skallerud et al. (11) note, dynamic stability relies on complex sensorimotor integration that must be trained functionally. This study reinforces the idea that combining structural correction with neuromuscular retraining may yield the most comprehensive outcomes for LCS patients.

The observed differences between dominant and non-dominant limbs also provide meaningful insights. Improvements in SEBT scores were slightly greater in the non-dominant leg, particularly in the sensorimotor group. Prior research has shown asymmetry in proprioceptive control between limbs, with the non-dominant side often exhibiting greater adaptability to targeted training (3, 4). Our results support the hypothesis that targeted proprioceptive exercises can reduce interlimb asymmetry and may improve overall functional stability, an important consideration for fall prevention and athletic performance.

These findings also integrate well with emerging evidence on exercise therapy personalization. For example, Wänman et al. (24) highlighted that baseline lumbar lordosis influences outcomes after spinal surgery, suggesting that individualized assessment of sagittal parameters is critical when designing interventions. Similarly, Tahmasbi et al. (27) found that specific manipulations such as Kinesio taping over abdominal muscles influence lumbopelvic control differently depending on anterior pelvic tilt severity. The present study supports such tailored approaches by demonstrating that both sensorimotor and postural reeducation are beneficial but act through distinct mechanisms.

Moreover, the results are consistent with studies linking core endurance to improved functional movement and reduced pain. Fallahasady et al. (4) showed that better core endurance correlates with higher Functional Movement Screen scores in women with hyperlordosis. Chughtai et al. (12) also demonstrated that stabilizing core muscles alleviates pain and improves mobility. Our findings add to this body of work by showing that when core training is coupled with dynamic proprioceptive challenges, as in the sensorimotor protocol, improvements in postural control can be robust even in a population with established LCS.

Interestingly, prayer-based and culturally adapted movement programs have also shown benefit for trunk endurance and pain in chronic low back pain (16), indicating that movement patterns familiar to participants can enhance adherence and outcomes. While our program used standardized exercises, cultural adaptation could further strengthen intervention uptake in future implementations.

Another dimension to consider is the measurement methodology. We used the flexible ruler to quantify lumbar lordosis, a tool validated as highly reliable compared with radiographic imaging (10, 28). This approach is safe and practical for both research and clinical practice, supporting non-invasive longitudinal monitoring. For dynamic stability, the SEBT was used, a test extensively validated in sports and rehabilitation contexts (11). This methodological rigor strengthens the credibility of our findings and aligns with recent recommendations to use functional rather than purely static outcome measures (1).

Collectively, the present study underscores the complementary strengths of sensorimotor and global postural strategies. While postural reeducation provides structural correction by targeting myofascial restrictions and realigning the pelvis, sensorimotor exercises optimize dynamic stability and balance control. Combining these two approaches may be a promising path forward, as noted in reviews emphasizing multimodal rehabilitation for spinal dysfunction (2, 19). Furthermore, our focus on women addresses an important gap since sex-specific musculoskeletal adaptations can influence both the etiology of LCS and the response to training (5, 6).

Although the present study provides valuable insights, it is not without limitations. The sample size was modest and restricted to middle-aged women from a single geographic location, limiting generalizability to other populations such as men, younger individuals, or those with different activity levels. The quasi-experimental design, while robust, cannot fully control for all confounding variables such as lifestyle habits and daily physical activity outside the intervention. Additionally, the intervention duration was limited to eight weeks, which may not capture the long-term sustainability of postural and functional improvements. Follow-up assessments beyond the immediate post-intervention phase were not conducted, leaving questions about recurrence of lordotic curvature and maintenance of balance gains unanswered. Finally, while validated tools were used, imaging methods like radiography could have provided additional confirmation of lordotic angle changes.

Future studies should expand the sample size and include diverse populations, including males, different age groups, and individuals with varying degrees of LCS severity, to improve external validity. Longitudinal designs with extended follow-up periods are needed to determine whether improvements in lumbar curvature and postural control persist and whether combining both sensorimotor and postural reeducation leads to superior long-term outcomes. Comparative trials should also explore optimal program duration and intensity, as well as the potential benefit of integrating other therapeutic modalities such as Kinesio taping, aquatic therapy, or culturally adapted movement patterns. Additionally, advanced biomechanical analyses and imaging could help clarify the structural changes induced by these interventions and identify predictors of responsiveness to different training strategies.

Clinicians working with patients with LCS should consider integrating both sensorimotor and comprehensive postural reeducation exercises into rehabilitation programs. Initial assessment of sagittal alignment and dynamic stability can guide exercise prescription, tailoring interventions to address both structural deviations and neuromuscular deficits. Sensorimotor exercises can be prioritized for patients with pronounced balance and proprioceptive deficits, while postural reeducation may be emphasized when correcting severe hyperlordosis and pelvic tilt. Incorporating non-invasive, reliable measurement tools such as the flexible ruler and SEBT can aid in monitoring progress and adjusting programs accordingly. Finally, progressive load management, patient education on postural habits, and long-term adherence strategies are essential to ensure sustained benefits and reduce the risk of recurrent pain and dysfunction.

Authors' Contributions

All authors equally contributed to this study.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

Acknowledgments

We would like to express our gratitude to all individuals helped us to do the project.

Declaration of Interest

The authors report no conflict of interest.

Funding

According to the authors, this article has no financial support.

Ethics Considerations

The study placed a high emphasis on ethical considerations. Informed consent obtained from all participants, ensuring they are fully aware of the nature of the study and their role in it. Confidentiality strictly maintained, with data anonymized to protect individual privacy. The study adhered to the ethical guidelines for research with human subjects as outlined in the Declaration of Helsinki.

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E-ISSN: 2981-2569