Research Paper

Effects of Core Stability Training on Kinematic and Kinetic Variables in Patients With Chronic Low Back Pain

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ABSTRACT

Purpose: This study aims to assess the effects of an 8-week core stability training on the kinematics and kinetics of trunk flexion and extension motions in patients with chronic non-specific low back pain (CNSLBP).

Methods: A total of 30 CNSLBP patients with the age range of 25 to 45 years were randomly divided into 2 equally sized groups. The subjects were identified through clinical examination. Before and after the training, tests were applied to assess peak 3-dimensional hip joint moments, peak negative and positive hip joint powers, and lumbopelvic coupling angles during trunk flexion and extension motions. The first group underwent an 8-week core stability training program, including the specific exercise of the deep muscles of abdominal along with the lumbar multifidus co-activation. After the 8-week program, the post-test stage was performed similarly to the pre-test.

Results: The main effects of "time" ($P=0.029$, $f=0.84$) and "time-by-group" interactions ($P=0.03$, $f=0.16$) for hip abductor moments and internal rotator moment ($P=0.03$, $f=0.87$) were significant. A trend toward the statistically significant main effect of "time" was found for the coupling angle during the flexion phase ($P<0.05$, $f=1.88$), extension phase ($P=0.02$, $f=0.93$), and "time×group" interaction during the flexion ($P<0.05$, $f=1.96$), extension ($P=0.01$, $f=0.96$) phases.

Conclusion: Core stability training has the potential to improve kinematics and kinetics during trunk flexion and extension motions in patients with CNSLBP.

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Highlights

- Core stability exercises are suitable for most age groups and most types of physical impairment.
- Core stability training showed significant improvements in movement coordination and control.
- Core stability training improved lumbopelvic motor control and decreased disability.

Plain Language Summary

This research assessed the effects of core stability training on the lumbar and pelvic motion in chronic non-specific low back pain patients. Overall, the intervention group showed an improvement in the kinematics and kinetics variables. Based on our results, the core stability training incremented muscle activation, and improved neuromuscular control and postural stability, along with the lumbopelvic rhythm.

Introduction

Non-specific low back pain (NSLBP) is determined for about 85% of low back pain (LBP) [1]. Literature suggested that NSLBP patients demonstrate different components that may result from different mechanisms [2-6]. To identify patients with chronic NSLBP (CNSLBP), many test procedures have been developed. Among others, observation of kinematics and kinetics variables during standing and forward bending is a valid, reliable, and often applied test [7, 8]. There is evidence to support changes in kinematics and kinetics variables in patients with recurrent NSLBP [9-11]. Following trunk loading, patients suffering from LBP showed earlier onsets or decreased lumbar muscle activities [12, 13]; in addition, following multi-directional perturbations, these subjects showed a reduction of trunk moments and enhanced the trunk musculature co-activation [14, 15]. Some research studies employed bilateral forward reaching [16, 17], axial trunk rotation [18], sit-to-stand activities [19], and walking and running [11, 20, 21] assessment. These patterns were characterized as decreased muscle moment in lumbar spine and hip altered power patterns limits [19], along with improved coordination of the lumbar spine and pelvis [16] altered proprioception of trunk movements [22] measured at discrete points during the movement.

The angle-angle graph of body segments against each other could provide information on the coordination pattern between limbs [23, 24]. The angle-angle graph does not determine true information about coordinated motion between the segments throughout an entire motion cycle. The coupling angle quantified the relationship between two joint variables derived from converting sagittal angle-angle plots. This plot contains only spatial information derived from positional data (angle-angle plot). It provides insights into segmental movement coordination [25]. Although these investigators demonstrated kinematic and kinetic changes that represent poor neuromuscular control in patients with CNSLBP, none of these investigators studied changes in kinematics and kinetics variables, such as coupling angle, power, and movement of the joint after motor control exercise. Core stabilization exercise is currently used as a form of individual intervention within physiotherapy. Core stabilization exercises are effective and restore appropriate trunk neuromuscular control in patients with movement coordination impairments [26-32]. However, treatment approaches designed to reduce pain and improve disability did not affect these motor control variables. Therefore, this study aimed to evaluate the effects of an 8-week core stabilization exercise program on kinematic (i.e. coupling angle values) and kinetics variables (hip joint power and moment) in patients with CNSLBP.

Materials and Methods

Study design

This was a prospective study. A total of 30 CNSLBP patients participated in this study and followed the 8-week program. The participants gave their informed consent to take part in the research. Then, each subject randomly entered the intervention (core stability exercise group) or control groups. The randomization method was known to only one investigator who was not engaged in the recruiting process.

Study participants

The subjects were selected in November 2022 from 3 clinics in Ardabil City, Iran. The inclusion criteria were as follows: I) being in the age range of 25 to 45 years; II) having LBP in between T12 and sacrum region; III) having no recent experience of pain in the upper/lower limbs at least a month before the experiments; and IV) having no impaired function of the spine or lower limbs that could potentially change trunk motion during standing. The clinical examinations for the diagnosis of movement impairment were provided by 2 experienced physiotherapists trained in this protocol. The exclusion criteria were as follows: having pain in the lower back for more than 8 weeks [33], having a previous history of using core stabilization training; having a history of serious pathologies (e.g. fractures, acute trauma, or serious illnesses); having contraindications to the exercise; having psychological and psychiatric problems; having a BMI >30 kg/m^2. Two patients in the intervention group were finally excluded.

Core stability exercise program (specific stabilization exercise)

Patients in the core stability exercise group received individual treatment. Each session was around 30 to 45 min twice per week for 8 weeks.

The subjects with CNSLBP also received daily individualized home exercise programs on a 5-7 days/week basis even if their symptoms resolved during the treatment. The activation of transversus abdominis/internal oblique muscles is accomplished by teaching the subject with CNSLBP the abdominal drawing-in maneuver and will be verified by palpation. This program aims to restore a precise co-contraction pattern to optimize spinal stability during functional tasks and confidence in using the spine. The treatment protocol was provided by two experienced physiotherapists.

The intervention protocol was a modified core stabilization exercise program based on a previous study [34]. The standardized treatment protocol targeted deep stabilizing muscles throughout static, dynamic, and functional tasks. The first instance included isolation and co-contraction of transversus abdominis/internal oblique muscle, lumbar multifidus muscle, and then increased exercise intensity and co-contraction with extremity movement [30] (Table 1). The intensity of the exercises was increased during treatments with subjects being encouraged to improve their performance. Patients were also instructed to use restore a precise co-contraction pattern to control posture, spinal stability, and breathing during functional tasks [35].

Table 1. Core stability exercise program

Phase 1
The aim is to improve the coordinated function of the trunk muscles, which involves training to activate the deep muscles of the spine and pelvis independently, while reducing excessive activity of the superficial muscles.
The process of rehabilitating the breathing pattern involves progressing exercises from techniques that alter breathing to training in various positions and incorporating functional tasks.
The rehabilitation of functional posture involves addressing movement patterns and posture to achieve several goals, including optimizing posture, avoiding positions that may exacerbate symptoms, optimizing loading, reducing excessive activity in superficial/global muscles, activating deep/local muscles in functional positions, optimizing respiratory patterns, and improving control of the pelvic floor muscles.
Enhancing the precision of training and co-activating deep muscles can help optimize movement patterns and improve overall muscle function.
This phase includes home daily exercises.
Phase 2
The exercise program should be progressed to incorporate functional movements that are specific to the patient's activities and goals.
This phase includes the progression of load, position, and dynamics.
Co-activating both deep and superficial muscles dynamically can help optimize muscle function.
Progressing the load, position, and dynamics of the exercises can facilitate improved outcomes.
Functional rehabilitation aims to enhance the patient's ability to perform daily activities and tasks by incorporating exercises and movements that simulate real-life situations.

PHYSICAL TREATMENTS

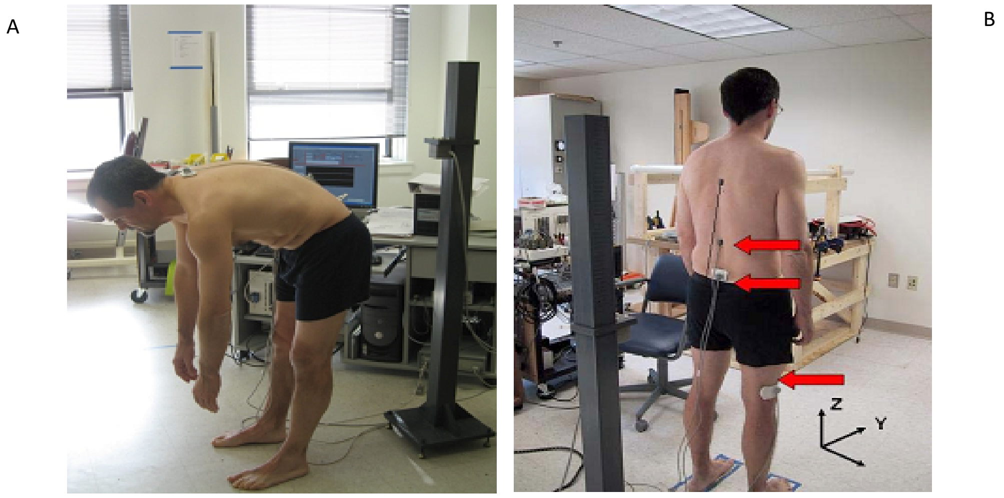

Figure 1. Trunk flexion and extension task

Home exercises were taught to be performed daily along with the sitting, four-point kneeling, and standing exercises. The group without core stability exercise continued with their normal daily activities and pain relief (i.e. no physiotherapy). After 8 weeks of treatment, the patients underwent the same biomechanical testing protocol. After the post-test, for the control group, we suggested home exercise and identified a clinic for their rehabilitation.

Kkinematics and kinetic analysis

Vicon cameras (6 cameras) and the Nexus software, version 1.7.5 (Oxford Metrics, UK) as a data capture software were used to record the trunk flexion–extension kinematics. A calibration procedure was performed [36] before the experiments started. The markers were located on the landmarks based on the full-body plug-in gait model. In addition, 2 markers were placed on the sacrum (S2) and lumbar spine (L1). The sampling frequency of the Vicon system was 100 Hz. The ground reaction force variables during trunk flexion/extension were measured using two Kistler force platforms (Kistler Instruments, Inc., Amherst, NY) with a sampling rate of 1000 Hz.

As dependent variables, trunk flexion, and extension were divided into 2 phases as follows: the first phase involved a flexion motion (first 50%) and the remaining

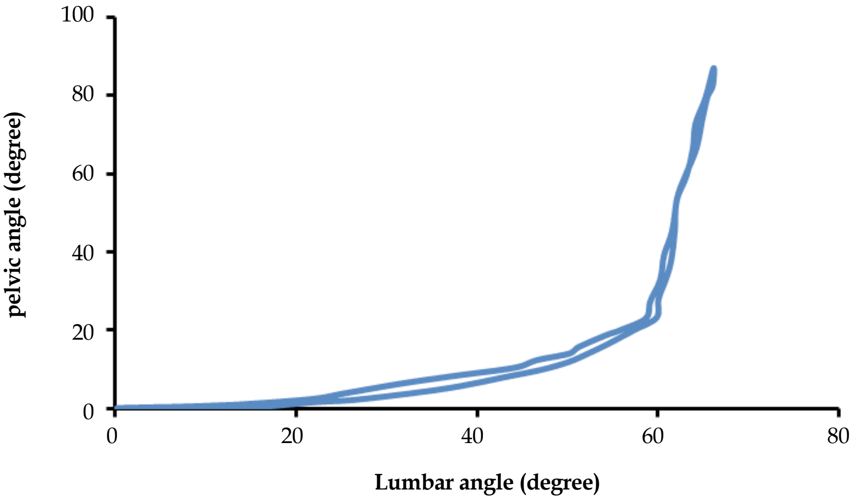

Figure 2. Example of lumbopelvic rhythm represented by angle-angle plot of aberrant lumbar spine and pelvis/hip coordination

Note: Upper line: Forward bend, lower line: Return.

Table 2. Participants' demographics

Variables		Mean±SD		P
		CST	Control	
Age (y)		33.93±5.93	34.80±6.20	0.69
Height (cm)		1.77±0.06	1.78±0.06	0.75
Mass (kg)		79.60±8.70	76.73±6.15	0.30
BMI (kg/m²)		25.26±3.12	24.09±1.61	0.21
RMQ		9.06±2.12	9.40±1.68	0.64
PSFS		6.13±1.19	6.40±1.24	0.53
Hip joint moment	Abduction moment	0.78±0.66	0.66±0.83	0.65
	Adduction moment	1.22±0.51	1.23±0.6	0.99
	Extension moment	0.34±0.29	0.26±0.27	0.43
	Flexion moment	3.09±1.76	3.04±1.59	0.92
	External rotation moment	0.09±0.03	0.87±0.04	0.84
	Internal rotation moment	0.25±0.09	0.22±0.1	0.45
Hip joint power	Concentric	3.01±0.64	2.97±0.91	0.87
	Eccentric	2.39±0.74	2.24±0.6	0.54
Coupling angle	Flexion	53.50±2.56	53.15±2.54	0.70
	Extension	47.80±2.71	47.59±2.35	0.82

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Abbreviations: CST: Core stability training; RMQ: Roland morris disability questionnaire; PSFS: Patient specific functional scale.

50% an extension motion (Figure 1). At least 6 accurate trials were captured. Kinematics and ground reaction force data were filtered by the cut-off frequency of 6 Hz and 20 Hz, respectively. Data were exported from the polygon authoring tool to a spreadsheet for patterns (ranges of motion, joint moments and powers, etc.). All moments and powers were normalized using the body weight. An angle–angle diagram was constructed from the successive sampled data points of sagittal lumbar and hip angles (Figure 2). Thereafter, the coupling angle between the data points vector regarding the horizontal axis was computed as described by Freeman^{17} as follows (Equation 1):

$$1.\ F_i = abs\left[\frac{\tan^{-1}(\theta_{\dot{y}+1} - \theta_{\dot{y}})}{(\theta_{\dot{x}+1} - \theta_{\dot{x}})}\right]$$

Where Ѳy and Ѳx represent the lumbar and hip sagittal plane rotation angles, respectively. An angle of 45° indicates a 1:1 motion ratio between two segments (pelvis and lumbar spine). An angle greater than 45°C indicates pelvis dominance, while an angle less than 45°C indicates lumbar dominant movement patterns [25].

Flexion–extension task

The forward bending task was explained and demonstrated by clinicians before any experimental trial was undertaken.

A metronome was used for movement pacing. The flexion and extension lasted 5 s. A total of 6 practice trials were also performed before the actual data collection. Patients stood with their feet open to the width of their shoulder and a footprint was drawn and used for re-test positioning. The patients were instructed to perform a total of 6 trials of forward bending moving as far as they could at their comfortable pace.

Statistical analysis

A multivariate analysis of variance (MANOVA) was used to determine between-group differences in baseline variables. Statistical analysis was done using separate 2 (group: CG, CST)×2 (time: Pre, post) analysis of variance with repeated measures test. The classification of effect sizes (d) was done by calculating partial η^2. According to Cohen [37], 0.00≤d≤0.24 demonstrate small, 0.25≤d≤0.39 demonstrate medium, and d≥0.4 demonstrate large effects. The significance level was P<0.05 for all analyses. All analyses were done using the SPSS software, version 21

Results

There were no significant between-group baseline differences (P>0.05) (Tables 2 and Table 3). Table 3 describes pre- and post-intervention results for all outcome variables during the trunk flexion task. The statistical analysis indicated significant main effects of "time" ($F_{(1, 28)}$=5.265, P=0.029, f=0.84) and "Time×group" interaction ($F_{(1, 28)}$=5.411, P=0.03, f=0.87) for the hip abductor moment. Our post hoc analysis indicated no statistically significant differences in hip abductor moments for the experimental group (P>0.05).

A tendency was observed toward a significant main effect of the "time×group" interaction ($F_{(1, 28)}$=5.401, P=0.03, f=0.87) for the external rotator moment. However, no significant main effects of "time" or "group" interactions were found. Our post hoc analysis indicated no statistically significant pre to post-change in hip external rotator moment for the experimental group (P>0.05) (Table 3).

According to the results indicated in the experimental group, the peak hip flexor moment during the post-test was significantly lower compared to the pre-test (Δ 14%, P<0.05, d=0.26). The findings indicated no statistically significant differences between the two groups in adductor and external rotator hip joint moments (P>0.05) (Table 3). In the control group, no significant differences were observed between the pre-test and post-test stages (P>0.05) (Table 3).

A trend toward a significant main effect of "time" was found for the coupling angle during the flexion phase ($F_{(1, 28)}$=25.78, P<0.05, f=1.88) and extension phase ($F_{(1, 28)}$=6.42, P=0.02, f=0.93). In addition, a significant "time×group" interaction was found for the flexion phase ($F_{(1,28)}$=27.84, P<0.05, f=1.96) and extension phase ($F_{(1, 28)}$=6.92, P=0.01, f=0.96). Moreover, the post hoc analysis indicated that in the experimental group, the mean coupling angles during the post-test in both flexions (Δ 5.1%, P<0.05; d=0.94) and extension (Δ 4.1%, P=0.02, d=0.63) phases were significantly lower compared to the pre-test (Δ 14%, P<0.05, d=0.26) (Table 4).

The findings indicated that in the experimental group, the peak negative hip joint power during the post-test increased by 17% compared to the pre-test (P<0.05, d=0.57) (Table 4). In the control group, both peak positive and negative hip joint powers and coupling angles were not statically altered in the post-test compared to the pre-test (Table 4).

Table 3. Three-dimensional peak hip joint moments in both groups during pre-test and post-test

Variables	Mean±SD						P (Effect Size)		
	CST			CG					
	Pre-test	Post-test	Change	Pre-test	Post-test	Change	Main Effect: Time	Main Effect: Group	Interaction: Time×Group
Flexor	3.09±1.76	2.67±1.51*	0.42±0.58$^{¥}$	3.04±1.59	3.05±1.75	-0.01±0.56	0.93(0.00)	0.85(0.00)	0.27(0.04)
Extensor	0.34±0.29	0.54±0.44*	0.19±0.29$^{¥}$	0.26±0.27	0.26±0.27	-0.001±0.03	0.88(0.01)	0.68(0.00)	0.23(0.05)
Abductor	0.78±0.66	0.70±0.55	-0.08±0.19	0.66±0.83	0.73±0.83	0.07±0.50	0.029(0.15)	0.15(0.07)	0.03(0.16)
Adductor	1.22±0.51	1.16±0.50	0.07±0.40	1.23±0.6	1.31±0.56	-0.09±0.28	0.06(0.11)	0.78(0.00)	0.05(0.01)
Internal rotator	0.25±0.09	0.22±0.09*	0.03±0.05$^{¥}$	0.22±0.1	0.27±0.11	0.003±0.01	0.29(0.04)	0.81(0.00)	0.88(0.00)
External rotator	0.09±0.03	0.09±0.04	0.004±0.02	0.87±0.04	0.09±0.05	0.003±0.01	0.07(0.10)	0.82(0.00)	0.03(0.16)

CST: Core stability training; CG: Control group.

*Significant within group difference, $^{¥}$Significant difference between control and experimental groups.

Table 4. Peak hip joint power, mean sagittal lumbo-pelvic coupling angle, in both groups during pre-test and post-test

Variables	Mean±SD						P (Effect Size)		
	CST			CG					
	Pre-test	Post-test	Change	Pre-test	Post-test	Change	Main Effect: Time	Main Effect: Group	Interaction: Time×Group
Negative power	-2.4±0.7	-2.8±0.7*	-0.38±0.46^{Y}	-2.2±0.6	-2.2±0.7	0.02±0.73	0.12(0.08)	0.12(0.1)	0.08(0.1)
Positive power	3.0±0.6	2.9±0.6	-0.06±0.26	2.9±0.9	2.9±0.8	-0.04±0.55	0.50(0.01)	0.89(0.00)	0.88(0.00)
Coupling angle (flexion phase)	53.5±2.5	51.0±2.8*	-2.48±1.6^{Y}	53.1±2.5	53.2±2.42	0.04±0.91	0.00(0.47)	0.32(0.03)	0.00(0.49)
Coupling angle (extension phase)	47.8±2.7	45.9±3.3*	-1.82±2.68^{Y}	47.5±2.3	47.6±2.3	0.03±0.52	0.02(0.18)	0.44(0.02)	0.014(0.19)

CST: Core stability training; CG: Control group.

PHYSICAL TREATMENTS

*Significant within group difference, ^{Y}Significant difference between control and experimental groups.

Discussion

Our results demonstrated that the changes in the sagittal mean coupling angle between the lumbar and pelvic after the implication of treatment demonstrated significantly decreased during the trunk flexion phase. The changes of roland morris disability questionnaire (RMQ), peak hip extension moment, peak hip extension moment, and peak negative hip power values were significantly larger in the core stabilization exercise group compared to the control group. Higher peak negative hip power in the experimental group after the training protocol may be because of the improvement in core muscular strength that was reported in the previous studies [6, 11, 32, 38, 39]. Shock absorption and load dissipation are related to negative joint power [40]; therefore, increased peak negative hip power may be one of the causes of pain reduction after the training protocol [41]. Furthermore, the back muscles of patients with LBP have shown protective guarding behavior and splinting, as indicated by earlier research [42]. This could affect the lumbar spine's range of motion and velocity [43]. Additionally, according to the pain-spasm-pain model, pain leads to heightened muscle activation that triggers agonist and antagonist muscle co-contraction; therefore, individuals with back pain are expected to exhibit reduced net muscle moment values because of the antagonistic co-contraction [44]. The present study demonstrated greater peak hip extension moments after the training protocol in the experimental group. The observed significant increase in the hip extensor moments in the experimental group, when compared to the control group, may have resulted from a variety of mechanical factors, including the activation of deep trunk muscles, the use of a motor learning approach to retrain optimal spinal control and coordination, progression of proprioceptive receptors, and an improvement in movement quality, motor skills, and stability. [6, 9, 45-49]. Furthermore, in the present study, the peak hip external rotator moment was significantly decreased after the treatment. According to Panjabi, inadequate spinal stability can cause excessive segmental rotations which may trigger pain [50]. Therefore, the reduction of peak hip internal rotor moment after core stabilization training protocol may be a possible mechanism in pain reduction.

To the best of our knowledge, existing studies on the effects of core stabilization exercise on movement impairments have focused on measuring changes in muscle activity patterns, specific to transverse abdominis and lumbar multifidus muscles using either electromyography or real-time ultrasound [6, 51-54]. These changes in muscle activity patterns after core stabilization exercise are also associated with improvement in pain and function [11, 51, 55, 56]. To date, we are unaware of investigations on movement pattern coordination changes after exercise intervention. Our results demonstrated lower sagittal mean coupling angles between the lumbar and pelvic after the implication of training protocol during both trunk flexion and extension phases. This alteration in mean coupling angle after the implication of treatment may lead to improvement in neuromuscular control and postural stability [57, 58]. This is the first study to assess the potential of core stabilization exercise on the trunk and pelvic coordination that represent clinically observed aberrant movement patterns. The understanding of these coordination changes after different treatment methods will help clinicians and researchers to better identify and understand the complexity of aberrant movement patterns. Previous studies demonstrated that kinematics in conjunction with the dynamic systems approach (based on spatial and/or temporal information) can be used to capture trunk and pelvis movement patterns and quantify the amount of deviation from typical movement patterns during standing forward bend tasks [59]. The kinematic variable derived from the lumbopelvic coupling-angle diagram represents the frequency of changes in movement coordination between segments without consideration of spatial and temporal information. Poor movement control of the lumbar segment could disrupt angular velocity and decoupling between the lumbar spine and hip/pelvis [60]. Decoupling in the NSLBP group between the lumbar spine and hip/pelvis and hip/pelvis domination in forward bending would increase the length of the pattern with minimal effect on the area kinematic variables, and might be large enough to increase the difference in the length of the Mean±SD. Our findings demonstrated that changes in movement control (reduced instability catch) were strongly and significantly associated with decreased pain and disability after the implication of treatment. Thus, the reduction in back pain [41] may be the result of an increase in negative hip joint power and a decrease in lumbar-pelvic mean coupling angle that improved the altered sensory and motor organization in NSLBP. Other authors have recommended that patients with CNSLBP may find relief from specific exercises as they have observed an improved range of motion in the lumbar spine and both hips, as well as decreased disability and pain during activities [26-28]. Even though adherence to the home protocol was not assessed, it was tracked through a log. The treating physiotherapist's verbal report indicated that compliance was satisfactory overall. These findings will be the first step toward future work that will directly assist in determining the effectiveness of core stabilization exercises and will progress our understanding of the therapeutic mechanism underlying this treatment approach. This will lead to more appropriate exercise prescriptions that may reduce the recurrence of symptoms associated with the lack of resolution of underlying motor impairments in patients with NSLBP [61].

Study limitations

This study faced a few limitations that should be considered. The sample size was small and the participants were relatively young (in the age range of 25 to 45 years). Although the study had enough statistical power to detect group differences, additional research is required to assess the impact of core stabilization exercises on walking speed, gait cycle, and the incline of walking surfaces. Incorporating electromyographic data from the relevant muscles involved in trunk flexion and extension movements, along with kinematic analysis, could provide further insights into the identification of risk factors associated with movement control impairments in patients with nonspecific low back pain.

Conclusions

A core stabilization exercise program can reduce pain and improve function in patients with CNSLBP [46]. Our findings also revealed that the intervention used in patients with CNSLBP resulted in statistically significant improvement in clinical outcome measures (peak hip joint moments, peak negative hip power, and mean coupling angles). Not all patients may respond to this treatment, and we expected that responders would have greater improvements in movement coordination and control. Therefore, when we further classified patients into responders and non-responders, patients with the presence of deviation away from the sagittal plane or altered lumbopelvic rhythm again demonstrated significant improvements in movement coordination and control with a medium effect size.

Ethical Considerations

Compliance with ethical guidelines

All ethical principles are considered in this article. The participants were informed of the purpose of the research and its implementation stages. They were also assured about the confidentiality of their information and were free to leave the study whenever they wished, and if desired, the research results would be available to them. A written consent has been obtained from the subjects. principles of the Helsinki Convention were also observed.

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Authors' contributions

Conceptualization and supervision: Vahid Mohammadi and Amir Letafatkar; Data analysis: Vahid Mohammadi and Amir Ali Jafarnezhadgero; Funding acquisition, methodology, data collection and resources: Vahid Mohammadi; Investigation, writing–original draft, review & editing: All authors.

Conflict of interest

The authors state that they have no competing interests regarding the publication of this manuscript.

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References

[1] Carey TS, Garrett JM, Jackman AM. Beyond the good prognosis: Examination of an inception cohort of patients with chronic low back pain. Spine. 2000; 25(1):115-20. [DOI:10.1097/00007632-200001010-00019] [PMID]

[2] Dankaerts W, O'Sullivan PB, Burnett AF, Straker LM. The use of a mechanism-based classification system to evaluate and direct management of a patient with non-specific chronic low back pain and motor control impairment-a case report. Manual Therapy. 2007; 12(2):181-91. [DOI:10.1016/j.math.2006.05.004] [PMID]

[3] Flynn T, Fritz J, Whitman J, Wainner R, Magel J, Rendeiro D, et al. A clinical prediction rule for classifying patients with low back pain who demonstrate short-term improvement with spinal manipulation. Spine. 2002; 27(24):2835-43. [DOI:10.1097/00007632-200212150-00021] [PMID]

[4] Hicks GE, Fritz JM, Delitto A, McGill SM. Preliminary development of a clinical prediction rule for determining which patients with low back pain will respond to a stabilization exercise program. Archives of Physical Medicine and Rehabilitation, 2005. 86(9):1753-62. [DOI:10.1016/j.apmr.2005.03.033] [PMID]

[5] O'Sullivan P. Diagnosis and classification of chronic low back pain disorders: Maladaptive movement and motor control impairments as underlying mechanism. Manual Therapy. 2005; 10(4):242-55. [DOI:10.1016/j.math.2005.07.001] [PMID]

[6] Smrcina Z, Woelfel S, Burcal C. A systematic review of the effectiveness of core stability exercises in patients with non-specific low back pain. International Journal of Sports Physical Therapy. 2022; 17(5):766-74. [DOI:10.26603/001c.37251] [PMID] [PMCID]

[7] Hicks GE, Fritz JM, Delitto A, Mishock J. Interrater reliability of clinical examination measures for identification of lumbar segmental instability. Archives of Physical Medicine and Rehabilitation. 2003; 84(12):1858-64. [DOI:10.1016/S0003-9993(03)00365-4] [PMID]

[8] Biely SA, Silfies SP, Smith SS, Hicks GE. Clinical observation of standing trunk movements: What do the aberrant movement patterns tell us? Journal of Orthopaedic & Sports Physical Therapy. 2014; 44(4):262-72. [DOI:10.2519/jospt.2014.4988] [PMID]

[9] Sung W, Abraham M, Plastaras C, Silfies SP. Trunk motor control deficits in acute and subacute low back pain are not associated with pain or fear of movement. The Spine Journal. 2015; 15(8):1772-82. [DOI:10.1016/j.spinee.2015.04.010] [PMID] [PMCID]

[10] Hodges P, van den Hoorn W, Dawson A, Cholewicki J. Changes in the mechanical properties of the trunk in low back pain may be associated with recurrence. Journal of Biomechanics. 2009; 42(1):61-6. [DOI:10.1016/j.jbiomech.2008.10.001] [PMID]

[11] Bagheri R, Parhampour B, Pourahmadi M, Fazeli SH, Takamjani IE, Akbari M, et al., The effect of core stabilization exercises on trunk-pelvis three-dimensional kinematics during gait in non-specific chronic low back pain. Spine. 2019; 44(13):935-44. [DOI:10.1097/BRS.0000000000002981] [PMID]

[12] MacDonald D, Moseley GL, Hodges PW. People with recurrent low back pain respond differently to trunk loading despite remission from symptoms. Spine. 2010; 35(7):818-24. [DOI:10.1097/BRS.0b013e3181bc98f1] [PMID]

[13] Bagheri R, Takamjani IE, Dadgoo M, Sarrafzadeh J, Ahmadi A, Pourahmadi MR, et al. A protocol for clinical trial study of the effect of core stabilization exercises on spine kinematics during gait with and without load in patients with non-specific chronic low back pain. Chiropractic & Manual Therapies. 2017; 25:31. [PMID] [PMCID]

[14] Henry SM, Hitt JR, Jones SL, Bunn JY. Decreased limits of stability in response to postural perturbations in subjects with low back pain. Clinical Biomechanics. 2006; 21(9):881-92. [DOI:10.1016/j.clinbiomech.2006.04.016] [PMID]

[15] Jones SL, Henry SM, Raasch CC, Hitt JR, Bunn JY. Individuals with non-specific low back pain use a trunk stiffening strategy to maintain upright posture. Journal of Electromyography and Kinesiology. 2012; 22(1):13-20. [DOI:10.1016/j.jelekin.2011.10.006] [PMID] [PMCID]

[16] Silfies SP, Bhattacharya A, Biely S, Smith SS, Giszter S. Trunk control during standing reach: A dynamical system analysis of movement strategies in patients with mechanical low back pain. Gait & Posture. 2009; 29(3):370-6. [DOI:10.1016/j.gaitpost.2008.10.053] [PMID] [PMCID]

[17] Spinelli BA, Wattananon P, Silfies S, Talaty M, Ebaugh D. Using kinematics and a dynamical systems approach to enhance understanding of clinically observed aberrant movement patterns. Manual Therapy. 2015; 20(1):221-6. [DOI:10.1016/j.math.2014.07.012] [PMID] [PMCID]

[18] Sung PS. A kinematic analysis for shoulder and pelvis coordination during axial trunk rotation in subjects with and without recurrent low back pain. Gait & Posture. 2014; 40(4):493-8. [DOI:10.1016/j.gaitpost.2014.06.001] [PMID]

[19] Shum GL, Crosbie J, Lee RY. Three-dimensional kinetics of the lumbar spine and hips in low back pain patients during sit-to-stand and stand-to-sit. Spine. 2007; 32(7):E211-9. [DOI:10.1097/01.brs.0000259204.05598.10] [PMID]

[20] Müller R, Ertelt T, Blickhan R. Low back pain affects trunk as well as lower limb movements during walking and running. Journal of Biomechanics. 2015; 48(6):1009-14. [DOI:10.1016/j.jbiomech.2015.01.042] [PMID]

[21] Seay JF, Van Emmerik RE, Hamill J. Low back pain status affects pelvis-trunk coordination and variability during walking and running. Clinical Biomechanics. 2011; 26(6):572-8. [DOI:10.1016/j.clinbiomech.2010.11.012] [PMID]

[22] Sung PS, Park HS. Gender differences in ground reaction force following perturbations in subjects with low back pain. Gait & Posture. 2009; 29(2):290-5. [DOI:10.1016/j.gaitpost.2008.09.012] [PMID]

[23] Esola MA, McClure PW, Fitzgerald GK, Siegler S. Analysis of lumbar spine and hip motion during forward bending in subjects with and without a history of low back pain. Spine. 1996; 21(1):71-8. [DOI:10.1097/00007632-199601010-00017] [PMID]

[24] Ebaugh DD, McClure PW, Karduna AR. Three-dimensional scapulothoracic motion during active and passive arm elevation. Clinical Biomechanics. 2005; 20(7):700-9. [DOI:10.1016/j.clinbiomech.2005.03.008] [PMID]

[25] Miller RH, Chang R, Baird JL, Van Emmerik RE, Hamill J. Variability in kinematic coupling assessed by vector coding and continuous relative phase. Journal of Biomechanics. 2010; 43(13):2554-60. [DOI:10.1016/j.jbiomech.2010.05.014] [PMID]

[26] Luomajoki H, Kool J, de Bruin ED, Airaksinen O. Improvement in low back movement control, decreased pain and disability, resulting from specific exercise intervention. Sports Medicine, Arthroscopy, Rehabilitation, Therapy & Technology. 2010; 2:11. [PMID] [PMCID]

[27] Saragiotto BT, Maher CG, Yamato TP, Costa LO, Menezes Costa LC, Ostelo RW, et al. Motor control exercise for chronic non-specific low-back pain. Cochrane Database of Systematic Reviews. 2016. [DOI:10.1002/14651858.CD012004]

[28] Gutknecht M, Mannig A, Waldvogel A, Wand BM, Luomajoki H. The effect of motor control and tactile acuity training on patients with non-specific low back pain and movement control impairment. Journal of Bodywork and Movement Therapies. 2015; 19(4):722-31. [DOI:10.1016/j.jbmt.2014.12.003] [PMID]

[29] Costa LO, Maher CG, Latimer J, Hodges PW, Herbert RD, Refshauge KM, et al. Motor control exercise for chronic low back pain: A randomized placebo-controlled trial. Physical Therapy. 2009; 89(12):1275-86. [DOI:10.2522/ptj.20090218] [PMID]

[30] Macedo LG, Maher CG, Latimer J, McAuley JH. Motor control exercise for persistent, nonspecific low back pain: A systematic review. Physical Therapy. 2009; 89(1):9-25. [DOI:10.2522/ptj.20080103] [PMID]

[31] Niederer D, Engel T, Vogt L, Arampatzis A, Banzer W, Beck H, et al. Motor control stabilisation exercise for patients with non-specific low back pain: A prospective meta-analysis with multilevel meta-regressions on intervention effects. Journal of Clinical Medicine. 2020; 9(9):3058. [DOI:10.3390/jcm9093058] [PMID] [PMCID]

[32] Ganesh GS, Kaur P, Meena S. Systematic reviews evaluating the effectiveness of motor control exercises in patients with non-specific low back pain do not consider its principles-A review. Journal of Bodywork and Movement Therapies. 2021; 26:374-93. [DOI:10.1016/j.jbmt.2020.08.010] [PMID]

[33] Von Korff M. Studying the natural history of back pain. Spine. 1994; 19(18 Suppl):2041S-6S. [DOI:10.1097/00007632-199409151-00005] [PMID]

[34] Hodges P, Ferreira PH, Ferreira ML. Lumbar spine: Treatment of instability and disorders of movement control. In: Magee DJ, Zachazewski JE, Quillen, WS, Editors. New York: Elsevier; 2009. [Link]

[35] Ferreira PH, Ferreira ML, Maher CG, Herbert RD, Refshauge K. Specific stabilisation exercise for spinal and pelvic pain: A systematic review. Australian Journal of Physiotherapy. 2006; 52(2):79-88. [DOI:10.1016/S0004-9514(06)70043-5] [PMID]

[36] Di Marco R, Rossi S, Castelli E, Patanè F, Mazzà C, Cappa P. Effects of the calibration procedure on the metrological performances of stereophotogrammetric systems for human movement analysis. Measurement. 2017; 101:265-71. [DOI:10.1016/j.measurement.2016.01.008]

[37] Cohen J. Statistical power analysis for the behavioral sciences . New York: Lawrence Earlbaum Associates; 1988. [Link]

[38] Miyake Y, Kobayashi R, Kelepecz D, Nakajima M. Core exercises elevate trunk stability to facilitate skilled motor behavior of the upper extremities. Journal of Bodywork and Movement Therapies. 2013; 17(2):259-65. [DOI:10.1016/j.jbmt.2012.06.003] [PMID]

[39] Akodu A, Okonkwo S, Akinbo S. Comparative efficacy of core stabilization exercise and pilates exercise on patients with non-specific chronic low back pain. Physiotherapy. 2016; 102(SUPPLEMENT 1,):e243-4. [DOI:10.1016/j.physio.2016.10.304]

[40] Winter DA. Biomechanics and motor control of human movement. New Jersey: John Wiley & Sons; 2009. [DOI:10.1002/9780470549148]

[41] Mohammadi V, Letafatkar A, Sadeghi H, Jafarnezhadgero A, Hilfiker R. The effect of motor control training on kinetics variables of patients with non-specific low back pain and movement control impairment: Prospective observational study. Journal of Bodywork and Movement Therapies. 2017; 21(4):1009-16. [DOI:10.1016/j.jbmt.2016.12.009] [PMID]

[42] Ahern DK, Follick MJ, Council JR, Laser-Wolston N, Litchman H. Comparison of lumbar paravertebral EMG patterns in chronic low back pain patients and non-patient controls. Pain. 1988; 34(2):153-60. [DOI:10.1016/0304-3959(88)90160-1] [PMID]

[43] Marras WS, WongsamPE. Flexibility and velocity of the normal and impaired lumbar spine. Archives of Physical Medicine and Rehabilitation. 1986; 67(4):213-7. [Link]

[44] van Dieën JH, Cholewicki J, Radebold A. Trunk muscle recruitment patterns in patients with low back pain enhance the stability of the lumbar spine. Spine. 2003; 28(8):834-41. [DOI:10.1097/00007632-200304150-00018] [PMID]

[45] Steele J, Bruce-Low S, Smith D, Jessop D, Osborne N. A randomized controlled trial of the effects of isolated lumbar extension exercise on lumbar kinematic pattern variability during gait in chronic low back pain.PM & R: The Journal of Injury, Function, and Rehabilitation. 2016; 8(2):105-14. [DOI:10.1016/j.pmrj.2015.06.012] [PMID]

[46] Hides JA, Jull GA, Richardson CA. Long-term effects of specific stabilizing exercises for first-episode low back pain. Spine. 2001; 26(11):e243-8. [DOI:10.1097/00007632-200106010-00004] [PMID]

[47] International Association for the Study of Pain. Abstracts: 11th World Congress on Pain, August 21-26, 2005, Sydney, Australia. Beijing: IASP Press; 2005. [Link]

[48] Tsao H, Hodges PW. Immediate changes in feedforward postural adjustments following voluntary motor training. Experimental Brain Research. 2007; 181(4):545-54. [DOI:10.1007/s00221-007-0950-z] [PMID]

[49] Hodges PW, Moseley GL. Pain and motor control of the lumbopelvic region: Effect and possible mechanisms. Journal of Electromyography and Kinesiology. 2003; 13(4):361-70. [DOI:10.1016/S1050-6411(03)00042-7] [PMID]

[50] Panjabi MM. Clinical spinal instability and low back pain. Journal of Electromyography and Kinesiology. 2003; 13(4):371-9. [DOI:10.1016/S1050-6411(03)00044-0] [PMID]

[51] Marshall PW, Murphy BA. Muscle activation changes after exercise rehabilitation for chronic low back pain. Archives of Physical Medicine and Rehabilitation. 2008; 89(7):1305-13. [DOI:10.1016/j.apmr.2007.11.051] [PMID]

[52] Kiesel KB, Underwood FB, Mattacola CG, Nitz AJ, Malone TR. A comparison of select trunk muscle thickness change between subjects with low back pain classified in the treatment-based classification system and asymptomatic controls. Journal of Orthopaedic & Sports Physical Therapy. 2007; 37(10):596-607. [DOI:10.2519/jospt.2007.2574] [PMID]

[53] Tsao H, Hodges PW. Persistence of improvements in postural strategies following motor control training in people with recurrent low back pain. Journal of Electromyography and Kinesiology. 2008; 18(4):559-67. [DOI:10.1016/j.jelekin.2006.10.012] [PMID]

[54] Mueller J, Niederer D. Dose-response-relationship of stabilisation exercises in patients with chronic non-specific low back pain: A systematic review with meta-regression. Scientific Reports. 2020; 10(1):16921. [DOI:10.1038/s41598-020-73954-9] [PMID] [PMCID]

[55] Akbari A, Khorashadizadeh S, Abdi G. The effect of motor control exercise versus general exercise on lumbar local stabilizing muscles thickness: Randomized controlled trial of patients with chronic low back pain. Journal of Back and Musculoskeletal Rehabilitation. 2008; 21(2):105-12. [DOI:10.3233/BMR-2008-21206]

[56] O'Sullivan PB, Twomey L, Allison GT. Altered abdominal muscle recruitment in patients with chronic back pain following a specific exercise intervention. Journal of Orthopaedic & Sports Physical Therapy. 1998; 27(2):114-24. [DOI:10.2519/jospt.1998.27.2.114] [PMID]

[57] Carpes FP, Reinehr FB, Mota CB. Effects of a program for trunk strength and stability on pain, low back and pelvis kinematics, and body balance: A pilot study. Journal of Bodywork and Movement Therapies. 2008; 12(1):22-30. [DOI:10.1016/j.jbmt.2007.05.001] [PMID]

[58] Ellenbecker TS. Reabilitação dos Ligamentos do Joelho. Plovdiv: Manole; 2002. [Link]

[59] Wattananon P. Movement coordination impairment in non-specific low back pain: Understanding aberrant patterns of movement and our ability to change them [PhD dissertation]. Philadelphia: Drexel University; 2014. [Link]

[60] Kurz M. Stergiou N. Applied dynamic systems theory for the analysis of movement. In: Stergiou N, Editor. Innovative analyses of human movement. Illinois: Human Kinetics; 2004. [Link]

[61] Jacobs JV, Henry SM, Jones SL, Hitt JR, Bunn JY. A history of low back pain associates with altered electromyographic activation patterns in response to perturbations of standing balance. Journal of Neurophysiology. 2011; 106(5):2506-14. [DOI:10.1152/jn.00296.2011] [PMID] [PMCID]