doi: 10.4085/1062-6050-0020.25

Effectiveness of Perturbation Training in Nonspecific Low Back Pain: A Randomized Controlled Trial

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This trial was prospectively registered in the ClinicalTrials.gov database under the registration number NCT06156163.

https://clinicaltrials.gov/study/NCT06156163?term=akg%C3%BCller&rank=3

Acknowledgments

The authors are thankful for all the participants' voluntary contribution during the completion of this study. This study was supported by Scientific and Technological Research Council of Turkey (TUBITAK) under the Grant Number 224S636 The authors thank to TUBITAK for their supports.

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Context: Trunk stabilization exercises, especially when performed under unstable conditions, may have a beneficial effect on low back pain (LBP) and related symptoms. However, more evidence is needed to determine whether adding a perturbation component to the training program contributes to greater improvement.

Objective: To determine the effects of perturbation training on trunk muscle endurance, disability, pain, functional mobility, quality of life, fear-avoidance beliefs, and satisfaction in patients with nonspecific low back pain (NSLBP).

Design: Randomized controlled trial

Setting: Physiotherapy laboratory

Patients: Forty-two patients with NSLBP (30 female, 12 male; age=33.06 ± 9.55 years) who had pain for at least three months (pain duration=3.02±3.25 years) were randomly assigned to either the exercise group (EG) or the perturbation group (PG).

Interventions: EG received a 2-phase trunk-based exercise program, while PG received a 4-phase training program with perturbations added to the exercises in EG. All interventions were performed 2 days per week for 8 weeks.

Main Outcome Measure(s): The McGill endurance tests and the Oswestry Disability Index (ODI) were the primary outcome measures. The Visual Analog Scale (VAS), Timed Up and Go test (TUG), Fear Avoidance Beliefs Questionnaire (FABQ), Short Form-12 (SF-12), and satisfaction were the secondary outcome measures.

Results: Both groups showed improvement in all parameters ($p<0.05$). However, PG was superior to EG in improving trunk muscle endurance (flexor $p=0.001$, extensor $p<0.001$, lateral flexor $p=0.001$ for right/ $p<0.001$ for left), and ODI ($p=0.005$). Between-group effect sizes were large (0.18 to 0.30). Additionally, improvements in TUG and FABQ total score were in favor of the PG (p=0.030), with a moderate effect size (0.11), and satisfaction was also higher in the PG (p=0.034).

Conclusion: An 8-week trunk-based exercise program, when combined with perturbation training, leads to greater improvements in trunk muscle endurance, function, total fear-avoidance belief scores, and satisfaction.

Key Words: Low back pain, perturbation, exercise

Abstract Word Count: 296

Manuscript Word Count: 4679

Key Point 1: The integration of a perturbation component into trunk-focused training enhances trunk muscle endurance and function, while positively influencing patients' total fear-avoidance belief scores and satisfaction with the treatment.

Key Point 2: Perturbation training, which can be performed using simple equipment readily available in most sports and rehabilitation settings, is a practical option due to its lack of adverse events and its positive clinical effects, particularly its functional benefits.

INTRODUCTION

Low back pain (LBP) is defined as pain or discomfort occurring between the lower ribs and the lower gluteal folds, with or without associated leg pain.[1] Based on its duration, LBP is classified as acute (<6 weeks), subacute (6-12 weeks), or chronic (>12 weeks).[2] Additionally, it is categorized as specific or non-specific low back pain (NSLBP) depending on its underlying cause. Only approximately 10% of LBP cases are classified as specific, while the remaining 90% are categorized as NSLBP.[1,3] Although no definitive pathology is identified as the cause of NSLBP, it is hypothesized to result from factors such as poor posture, a history of previous injury, reduced flexibility, heavy lifting, obesity, and psychological stress. Other potential contributors include common conditions such as deep trunk muscle weakness, muscle imbalances, and poor coordination.[3]

There are many treatment options for the management of NSLBP, including patient education, electrotherapy modalities, exercise, manual therapy, massage, acupuncture, cognitive behavioural therapy, pharmacotherapy, invasive interventions and surgery.[1,4] Despite the wide range of treatment options, the optimal approach remains unclear. Current guidelines report that exercise training in particular is supported by strong evidence. Specifically, exercises that focus on trunk muscle strength, endurance or stabilization are effective in reducing pain intensity and disability.[3] Trunk stabilization training involves retraining the function of deep trunk muscles and improving the coordination between deep and superficial trunk muscles during static postures, dynamic movements and functional tasks.[5] When trunk stabilization training is applied under unstable conditions, it may increase the demand for the activation of trunk muscles necessary for postural stability.

Perturbation training is an intervention that involves repeated postural perturbations to improve the control of rapid balance responses. The aim of perturbation training is to develop the stabilization response produced by stresses applied to the joint from different directions. It is believed that perturbation training increases the number of motor units involved in contraction and proprioceptive input.[3] Although perturbation training has long been used in neurological and geriatric populations, it has recently been investigated in some orthopaedic problems such as shoulder problems, ACL injuries and ankle instability.[6-8] Perturbation training has recently started to be explored in the context of LBP, and a review has suggested that perturbation-based interventions could improve spinal stability and neuromuscular control errors during perturbations.[3]

In individuals with chronic low back pain (CLBP), a delay in deep muscle activation and instability in trunk motor control following sudden, unexpected perturbations have been observed, compared to healthy individuals. The commonly used trunk strengthening exercises in LBP have the potential to improve trunk function and stability, but it is questionable whether these improvements directly translate to the motor control of the spine in response to sudden and unexpected perturbations. Therefore, the specificity of perturbation training in the perception and processing of sensory information within the motor system could enhance this transfer.[3] The presence of challenging conditions, such as external perturbations, increases the demand on the sensorimotor system to perceive sensory signals and generate appropriate motor commands.[3,9] It has been reported that external perturbations challenge the neuromotor system during movement, and in response, the system adapts its motor control, thereby improving its ability to cope with perturbations. Specifically, external perturbations applied to the trunk may enhance the nervous system's ability to perceive sensory signals and generate appropriate motor commands, while simultaneously improving trunk muscle strength by increasing muscle activation.[3,10] In other words, these data suggest that perturbation training has the potential to increase the demand for deep trunk muscle activation, improve neuromuscular control of spinal stability, and thereby reduce the severity and recurrence of LBP. However, clinical research in this area is quite limited. A recent dose-response study in

NSLBP reported that adding a perturbation component to stabilization exercises may have more beneficial effects than adding stretching or cognitive behavioural therapy (CBT).[9] In the mentioned study, the interventions were supervised for 3 weeks, while the remaining 9 weeks were conducted at home. Therefore, the duration of the intervention was not sufficient to demonstrate the effectiveness of a supervised perturbation program. Additionally, since stretching and CBT interventions were added to the stabilization exercises, the effectiveness of perturbation training has not been demonstrated specifically. The study by Aramptazis and colleagues focused on adolescent athletes, and the sample consisted of a heterogeneous athlete population involved in canoe racing, swimming, and athletics. Additionally, there was no control group that would allow for a direct comparison of the effects of perturbation training.[11] The study by Schäfer and colleagues with elite rowers included both an intervention and control group, but it had a small sample size of 26 participants in total. [12] The other study included individuals with NSLBP; however, in this study, trunk perturbation was applied using a laboratory-type device.[13]

Reviews on perturbation have emphasized the need for perturbation-based exercise programs that can be implemented in rehabilitation settings by therapists and trainers without the need for expensive and cumbersome equipment (such as laboratory-type perturbation devices) in LBP.[3,14] Most studies in the literature investigating perturbation training have focused on pain and muscle strenght. [9-13] However, according to the biopsychosocial model of LBP management, changes in disability levels cannot be solely attributed to physical factors but rather result from a combination of changes in patients' activity, beliefs, and quality of life (QoL). In conclusion, there is a need for a comprehensive study in the literature that investigates the effects of a perturbation training program, which can be easily applied without the need for a laboratory setting, on both physical and psychosocial factors in individuals with LBP. Furthermore, a methodologically well-structured clinical study, compared to previous studies, that includes a homogeneous sample group, adequate intervention duration, and a control group, will more clearly demonstrate the effectiveness of perturbation training.

The aim of this study was to investigate the effectiveness of adding perturbation training to trunk stabilization exercises in the management of NSLBP on trunk muscle endurance, disability, pain, functional mobility, QoL, fear-avoidance beliefs, and satisfaction, and to compare the effects of perturbation training with trunk stabilization exercises alone. The hypothesis of the study was that perturbation training would increase trunk muscle endurance and improve functionality. Additionally, improvements in pain, functional mobility, QoL, fear-avoidance beliefs, and satisfaction were expected.

METHODS

Study design

This study was designed as a prospective, randomized controlled trial. The study protocol was designed in accordance with the CONSORT guidelines (see CONSORT checklist). The study was conducted in accordance with the Declaration of Helsinki and was registered at ClinicalTrials.gov under the identification number .... The study was conducted at .... University, Faculty of Health Sciences, Department of Physiotherapy and Rehabilitation. Ethical approval was obtained from the ……… Ethics Committee (Institutional review board approval no: …./…..). Informed consent was obtained from all participants prior to all procedures. The data assessor was blinded to the study, and an independent investigator randomly assigned participants to the 'Exercise group (EG)' or the 'Perturbation group (PG)' using the "Research Randomizer" program. This researcher was unaware of the relationship between the numerical codes and the intervention groups. Additionally, the participants were blinded to the theoretical basis of the interventions in groups other than their own.

Participants

Sample size was calculated using the program 'G*Power 3.1.9.7' with a 95% confidence interval, 90% power and a significance level of 0.05. When the difference between groups for the trunk extensor endurance test was considered to be 50 seconds with a standard deviation of 57 seconds, a total sample size of at least 32 participants was required.[15] A total of 48 subjects were included in the study to maintain statistical power, considering the potential risk of dropout.

Inclusion criteria were: (1) 18-50 years of age; (2) NSLBP lasting at least 3 months; and (3) at least 3 points on VAS. Exclusion criteria were: (1) previous spinal surgery or trauma; (2) LBP associated with systemic diseases (e.g., multiple sclerosis, ankylosing spondylitis); (3) neurological or orthopaedic conditions that could cause balance impairments;

(4) pregnancy; (5) BMI (body mass index) 30 or above; (5) presence of spinal instability (such as spondylolysis or spondylolisthesis); (6) history of professional sports; and (6) any healthcare intervention for LBP within the previous 3 months. NSLBP was diagnosed by clinical examination by a neurosurgeon, including x-ray or magnetic resonance imaging for all patients included in the study.

Intervetions

Prior to the interventions, all subjects were trained to perform 'abdominal hollowing' in supine and prone positions using the Stabilizer Pressure Biofeedback Unit® device (Chattanooga Medical Supply Inc., Chattanooga, TN) twice a week for a duration of two weeks.

Exercise Group (EG). A two-stage exercise programme for trunk stabilization and strengthening was performed under supervision. The exercise programme consisted of 4 exercises: 'bird dog', 'single-leg deadlift', 'back extension' and 'side planks'. These exercises were performed at an initial level (level 1) for the first 4 weeks and at a more difficult level (level 2) for the next 4 weeks (Figure 1).[16]

Perturbation Group (PG). The exercises in the EG were performed in 4 stages, accompanied by perturbations and involving increasing difficulty and instability. Throughout the perturbation training, foam surfaces, bosu ball, water tube and manual push-pull manoeuvres performed by the physiotherapist were used to expose the participants' extremities and body to destabilising forces (Figure 2). Progression was defined according to the following criteria: (1) the exercise did not cause LBP and (2) could be performed in a technically correct manner; (3) perceived exertion during the exercise was 5 points or less on the CR-10 scale, which rates effort from 1 to 10; (4) perceived instability during the exercise was 5 points or less on the instability scale (1: stable standing, 10: maximum instability).[12,16]

The interventions in both groups were conducted for a total of 8 weeks, with 2 sessions per week, and there was a 2- or 3-day rest period between each exercise session. All exercises were performed in 3 sets of 10 repetitions. The session duration was approximately 30 minutes in the EG and approximately 45 minutes in the PG.

Outcome measures

Trunk endurance (McGill tests) and LBP-related disability (Oswestry Disability Index-ODI) were the primary outcome measures. Pain intensity (Visual Analog Scale-VAS), functional mobility (Timed Up and Go Test-TUG), fear avoidance attitudes, QoL (Short Form-12/SF-12) and patient satisfaction were the secondary outcome measures. All assessments were performed twice, before and after the interventions. To prevent physical assessments from causing fatigue or being affected by it, the baseline assessment was conducted 2-3 days before the first session, and the final assessment was performed 2-3 days after the last session.

Trunk endurance. Trunk endurance was assessed using the McGill isometric endurance tests. These tests consisted of four positions: trunk flexor test, trunk extensor test and side plank test (bilateral). The minimum detectable change (MDC) time reported in the literature for the trunk endurance tests is at least 29 seconds.[17]

Disability. LBP-related disability was assessed using the Oswestry Disability Index (ODI). The ODI consists of 10 items covering activities of daily living that may be affected by LBP, such as standing, walking, lifting, sitting, lying down, dressing and personal care. There are six response options for each item, ranging from 0 to 5 points. The total score is calculated from 0-50 points or 0%-100%, with higher scores indicating increasing disability. A reduction of at least 7 points in the ODI score from baseline has been identified as a clinically important threshold for spinal disorders.[18]

Pain intensity. The intensity of pain felt by the subjects at 'rest', 'during activity' and 'at night' was assessed using a visual analogue scale (VAS). The VAS usually consists of a straight line 10 cm long, with the ends representing the extreme points of pain (e.g. 'no pain' - 'pain at its worst'). Patients are asked to mark the point on this straight line that represents the intensity of the pain they feel. For CLBP, a 2 cm decrease in VAS is considered the minimum clinically important difference (MCID).[19]

Functional mobility. Functional mobility was assessed using the Timed Up and Go Test (TUG), in which subjects were asked to get up from a standard chair, walk to a specific object 3 m away, turn around the object, walk back and sit down again. The TUG is a reliable and valid test for measuring changes in functional mobility and has excellent inter-rater reliability (ICC>0.95) in people with LBP. The MCID for TUG test time in patients with lumbar degenerative disc disease was reported as 3.4 seconds.[19]

Quality of life. QoL was assessed using the Short Form-12 (SF-12), an abbreviated version of the SF-36 questionnaire. The SF-12 indicates the general health status of the individual and results in 2 subscores: 'physical component summary' (PCS) and 'mental component summary' (MCS). In the literature, the MDC for CLBP was predicted to be 3.28 for the PCS-12 and 3.77 for the MCS-12.[20]

Fear-avoidance attitudes. Participants' fear-avoidance attitudes towards physical activity and work were measured using the Fear Avoidance Beliefs Questionnaire (FABQ). The questionnaire consists of 16 questions and is scored from 0 (strongly disagree) to 6 (strongly agree). It contains two sub-sections: physical activity (FABQ-PA) and work (FABQ-Work).[21] Each section is scored separately, with higher scores indicating greater fear-avoidance beliefs.

Satisfaction. Participants' satisfaction with the treatment at the end of 8 weeks was assessed using a 5-point Global Rating of Change (GRC) scale. (-2: I am much worse; -1: I am worse; 0: I am the same; + 1: I am better; + 2: I am much better).[22]

Statistical analysis

Statistical analysis was performed using SPSS (version 22, IBM, Chicago, IL). Independent samples t-test for continuous variables and chi-squared test for categorical variables were used to compare baseline measurements between groups. Changes within groups were analysed using a paired samples t-test. We used analysis of covariance (ANCOVA) to determine the effect of the interventions on all outcome measures, with baseline data as the covariate. Statistical significance was set at $p<0.05$. We also calculated the effect size (ES) of the treatments, as the p value alone is not sufficient to determine the effectiveness of the treatments. The ES for within-group change was calculated using Cohen's d, which is determined by dividing the difference between the means by the standard deviation of the baseline mean (small=0.2, medium=0.5, and large ≥0.8). Partial eta squared was considered as an indicator of ES between groups (0.01=small, 0.06=medium, 0.14=large).[23]

RESULTS

Participants

During the follow-up period of the study, 4 subjects (n=2 per group) dropped out, and the study was completed with a total of 44 participants (30 females and 14 males; mean age, 33.06 ± 9.55 years) (Figure 3). Symptom durations in EG and PG were 2.43 ± 3.15 and 3.61 ± 3.31 years, respectively. Demographic characteristics and baseline outcome measures of the groups were similar (p>0.05) (Table 1).

Outcome Measures

At the end of 8 weeks, trunk flexor (p=0.006; p<0.001, respectively), extensor (p<0.001), bilateral side (p<0.001) endurance test times increased significantly in both the EG and PG. The ES were large in the PG for all endurance tests (1.52 to 1.91). The EG showed a large ES for the lateral endurance tests (0.80 to 0.82), and a moderate ES for the trunk flexor and extensor endurance tests (0.61 to 0.76). All test scores were significantly higher in the PG (flexor p=0.001, extensor p<0.001, lateral flexor p=0.001 for right/ p<0.001 for left) and improvements exceeded the MDC only in this group. In addition, the between-group ES was large (0.24 to 0.30) (Table 2).

ODI scores improved significantly in both EG and PG (p<0.001) and showed large ESs (1.34 and 2.29, respectively). However, the improvement in the PG was significantly greater (p=0.005) and the between-group ES was large (0.18) (Table 2). The mean difference for ODI score was above the MCID only in PG (-7.27).

Rest, activity and night VAS scores improved significantly in both groups (p<0.001) and there was no difference between groups (p>0.05). The mean differences in both EG (-2.66, -3.77, and -2.46) and PG (-2.86, -3.41, and 2.97) exceeded the MCID and had large ESs (1.43, 2.23, 1.32, and 1.14, 1.32, 2.13, respectively) (Table 3).

The TUG score improved significantly in both the EG and PG ($p=0.015$ and $p<0.001$, respectively). The ES was medium (0.57) in the EG and large (0.85) in the PG. The PG showed a greater improvement ($p=0.030$) and a medium ES between groups (0.11). The mean differences in both groups did not reach MCID (Table 3).

The PCS-12 score improved significantly in both the EG and the PG ($p<0.001$) and showed a large ES (0.80 and 1.43, respectively). For the MCS-12 score, the EG had a medium ES (0.60) and the PG had a small ES (0.49), with only the EG showing a significant improvement ($p=0.025$). The mean differences in PCS-12 (5.69 and 9.64) and MCS-12 (5.69 and 4.67) scores were above the MDC in both the EG and the PG, and there was no significant difference between the groups ($p>0.05$) (Table 3).

FABQ-PA ($p=0.014$ and $p=0.002$, respectively) and FABQ total scores ($p=0.003$ and $p<0.001$, respectively) improved significantly in both EG and PG. FABQ-Work score improved significantly only in the PG ($p=0.001$). ESs in the EG ranged from small to medium (0.26-0.55), while in the PG they ranged from medium to large (0.67-1.13). Only the FABQ total score favoured the PG ($p=0.030$) and the between-group ES was medium (0.11) (Table 3).

At the end of the interventions, 63.63% of subjects in PG reported much better and 36.6% reported better. In the EG, 31.81% reported much better and 68.18% reported better. Subject satisfaction was in favour of PG ($p=0.034$).

DISCUSSION

The main findings of this study demonstrated that adding a perturbation component to an 8-week trunk stabilization based training program led to greater improvements in trunk muscle endurance, ODI, TUG, FABQ total, and patient satisfaction in individuals with NSLBP. In contrast, both perturbation training and trunk stabilization training led to important but similar improvements in VAS, FABQ-PA, FABQ-Work, and SF-12. These results partially support our hypothesis.

Primary outcomes

Trunk endurance

NSLBP is a complex and multifactorial condition, and impairments in neuromuscular trunk responses—including muscle activity, coordination, reaction time, and muscle strength—are well-supported in the literature.[3,10] It has previously been shown that trunk-focused stabilization training performed under various instability conditions leads to greater neuromuscular activation of both deep and superficial muscles responsible for trunk stabilization.[5,10] Similarly, perturbation-based interventions have been reported as an effective means of promoting increased muscle activation. Several authors, based on laboratory studies, have indicated that postural manipulations, when combined with elastic resistance and/or unstable conditions (e.g., unstable surfaces or devices), lead to increased trunk muscle activity.[10,24] Mueller and colleagues demonstrated that high-intensity perturbations (via a split-belt platform) applied in conjunction with unstable surfaces during sensorimotor training enhance the neuromuscular activation of trunk muscles.[10] Aramptazis et al. reported a 22% improvement in trunk extensor strength and a 15% improvement in trunk flexor strength compared to the control group after 13 weeks of training 2 days a week with a random perturbation device in patients with NSLBP.[13] Another study conducted with adolescent athletes reported that adding perturbation-based trunk exercises twice a week to their annual training program increased trunk flexor and extensor muscle strength and reduced imbalances between these muscle groups.[11] Consistent with previous studies, the present study found that improvements in endurance of the trunk extensor (59%), flexor (92%), and right-left lateral flexor (136%-121%) exceeded the MDC (30%) in the PG and were greater compared to the EG. The present findings support previous studies suggesting that increasing levels of instability may place greater muscular demands on the trunk muscles. Although muscle activation was not measured, exercises such as bird-dog and side plank, which have previously been shown to specifically increase trunk muscle activation, were selected.[5,10] Challenging conditions, such as exposure to external perturbations, increase the demand on the sensorimotor system to perceive sensory signals and generate appropriate motor commands. Perturbations have been reported to increase movement instability and place additional demands on the neuromotor system during motion.[10] In response, the neuromotor system modifies motor control strategies to enhance its ability to cope with disturbances. Feedback provided particularly by proprioceptors has been shown to play a significant role in the modulation of motor control. Evidence suggests that exposure to perturbations leads to specific modulations in motor control and neural network reorganization, both of which are strongly influenced by proprioceptive input.[10,11] In the present study, perturbations applied at progressively increasing levels of difficulty may have elevated the demand for sensorimotor integration, potentially compelling the central nervous system to engage specific modulations in order to cope with challenging conditions.

Disability

Recent systematic reviews and meta-analyses have highlighted the positive impact of trunk-focused exercises on reducing LBP-related disability.[1,25] There are also studies showing that trunk stabilization training in unstable conditions leads to a greater improvement in disability.[5,26] However, the effects of perturbation training specifically on disability have rarely been investigated. Schäfer et al. reported that 16 supervised sessions of perturbation-based trunk training over 10 weeks resulted in less disability compared to the control group.[12] Niederer et al. reported that 3 weeks of supervised, 9 weeks of self-administered stabilization plus perturbation training showed no difference in disability compared with stabilization plus stretching or stabilization plus behavioural therapy, but the number of disability days in the last three months decreased.[9] In the mentioned study, providing supervised training for only 3 weeks may not have been sufficient for significant improvement in disability. In contrast to the present study, both the Schäfer et al. and Niederer et al. studies assessed disability using the Chronic Pain Rating Questionnaire instead of a LBP-specific scale, such as the ODI or Roland-Morris Disability Questionnaire. This may have reduced the likelihood of detecting subtle changes in disability levels associated with LBP. In the present study, disability was assessed using the ODI, a valid and reliable scale specific to LBP. Improvement was observed in both groups; however, this improvement was clinically important only in the PG and was greater than that in the EG. The current results confirm the effectiveness of previous trunk-based training and support the notion that perturbation training has a potential impact on reducing disability associated with LBP.

Secondary outcomes

VAS

Trunk-focused exercises have been shown to have a positive effect on pain intensity.[1,25] Although some studies suggest that stabilization training on unstable surfaces may be more effective for pain.[5,27], others report a similar effect to training on a stable surface.[26,28] Similarly, studies using perturbation training have produced conflicting results. Aramptazis et al. found a 49% reduction in the prevalence of 3-month back pain in elite athletes in the year of perturbation training compared to the control year (no perturbation training).[11] Niederer et al. reported that stabilization plus perturbation training was more effective on pain compared to the stretching and behavioral therapy groups.[9] However, Schäfer et al. reported that there was no difference between perturbation-based trunk training and the control group in elite rowers.[12] In the present study, both intervention groups showed statistically and clinically important improvements in all VAS scores, with no difference found between the groups. Unlike other studies, the control group also received trunk-based supervised training, which may have contributed to the reduction in pain intensity. Additionally, prior to the 8-week interventions, participants underwent pressure biofeedback training, which may have improved lumbopelvic alignment quality during exercises in all participants, thereby enhancing the effectiveness of the exercises.

TUG

Previously, Ge et al. reported that a 4-week trunk stabilization training program, performed 4 days per week, had positive effects on the TUG, 10-m walking, and four square step test in older women with LBP.[29] Unlike previous studies, the sample in the present study consisted of patients with NSLBP. However, the greater improvement in PG supports the effect of perturbation training on functional mobility. This result was not surprising, as it was similar to the improvement in ODI scores, which also assess walking function in daily life. The TUG is used to assess both functional/dynamic balance and functional mobility in LBP. A close relationship between dynamic balance and trunk muscle endurance has been demonstrated.[30] Oliveira et al. proposed that during balance training, the trunk muscles and proximal hip extensors exhibited increased activation, and that in the presence of perturbations, positive adaptations were induced to control trunk posture.[31] On the other hand, Arapmtazis et al. attributed the significant improvement in trunk stiffness of subjects with perturbation training to its potential to improve trunk stabilization.[11] Based on previous findings, perturbation training, along with increased trunk muscle endurance, has supported improvements in trunk postural control. As a result of enhanced trunk stabilization, disruptions in dynamic balance during functional tasks such as walking are likely reduced, leading to improvements in movement quality and speed.

SF-12, FABQ and GRC

A recent meta-analysis reported that trunk-based exercises had a positive effect on QoL in patients with chronic LBP compared to a control group.[25] However, no previous data were found regarding the effects of perturbation training on QoL. In the present study, it was observed that the PCS-12 and MCS-12 scores improved in both groups, surpassing the minimum MDC. The inclusion of exercises, which have previously demonstrated efficacy, in both groups may have contributed to improvements in QoL due to the clinically important improvements in disability and pain.

Moderate evidence suggests that stabilization-based exercises are effective for kinesiophobia in the medium term with a medium ES in NSLBP.[20] Fapojuwo et al. reported that trunk stabilization exercises and trunk balance exercises applied for 8 weeks had similar effects on FABQ total.[32] Muthukrishan et al reported that water-based and land-based perturbation training in adults over 55 years of age with CLBP resulted in significant improvement in FABQ-Work scores.[33] In the present study, both the FABQ-PA and FABQ total scores showed improvements in both groups, with the FABQ-Work improving only in the PG and the FABQ total showing greater improvement in the PG. Unlike the intervention methods in previous studies, this study applied perturbations under progressively challenging conditions, including manual push-pull maneuvers. The trust established between the therapist and the patient during the perturbations may have improved self-efficacy in the patients. Moreover, the fact that patients experienced unstable conditions similar to those in daily life through these challenging conditions may have positively affected their fear avoidance attitudes related to the activity. Decreased self-efficacy and increased fear avoidance have been shown to be associated with an increased level of disability before.[34] On this basis, the results of the present study may explain why function improved significantly more in the PG compared to the EG. Considering the results, combining trunk stabilization training with perturbation may effectively improve fear-avoidance behaviors in patients with NSLBP. The greater improvements in function and fear-avoidance behaviors, which directly affect daily life, may have led to higher satisfaction levels in the PG.

This study had some limitations. Firstly, there was no no-intervention control group against which the effects of the interventions could be directly compared. Secondly, the lack of long-term follow-up data was a limitation of the study. Another limitation is that the sample size of the study was relatively small and consisted solely of individuals with NSLBP. Therefore, it is difficult to generalize the findings to the entire LBP population. Finally, although the training frequency of two days per week or the 8-week training duration were sufficient to alter the primary outcomes, they may not have been adequate to produce potentially significant effects on the secondary outcomes.

In conclusion, this study provided important data as a randomized controlled trial demonstrating the effects of perturbation training on both psychosocial and physical parameters in patients with NSLBP. Given the lack of adverse events reported with perturbation training and the positive effects on outcome measures, it appears that this training method can be used in combination with exercise programs for NSLBP. Additionally, since this training program requires minimal equipment and space for the exercises, it can be easily implemented by therapists and trainers without the need for expensive laboratory equipment. Future studies should include larger samples and clarify the long-term effects of perturbation training. Additionally, studies conducted in different populations of individuals with LBP, with varying training durations and dosages, will be useful for determining the optimal training for various subgroups and identifying which groups may benefit more from perturbation training.

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TABLES

Table 1. Baseline Demographics of Groups

Table 2. Comparison of Changes in Primary Outcome Measure Within and Between Groups

Table 3. Comparison of Changes in Secondary Outcome Measures Within and Between Groups

FIGURES

Figure 1. Exercise Program

Figure 2. Perturbation Training Program

Figure 3. Flow Diagram

Table 1. Comparison of demographic and clinical characteristics of the groups

	EG	PG	p*
Age (years)			
Mean ± SD	33.00 ± 10.30	33.13 ± 8.98	0.96
Symptom duration (years)			
Mean ± SD	2.43 ± 3.1	3.61 ± 3.3	0.23
BMI(kg/m^2)			
Mean ± SD	25.62 ± 3.68	23.68 ± 3.03	0.06
Sex (n)			
Female	14	16	0.50
Male	8	6	
Employment status (n)			
Employee	14	13	0.24
Unemployee/housewife	8	9	

EG: Exercise group, PG: Perturbation group, BMI: Body Mass Index, SD: Standard deviation,*Independent sample t-test; significance level set at <0.05.

Table 2. Comparison of changes in primary outcome measures within and between groups

Assessment		Baseline	After 6 weeks	Within-group score change		p*	ANCOVA		
		Mean ± SD	Mean ± SD	Mean [95% CI]	Cohen's d		F	p†	Partial Eta Squared
Extensor endurance test (sec)									
EG		59.28 ±23.68	75.95 ± 19.50	16.66 [8.24, 25.09]	**0.76**	**<0.001**	17.67	**<0.001**	0.30
PG		63.22 ± 20.98	100.22 ± 23.01	37.90 [28.03, 45.96]	**1.86**	**<0.001**			
Flexor endurance test (sec)									
EG		47.00 ± 21.60	60.00 ± 20.91	13.00 [4.07, 21.92]	**0.61**	**0.006**	12.24	**0.001**	0.23
PG		47.04 ± 18.65	90.70 ± 35.79	43.65 [25.57, 61.74]	**1.52**	**<0.001**			
Side endurance test (sec)									
R	**EG**	24.63 ± 17.17	39.06 ± 18.70	14.43 [7.70, 21.15]	**0.80**	**<0.001**	12.93	**0.001**	0.24
	PG	22.10 ± 14.16	53.04 ± 20.38	30.94 [24.50, 37.37]	**1.76**	**<0.001**			
L	**EG**	21.53 ± 13.70	34.43 ± 17.51	12.90 [7.48, 18.31]	**0.82**	**<0.001**	15.02	**<0.001**	0.26
	PG	22.58 ± 14.82	50.09 ± 13.88	27.50 [20.99, 34.01]	**1.91**	**<0.001**			
ODI									
EG		10.04 ± 4.36	5.09 ± 2.81	-4.95 [-6.11, -3.78]	**1.34**	**<0.001**	9.03	**0.005**	0.18
PG		10.90 ± 3.75	3.63 ± 2.46	-7.27 [-8.79, -5.75]	**2.29**	**<0.001**			

EG: Exercise group, PG: Perturbation group, R: Right, L: Left, SD: Standard deviation, CI: Confidence interval, R: Right, L: Left,
*Paired samples t-test; significance level set at <.05.
†Analysis of covariance (ANCOVA); significance level set at <.05.

Table 3. Comparison of changes in secondary outcome measures within and between groups

Assessment	Baseline	After 8 weeks	Within-group score change		p^*	ANCOVA		
	Mean ± SD	Mean ± SD	Mean [95% CI]	Cohen's d		F	$p^†$	Partial Eta Squared
VAS-rest						0.53	0.47	0.013
EG	4.32 ± 2.12	1.65 ± 1.73	-2.66 [-3.44, -1.89]	1.37	**<0.001**			
PG	4.17 ± 1.36	1.30 ± 1.12	-2.86 [-3.65, -2.07]	2.30	**<0.001**			
VAS-activity						1.032	0.31	0.025
EG	6.44 ±1.61	2.67 ± 1.42	-3.77 [-4.60 -2.93]	2.48	**<0.001**			
PG	5.43 ± 2.15	2.01 ± 1.35	-3.41 [-4.33, -2.50]	1.90	**<0.001**			
VAS-night						3.91	0.05	0.087
EG	4.16 ± 2.53	1.69 ± 1.90	-2.46 [-3.56, -1.36]	1.10	**<0.001**			
PG	3.69 ± 2.25	0.71 ± 1.06	-2.97 [-3.92, -2.02]	1.69	**<0.001**			
TUG (sec)						4.96	**0.030**	0.11
EG	7.84 ± 1.25	7.26 ± 0.70	-0,58 [-1.04, -0.12]	0.57	**0.015**			
PG	7.38 ± 0.91	6.65 ± 0.80	-0.73 [-0.99, -0.46]	0.85	**<0.001**			
PCS-12						8.92	0.05	0.17
EG	40.79 ± 7.91	46.48 ± 6.11	5.69 [2.24, 9.13]	0.80	**<0.001**			
PG	41.88 ±8.21	51.52 ± 4.72	9.64 [5.35, 13.93]	1.43	**<0.001**			
MCS-12						0.45	0.50	0.01
EG	41.70 ± 6.15	47.39 ± 10.50	5.69 [0.77, 10.60]	0.60	**0.025**			
PG	40.32 ± 10.18	44.99 ± 9.05	4.67 [-0.12, 9.47]	0.48	0.056			
FABQ-PA						3.58	0.06	0.080
EG	14.54 ± 4.68	11.86 ± 4.93	-2.68 [-4.77, -0.59]	0.55	**0.014**			
PG	14.13 ± 5.32	9.18 ± 4.40	-4.95 [-7.81, -2.09]	1.01	**0.002**			
FABQ-W						2.45	0.12	0.057
EG	13.86 ± 8.96	11.36 ± 9.66	-2.50 [-5.43, 0.43]	0.26	0.091			
PG	13.72 ± 8.32	8.31 ± 7.72	-5.40 [-8.35, -2.46]	0.67	**0.001**			
FABQ-Total						5.06	**0.030**	0.11
EG	35.72 ± 14.51	28.40 ± 14.23	-7.31 [-11.94, -2.69]	0.50	**0.003**			
PG	34.27 ± 12.31	20.45 ± 11.95	-13.81 [-19.38, -8.24]	1.13	**<0.001**			

EG: Exercise group, PG: Perturbation group, ODI: Oswestry Disability Index, VAS: Visual Analog Scale, TUG: Timed Up and Go, PCS-12: Physical component score of Short Form-12, MCS-12: Mental component score of Short Form-12, FABQ-PA: Fear Avoidance Belief Questionnaire-Physical Activity, FABQ-W: Fear Avoidance Belief Questionnaire-Work, SD: Standard deviation, CI: Confidence interval,

*Paired sample t-test; significance level set at <.05.

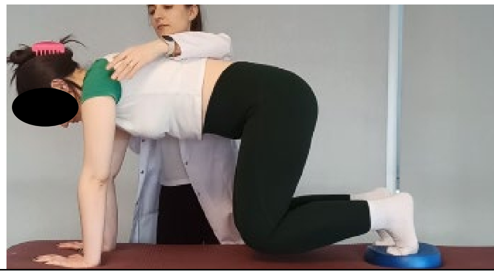
†Analysis of covariance (ANCOVA); significance level set at <.05.

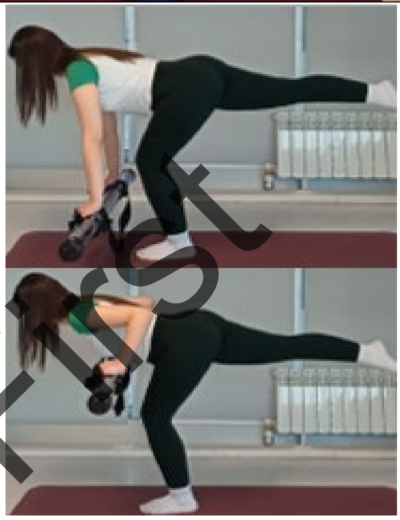
Figure 1. Exercise Program

Exercise	Description	
(1) Bird dog	-**Level I (1-4 weeks)** Begin in a crawling position, ensuring your knees are aligned with your hips and your hands are aligned with your shoulders. Simultaneously lift one arm and the opposite leg, keeping them extended and parallel to the floor. Lower them back to the starting position and repeat the movement on the opposite side (3 sets x10 reps per side).	
	-Level II (5-8 weeks) While in a crawling position, gently lift both knees off the floor while maintaining proper spinal alignment, then lower them back down. This variation of the exercise is commonly referred to as the 'bear plank'(3 sets x10 reps).	
(2) Single-leg deadlift	-**Level I (1-4 weeks)** "Stand upright and shift your weight onto one leg with the knee slightly bent, keeping your torso straight. Lean forward while extending the other leg straight behind you, maintaining alignment with your torso. Return to the starting position in a controlled manner (3 sets x10 reps per side).	
	-**Level II (5-8 weeks)** The single-leg deadlift exercise is performed using a barbell weighing approximately 3.5 kg, held with the hands positioned shoulder-width apart (3 sets x10 reps per side).	

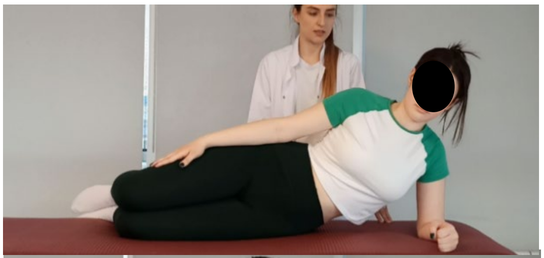
(3) Back extension	-**Level I (1-4 weeks)** "In the prone position, simultaneously lift one arm and the opposite leg off the ground. Return them to the starting position, then repeat the movement by lifting the other arm and opposite leg (3 sets x10 reps per side).	
	-**Level II (5-8 weeks)** "In the prone position, lift both arms and both legs off the floor simultaneously, then lower them back down to the floor in a controlled manner (3 sets x10 reps).	
(4) Side planks	-**Level I (1-4 weeks)** Lie on your right side with your elbow directly beneath your shoulder, ensuring your head, shoulders, hips, and knees are aligned, with your knees bent. From this position, lift your hip off the floor, then lower it back down in a controlled manner. Repeat the exercise on your left side (3 sets x10 reps per side).	
	-Level II (5-8 weeks) The head, shoulders, hips and knees are in line, the knees are straight and the elbow is perpendicular to the ground. In this position the hips and knees are separated from the floor and then lowered back to the floor (3 sets x10 reps per side).	

Figure 2. Perturbation Training Program

Exercise	Description	
(1) Bird dog	**-Level I (1-2 weeks)** The “bird dog” exercise is performed on a stable surface with manual push-pull perturbations by the physiotherapist (3 sets x10 reps per side).	
	-Level II (3-4 weeks) The "Bird dog" exercise is performed on unstable ground (under the knees) with manual push-pull perturbations by the physiotherapist (3 sets x10 reps per side).	
	-Level III (5-6 weeks) The ‘Bear plank’ exercise is performed on a stable surface, accompanied by manual push-pull perturbations by the physiotherapist. (3 sets x10 reps)	
	-Level IV (7-8 weeks) The "Bear plank" exercise is performed on unstable ground (under the feet), accompanied by manual push-pull perturbations by the physiotherapist. (3 sets x10 reps)	
(2) Single-leg deadlift	**-Level I (1-2 weeks)** The single-leg deadlift exercise is performed on a stable surface with the physiotherapist's manual push-pull perturbations. (3 sets x10 reps per side)	

	-Level II (3-4 weeks) The single-leg deadlift exercise is performed on an unstable surface with the physiotherapist's manual push-pull perturbations (3 sets x10 reps per side).	
	-Level III (5-6 weeks) When the body is bent forward to perform a single-leg deadlift with a water tube weighing approximately 3.5 kg, held with hands shoulder-width apart on a stable surface, the water tube is pulled towards the chest as if rowing and released. Then return to starting position (3 sets x10 reps per side).	
	-Level IV (7-8 weeks) When the body is bent forward to perform a single-leg deadlift with a water tube weighing approximately 3.5 kg, held with hands shoulder-width apart on an unstable surface, the water tube is pulled towards the chest as if rowing, and released. Then return to starting position (3 sets x10 reps per side).	

(3) Back extension	**-Level I (1-4 weeks)** While lying on a stable surface in a prone position, the crossed arm and leg are simultaneously lifted off the floor and the physiotherapist applies manual push-pull perturbations. After the arms and legs are lowered to the floor, the other arm and leg are raised crosswise and the movement is repeated (3 sets x10 reps per side).	
	-Level II (5-8 weeks) While lying prone on an unstable surface, the crossed arm and leg are simultaneously lifted off the ground and the physiotherapist applies manual push-pull perturbations. After the arms and legs are lowered to the floor, the other arm and leg are raised crosswise and the movement is repeated (3 sets x10 reps per side).	
	-Level III (5-6 weeks) While lying on a stable surface in a prone position, both arms and both legs are lifted off the ground at the same time and the physiotherapist applies manual push-pull perturbations. The patient then returns to the starting position (3 sets x10 reps).	
	-Level IV (7-8 weeks) While a prone position on an unstable surface, both arms and legs are lifted off the ground at the same time and the physiotherapist applies manual push-pull perturbations. The patient then returns to the starting position (3 sets x10 reps).	

(4) Side planks	**-Level I (1-4 weeks)** Lie on your right side on a stable surface with your head, shoulders, hips and knees in line, your knees bent and your right elbow perpendicular to the floor. In this position, the hip is separated from the floor and the physiotherapist applies manual push-pull perturbations. For the left side the same procedure is applied (3 sets x10 reps per side).	 
	-Level II (5-8 weeks) On an unstable surface (under the forearm), the head, shoulders, hips and knees are in line, the right elbow is perpendicular to the ground and the knees are bent. In this position, the hip is separated from the floor and the physiotherapist applies manual push-pull perturbations. For the left side the same is repeated. For the left side the same procedure is applied (3 sets x10 reps per side).	 
	-Level III (5-6 weeks) Lie on your right side on a stable surface with your head, shoulders, hips and knees in line, your knees straight and your right elbow perpendicular to the floor. In this position, the physiotherapist applies manual push-pull perturbations while your hips and knees are separated from the floor. For the left side the same procedure is applied (3 sets x10 reps per side).	

	-Level IV (7-8 weeks) On an unstable surface (under the forearm), the head, shoulders, hips and knees are in line, the knees are straight and the right elbow is perpendicular to the ground, lying on the right side. In this position, the hips and knees are separated from the floor while the physiotherapist applies manual push-pull perturbations. For the left side the same procedure is applied (3 sets x10 reps per side).	

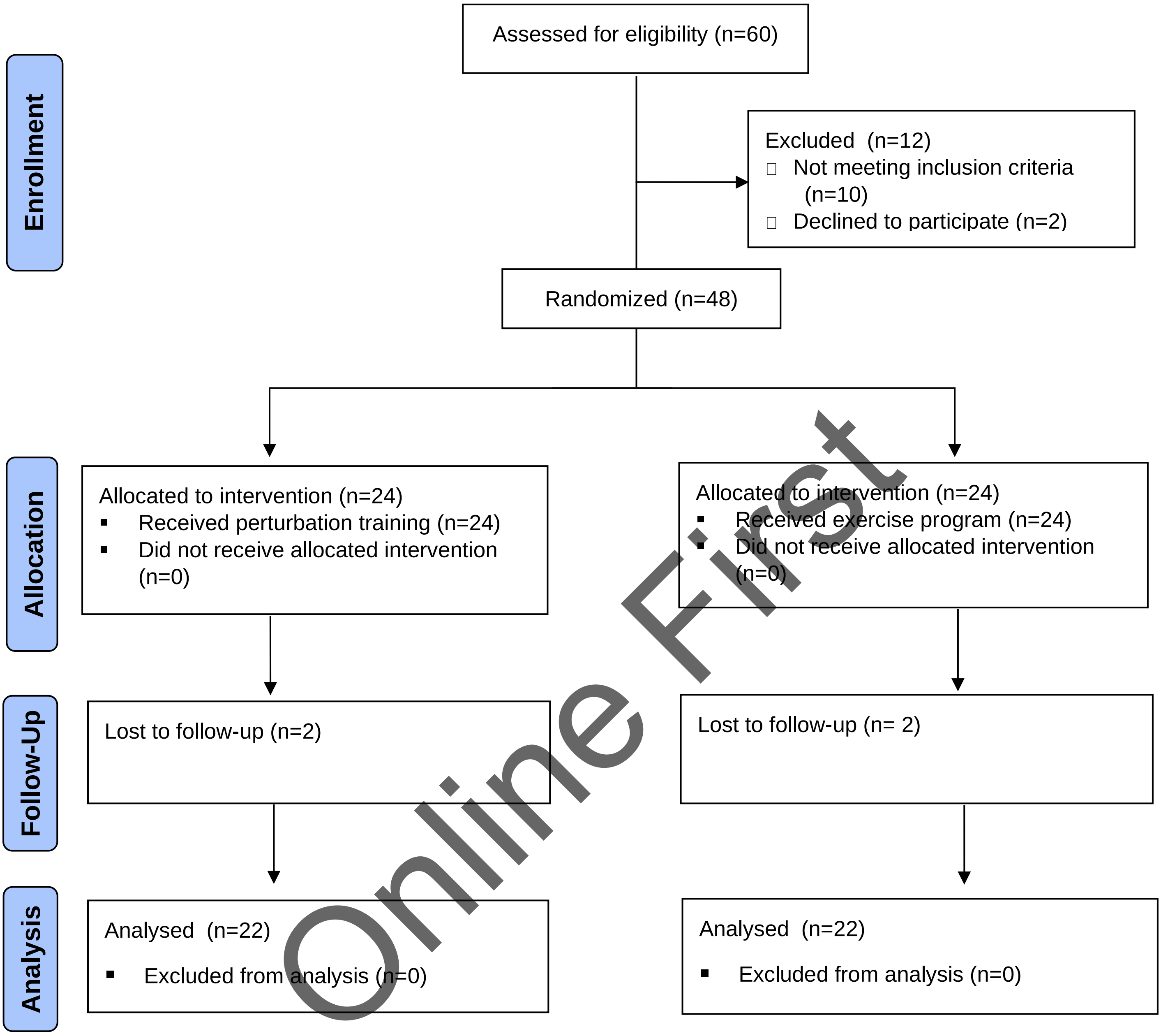


Figure 3. Flow diagram