Somatosensory & Motor Research

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/ismr20

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SOMATOSENSORY & MOTOR RESEARCH
https://doi.org/10.1080/08990220.2023.2191705

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RESEARCH ARTICLE

The effects of dynamic neuromuscular stabilization approach on clinical outcomes in older patients with chronic nonspecific low back pain: a randomized, controlled clinical trial

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ABSTRACT

Objective: We aimed to examine the effects of Dynamic Neuromuscular Stabilization (DNS) approach in older patients with chronic non-specific low back pain (CNSLBP).

Methods: A total of 72 participants with CNSLBP were assigned to either the experimental group ($n=36$) or control group ($n=36$) in this randomized study. A conventional physiotherapy program was administered to the participants in the control group for 3 days per week for a total of 6 weeks. In addition to the conventional program, DNS exercise protocol was performed for 3 days per week for 6 weeks for the participants in the experimental group. While quality of movements and exercise capacity were our primary outcomes, functional balance and quality of life constituted our secondary outcomes. The participants were assessed both at baseline and post-treatment.

Results: The improvement in a deep squat, in-line lunge, hurdle step, shoulder flexibility, rotary trunk stability, total Functional Movement Screening score, and Timed-up and Go Test score was greater in the experimental group ($p<.05$). The improvement was similar in both groups in terms of the rest of outcome measures.

Discussion: This study demonstrated the effectiveness of the DNS approach on some functional movement patterns and functional balance performance in older patients with CNSLBP.

ARTICLE HISTORY
Received 22 August 2022
Accepted 13 March 2023

KEYWORDS
Low back pain; dynamic neuromuscular stabilization (DNS); older adults

1. Introduction

Affecting approximately 70% of the older population, low back pain (LBP) is an important health problem with considerable social, economic, and functional loss (Bresler et al. 1999; Podichetty et al. 2003). In the absence of specific findings such as fracture, inflammation, radiculopathy, etc., LBP is classified as non-specific low back pain (NSLBP) (Maher et al. 2017). When present for longer than three months, NSLBP is referred to as chronic NSLBP (CNSLBP), which is commonly accompanied by varying degrees of decrease in trunk proprioception, biomechanical malalignment, sedentary lifestyle, prolonged bed rest, and deterioration, especially in lumbopelvic motor control (Wong et al. 2017).

As an important muscle in lumbopelvic motor control, the diaphragm counteracts perturbation forces, especially during postural activities, by modulating the pressure difference between the thorax and abdomen (Hagins and Lamberg 2011). In this context, limitations in the mobility of the diaphragm hamper postural control during dynamic activities, since anticipatory postural adjustments (APA) require shortening of the diaphragm prior to trunk movements (Kolar et al. 2009; 2010; 2012; Wong et al. 2017). It is reported that the mobility of the diaphragm, especially in the anterior-middle part of the muscle, decreases during isometric upper and lower extremity flexion exercises in individuals with CNSLBP (Kolar et al. 2012). Kolar reported impairment in the regulation of intra-abdominal pressure due to insufficient mobility of the diaphragm, which causes compressive forces on the vertebrae as a result of the compensatory activity of the superficial spinal extensor muscles (Kolar et al. 2012). Muscular imbalance between the upper and lower quadrants also results in an abnormal position of the chest or rib cage, negatively affecting lung functions and exercise capacity (Scott et al. 2006; Kolář et al. 2009; Kolar et al. 2010).

There in an ongoing body of research investigating the effectiveness of the Dynamic Neuromuscular Stabilization (DNS) approach (Son et al. 2017; Lee et al. 2018; Mahdieh et al. 2020; Yoon et al. 2020) in different pathologies, making it a potential treatment option in minimizing the aforementioned problems (Scott et al. 2006; Kolář et al. 2009; Kolar et al. 2010; 2012) in older patients with CNSLBP (Frank et al. 2013; Son et al. 2017; Lee et al. 2018; Mahdieh et al. 2020; Yoon et al. 2020). The DNS approach, which is based on the principles of developmental kinesiology, utilizes infants' motor development curves in the treatment of motor disorders (Son et al. 2017; Yoon et al. 2020). The main focus is to regulate intra-abdominal pressure and the spinal stabilizing system through specific functional exercises based on the

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positions exhibited by a healthy infant (Son et al. 2017; Yoon et al. 2020). In the DNS approach, every developmental position is considered an exercise position, but every exercise must follow basic principles (Son et al. 2017; Yoon et al. 2020), namely the restoration of correct respiratory pattern and intra-abdominal pressure, applying for the correct support during dynamic activities of the extremities, and ensuring biomechanical alignment during movements (Frank et al. 2013; Son et al. 2017; Lee et al. 2018; Mahdieh et al. 2020; Yoon et al. 2020). Considering these principles, the DNS seems to be a potential action mechanism for anomalies in older patients with CNSLBP (Scott et al. 2006; Kolář et al. 2009; Kolar et al. 2010; 2012). Therefore, we aimed to examine the effectiveness of the DNS approach on functional movement patterns, functional balance, exercise capacity, and quality of life in older patients with CNSLBP. The primary endpoint was to compare pre- and post-treatment scores of the experimental versus control groups on the Functional Movement Screening (FMS) and 6-Minute Walk Test (6MWT). Our secondary endpoint included the comparisons of scores on the Timed-Up and Go Test (TUG) and WHOQOL-OLD module. As the first randomized controlled study in the relevant literature, it is hypothesized that the DNS can be an effective therapeutic approach for the intended features.

2. Materials and methods

Study design

This single-blind, prospective, randomized, controlled clinical trial is registered with the Clinical Trials Registry (NCT04948073). The study protocol was reviewed and approved by the local ethics committee (2021/813). The procedures were in accordance with the Declaration of Helsinki. The CONSORT guidelines were followed (Schulz et al. 2010).

Participants

The study population consisted of 72 older people with CNSLBP (duration $>$ 3 months, without leg pain), who were admitted to the Orthopaedics and Traumatology Outpatient Clinic between June 2021 and April 2022. In the absence of specific findings such as fracture, inflammation, radiculopathy, etc., LBP is classified as non-specific low back pain (NSLBP) (Maher et al. 2017). When present for longer than three months, NSLBP is referred to as chronic NSLBP (CNSLBP). For the diagnosis of CNSLBP, the operational definition, magnetic resonance imaging, and clinical tests were used by the orthopaedic specialist (Stanton et al. 2011). Consecutive patients attending the clinic were screened and invited to participate in the study. They were informed about the purpose and procedure of the study and gave their informed written consent.

The inclusion criteria were as follows: pain severity of at least 3 measured on a 0-10 cm Visual Analog Scale (VAS), being over 65 years of age, ability to comprehend and follow verbal instructions, and to volunteer to participate in the study (Inani and Selkar 2013; Vibe Fersum et al. 2013; Ozsoy et al. 2019; Kararti et al. 2021). The exclusion criteria were: history of spinal surgery; medical contraindications to active exercise; severe spinal pathologies (e.g., spina bifida, lumbar spinal stenosis, spinal tumours, ankylosing spondylitis, osteoporosis, and cauda equina syndrome); concurrent somatic or psychiatric disorders (Mini-Mental State Examination score (MMSE)$\leq$24); specific causes of LBP (e.g., facet joint problem, disc herniation, sacroiliac joint dysfunction, and nerve root compression); neurological deficits (e.g., brain tumour and nerve palsies); diagnosis of diabetes mellitus, hypertension, autoimmune diseases (e.g., rheumatoid arthritis and systemic lupus erythematosus); and cancer (Inani and Selkar 2013; Vibe Fersum et al. 2013; Ozsoy et al. 2019; Kararti et al. 2021).

Randomization

A simple computer-generated randomization was carried out by a secretary who was not directly involved in the research. The allocation was concealed using consecutive numbered, sealed, and opaque envelopes (Doig and Simpson 2005). The participants were randomly assigned to either the experimental group (conventional treatment + DNS) or the control group (conventional treatment only).

Blinding

Given the nature of the study, it was not possible to blind the physiotherapist (CK) to the interventions. The patients were informed about the study being "a comparison between two physiotherapy treatments, one of which was the DNS." At the end of the study, to evaluate blinding, the blinded orthopaedic specialist (ÇB) was asked whether each patient was allocated to the experimental or to the control group.

Interventions

After being evaluated by the blinded orthopaedic specialist, the participants were referred to the Physiotherapy and Rehabilitation Outpatient Clinic. An experienced physiotherapist (CK) administered the 6-week-long treatment program (a total of 18 sessions, three days/week, 30-40 min per session) for both groups. This program included: 15 min of TENS for the low back (100 Hz, fixed pulse); 5 min of ultrasound (1 Hz, continuous mode of application 1.5 w/cm^2), and strengthening and stretching exercises for the abdominal, back, pelvic floor, and lower limb muscles based on previous research (Hayden et al. 2005; Thiese et al. 2013).

All participants continued their usual daily activities, received leaflets regarding physical activity, and were asked to discontinue analgesic treatments and avoid any other types of physiotherapy and/or rehabilitation programs during the study.

In addition to the conventional treatment, a DNS exercise protocol was administered for the experimental group for a whole period of 6 weeks (three days/week, 50 min per session) (Mahdieh et al. 2020). To promote treatment fidelity, the study team developed a detailed manual of procedures and fidelity checklists, completed role plays to standardize treatment administration, and video-recorded all treatment sessions for review. To assess protocol adherence during treatment delivery, trained research assistants, who were not involved in the treatment, reviewed video recordings of randomly selected DNS sessions and completed the fidelity checklists. This process was completed for all the participants, which allowed for the measurement of protocol adherence over time. Percent accuracy of protocol adherence was calculated across clinicians. The percent accuracy was excellent and good to excellent. The DNS protocol included 5 min of warm-up, 40 min of DNS exercises (4 different body parts, 10 min per part) accompanied with breathing exercises, and 5 min of cool-down. The DNS exercises included diaphragmatic breathing, Baby Rock, Rolling, Side Lying, Oblique Sitting, Tripod, Kneeling, Squat, Prone, and Czech Get Up (CGU). Figures 1 and 2 represent the starting positions of the DNS protocol and the eleven phases of the CGU. The focus of the first week was to learn and practice basic DNS exercises. To gradually increase the complexity of the exercises, every week a new task was added to an already practiced task. The increase in the complexity enabled the participants automate their performance. We used the dual-task paradigm to examine whether the task was automated (e.g., diaphragmatic breathing should not be disturbed by the new task). A detailed description of the DNS training protocol and different levels of exercises are presented in the study by Mahdieh et al. (Mahdieh et al. 2020).

Outcome measures

Demographic data and clinical characteristics of the participants were recorded at baseline. These included age, gender, body mass index, pain intensity (*via* VAS) (Suh et al. 2019), duration of symptoms, medication, mental state (*via* MMSE) (Hoshino et al. 2013), level of physical activity (International Physical Activity Questionnaire$>$ 150 min/week) (Brandão et al. 2021), smoking, educational status, kinesiophobia (*via* Tampa Scale of Kinesiophobia (TSK)) (Ozsoy et al. 2019), and anxiety and depression levels (*via* Hospital Anxiety and Depression Scale (HADS)) (Zigmond and Snaith 1983). Presence of anxiety, depression, and kinesiophobia are reported to have potential impacts on post-treatment results (Tagliaferri et al. 2020). The demographic and clinical characteristics were used as covariates in the data analyses.

Both at baseline and post-treatment (after the administration of the DNS exercise protocol for a whole period of 6 weeks), all clinical outcomes were measured by the orthopaedic specialist who was blinded to the group allocations. While functional movement patterns (Farrell et al. 2021) and exercise capacity (Yilmaz Yelvar et al. 2017; Sunde et al. 2020) were our primary outcomes, functional balance (Yingyongyudha et al. 2016) and quality of life (QoL) (Gobbens and Remmen 2019) constituted our secondary outcomes. The participants were evaluated with the following reliable, valid, and culturally adapted tests and tools:

Primary outcome measurements

- The Functional Movement Screening (FMS): Evaluating the quality of movements, this screening tool assesses 7 fundamental movement patterns to identify any imbalance and/or asymmetry leading to movement limitations (Cook et al., 2006; 2006). The 7 test items include deep squat, in-line lunge, hurdle step, shoulder flexibility, push-up, straight leg raise, and rotary trunk stability (Cook et al., 2006). Each of these 7 test items is scored on a scale of 0 (= pain is reported during the test item, regardless of the quality of the movement) to 3 (= the item was performed successfully with no compensatory movements). The sum of item scores creates the total score ranging from 0 to 21 (Cook et al., 2006). Five of the test items (namely hurdle step, in-line lunge, shoulder flexibility, straight leg raise, and rotary trunk stability) are administered bilaterally to assess asymmetry. In case of a discrepancy between the left and right scores, an asymmetry is noted and the lower of the 2 scores is recorded (Cook et al., 2006; 2006). In this study, we used both the item scores and total scores of the tool.
- The 6-Minute Walk Test (6MWT) evaluates exercise capacity (Yilmaz Yelvar et al. 2017; Sunde et al. 2020).

Secondary outcome measurements

- The Timed-up and Go Test (TUG) evaluates functional balance (Yingyongyudha et al. 2016).
- The WHOQOL-OLD module to evaluate the quality of life: The questionnaire consists of 24 items in 6 dimensions, and the response format is a five-point Likert scale. Higher scores indicate better QoL (Eser et al. 2010; Gobbens and Remmen 2019).

Sample size

A previous study on patients with LBP that used the 6MWT as a primary outcome measure for ANCOVA was referenced as there was no study in the relevant literature investigating the effects of DNS in older adults with CNSLBP (Yilmaz Yelvar et al. 2017). Based on the results of the reference study and using G*Power Software (Version 3.1.9.2, Düsseldorf University, Düsseldorf, Germany), the minimum required sample size was calculated as 32 participants per group for the probability level of .05, anticipated effect size of .36, and statistical power level of 80%. Considering a drop-out rate of 10%, 72 participants were recruited.

Statistical analysis

The IBM® SPSS® Statistics for Windows software (ver. 22.0; IBM Corp., NY, USA) was used to analyze the data. Visual (histograms, probability plots) and analytical methods (Kolmogorov-Simirnov/Shapiro-Wilk's test) were used to examine the normal distribution of the data. Continuous and categorical variables were expressed as mean ± standard deviations (mean ± SD) and ratios (%), respectively. For intergroup comparison of the continuous and categorical variables, independent samples *t*-test and Chi-square test were used respectively. In the second step, we performed a two-way analysis of covariance (ANCOVA) for repeated measures, where demographic and clinical

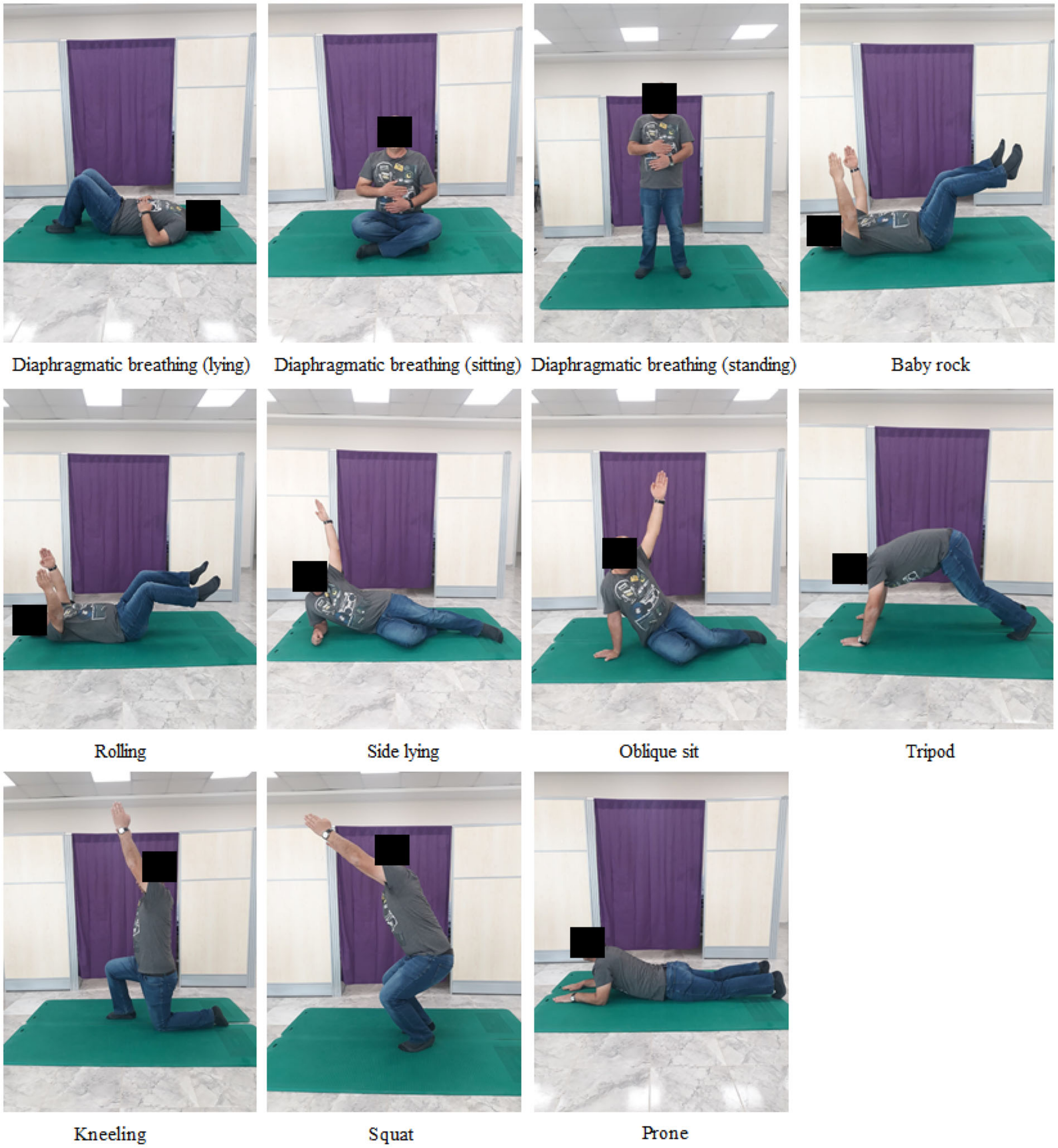

Figure 1. Starting positions of the DNS training protocol.

characteristics were used as covariates. Bonferroni's *post hoc* test was applied to identify the mean differences when the F-ratio was significant. Effect sizes were determined as partial eta squared (η^2p). For all statistical analyses, the significance level was set at $p<.05$.

3. Results

A total of 72 older patients with CNSLBP were randomly assigned to either the experimental group ($n=36$) or control group ($n=36$). However, in the experimental group 2 patients were excluded due to a new diagnosis of comorbidities. Thus, the study was completed with 70 participants attending 6 weeks of treatment. Of these, 34 received DNS exercise protocol in addition the conventional treatment, and 36 received conventional treatment solely. The study flowchart and details of adherence to treatment are presented in Figure 3.

Demographic and clinical characteristics of participants are presented in Table 1. While the groups were similar in most of the basic parameters (p>.05), the rate of smokers differed significantly, having a higher percentage in the experimental group ($p=.04$).

Our analyses showed that DNS approach combined with conventional treatment conferred beneficial effects in terms of some functional movement patterns. ANCOVA performed on some functional movement patterns revealed both a time effect ($p<.05$) and a group*time interaction effect ($p<.05$, Table 2, Figure 4). It was found that the improvement in total

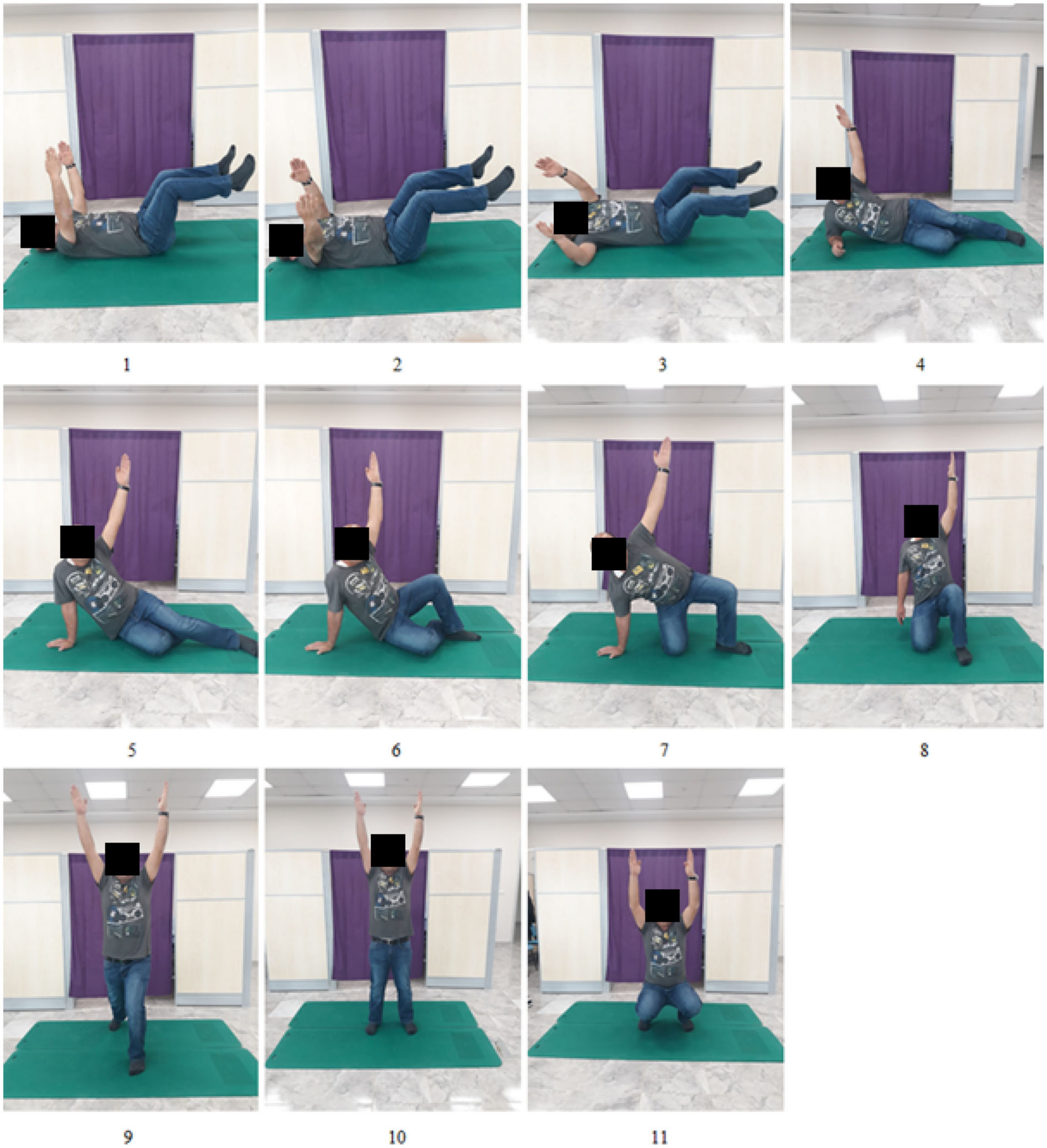

Figure 2. Eleven phases of the Czech Get Up.

FMS score [(−2.14, 95%CI= −2.78; −1.49); (−0.73, 95%CI= −1.21; −0.24)], deep squat [(−0.56, 95%CI= −0.81; −0.30); (−0.20, 95%CI= −0.44; 0.04)], in-line lunge [(−0.41, 95%CI= −0.61; −0.20); (-0.03, 95%CI= −0.26; 0.20)], hurdle step [(−0.18, 95%CI= −0.33; −0.02); (-0.05, 95%CI= −0.26; 0.16)], shoulder flexibility [(−0.33, 95%CI= −0.50; −0.15); (−0.03, 95%CI= −0.21; 0.15)], and rotary trunk stability [(−0.36, 95%CI= −0.53; −0.18); (−0.06, 95%CI= −0.27; 0.15)] was greater in the experimental group compared to the control group. There was no significant difference between the two groups in terms of push-up and straight leg raise ($p>.05$).

Compared to the baseline, the post-intervention mean values of the 6MWT improved with 44.29 metres (8.76%) in the experimental group and 26.62 metres (5.14%) in the control group. However, ANCOVA performed on the 6MWT did not reveal any time effect [(p=.230; η^2p=.043)] nor group*time interaction effect [(p=.377; η^2p=.024), Table 2, Figure 4].

Similarly, the results showed that the combination of conventional treatment and DNS conferred beneficial effects in terms of functional balance performance. ANCOVA performed on TUG revealed both a time effect [(p= <.001; η^2p=.575] and a group*time interaction effect [(p=.025; η^2p=.144, Table 2, Figure 4]. For the experimental group, the mean TUG score was 8.70 and 7.02 s pre- and post-treatment, respectively; demonstrating an improvement of 1.68 (19.31%). For the control group, the mean TUG score was 8.79 s before and 7.82 s after the treatment, indicating an improvement of 0.97 (11.03%).

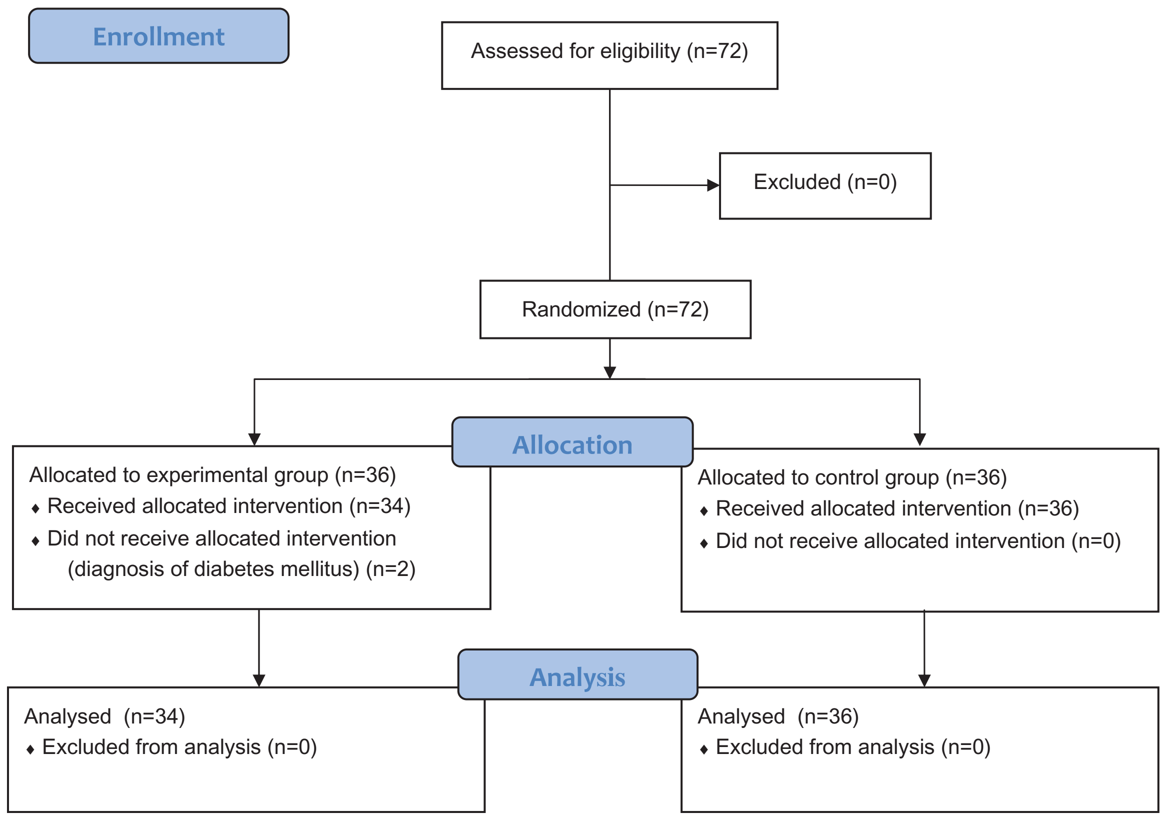

Figure 3. Flowchart of the clinical trial phases.

Table 1. Demographic and clinical characteristics of groups.

	Experimental Group	Control Group	*p*
Age (years)	68.08 ± 1.54	67.75 ± 1.33	.33
Gender (female %)	12 (33.3%)	15 (41.6%)	.63
Body mass index (kg/m^2)	27.94 ± 3.45	29.33 ± 3.07	.07
Pain intensity (VAS)	5.97 ± 1.11	5.80 ± 1.09	.53
Duration of symptoms (months)	26.58 ± 7.41	23.44 ± 7.56	.08
Medication before the study protocol (yes %)	17 (47.2%)	11 (30.5%)	.09
Mini-Mental State Examination score	26.88 ± 1.64	26.94 ± 1.81	.88
Being physically active (IPAQ > 150 min/week, yes %)	8 (22.2%)	10 (27.7%)	.78
Smoking (yes %)	14 (38.8%)	8 (22.2%)	.04*
Educational status			
Primary school	2 (5.5%)	1 (2.7%)	.60
Secondary school	6 (16.6%)	4 (11.1%)	
High school	21 (58.3%)	22 (61.1%)	
University	7 (19.4%)	9 (25.0%)	
Tampa Scale of Kinesiophobia	47.52 ± 4.08	45.72 ± 4.32	.07
Hospital Anxiety and Depression Scale			
Anxiety	7.64 ± 2.24	7.38 ± 2.11	.62
Depression	6.61 ± 2.54	6.36 ± 2.34	.66

VAS: visual analog scale, IPAQ: international physical activity questionnaire.

Lastly, there was a significant time effect [(p= <.001; η^2p=.356)] but no group*time interaction effect [(*p*=.086; η^2p=.087)] regarding WHOQOL-OLD module (Table 2, Figure 4). After the treatment, the mean WHOQOL-OLD score was 7.76 units (13.50%) higher in the experimental group and 3.91 units (7.13%) higher in the control group.

4. Discussion

The current study aims to compare the primary endpoints (i.e., FMS and 6MWT scores) and secondary endpoints (i.e., TUG and WHOQOL-OLD module) of the experimental versus control group in older patients with CNSLBP in terms of pre- and post-treatment. The results demonstrated the effectiveness of DNS approach on total FMS score, deep squat, in-line lunge, hurdle step, shoulder flexibility, rotary trunk stability, and TUG performance. The improvement was similar in both groups in terms of the rest of the outcome measures. As hypothesized, conventional treatment combined with DNS training was more effective in improving quality of movement (QoM) and functional balance. To our knowledge, this is the only study demonstrating positive effects of the DNS

Table 2. Comparison of the outcome measurements between the groups.

	Pre-treatment				Post-treatment				Time	Group*Time
Outcome Measures	Experimental Group	Control Group	Δ	p[1]	Experimental Group	Control Group	Δ	p[1]	p[2] (η^2p)	p[2] (η^2p)
Functional movement patterns										
Deep squat	1.05 ± 0.54	1.08 ± 0.54	.03	.817	1.61 ± 0.51	1.28 ± 0.49	−.33	.007	<.001 (.360)	.017 (.160)*
In-line lunge	1.14 ± 0.50	1.11 ± 0.49	−.03	.800	1.55 ± 0.35	1.14 ± 0.50	−.41	<.001	.002 (.245)	.046 (.116)*
Hurdle step	1.49 ± 0.41	1.31 ± 0.49	−.18	.101	1.67 ± 0.17	1.36 ± 0.43	−.31	<.001	.019 (.155)	.018 (.157)*
Shoulder flexibility	1.64 ± 0.48	1.79 ± 0.41	.15	.163	1.97 ± 0.17	1.82 ± 0.38	−.15	.038	.023 (.147)	.021 (.151)*
Push-up	1.37 ± 0.47	1.28 ± 0.49	−.11	.436	1.46 ± 0.43	1.34 ± 0.48	−.12	.275	.377 (.024)	.861 (.001)
Straight leg raise	1.75 ± 0.34	1.72 ± 0.45	−.03	.755	1.96 ± 0.44	1.84 ± 0.35	−.12	.209	.039 (.123)	.556 (.011)
Rotary trunk stability	1.31 ± 0.49	1.37 ± 0.47	.06	.506	1.67 ± 0.17	1.43 ± 0.44	−.24	.004	.006 (.206)	.039 (.123)*
Total FMS score	9.77 ± 1.56	9.68 ± 1.10	−.09	.602	11.91 ± 1.08	10.41 ± 0.94	−1.5	<.001	<.001 (.552)	<.001 (.340)*
Exercise capacity										
6MWT	505.38 ± 153.44	517.11 ± 176.10	11.7	.767	549.67 ± 93.27	543.73 ± 85.17	−5.9	.716	.230 (.043)	.377 (.024)
Balance										
TUG	8.70 ± 0.90	8.79 ± 1.22	.09	.555	7.02 ± 1.14	7.82 ± 1.21	.8	.019	<.001 (.575)	.025 (.144)*
Quality of life										
WHOQOL-OLD	57.44 ± 5.79	54.82 ± 5.05	−2.6	.053	65.20 ± 9.46	58.73 ± 8.77	−6.4	.005	<.001 (.356)	.086 (.087)

p[1]: independent samples *t*-test for between-group comparisons; p[2]: two-way repeated measures analysis of covariance with a mixed model; FMS: functional movement screening; 6MWT: 6-minute walk test; TUG: timed-up and go test; WHOQOL-OLD: WHOQOL-OLD modüle. Values are expressed as mean ± standard deviation. Effect sizes were determined as partial eta squared (η^2p), Δ: Mean difference.

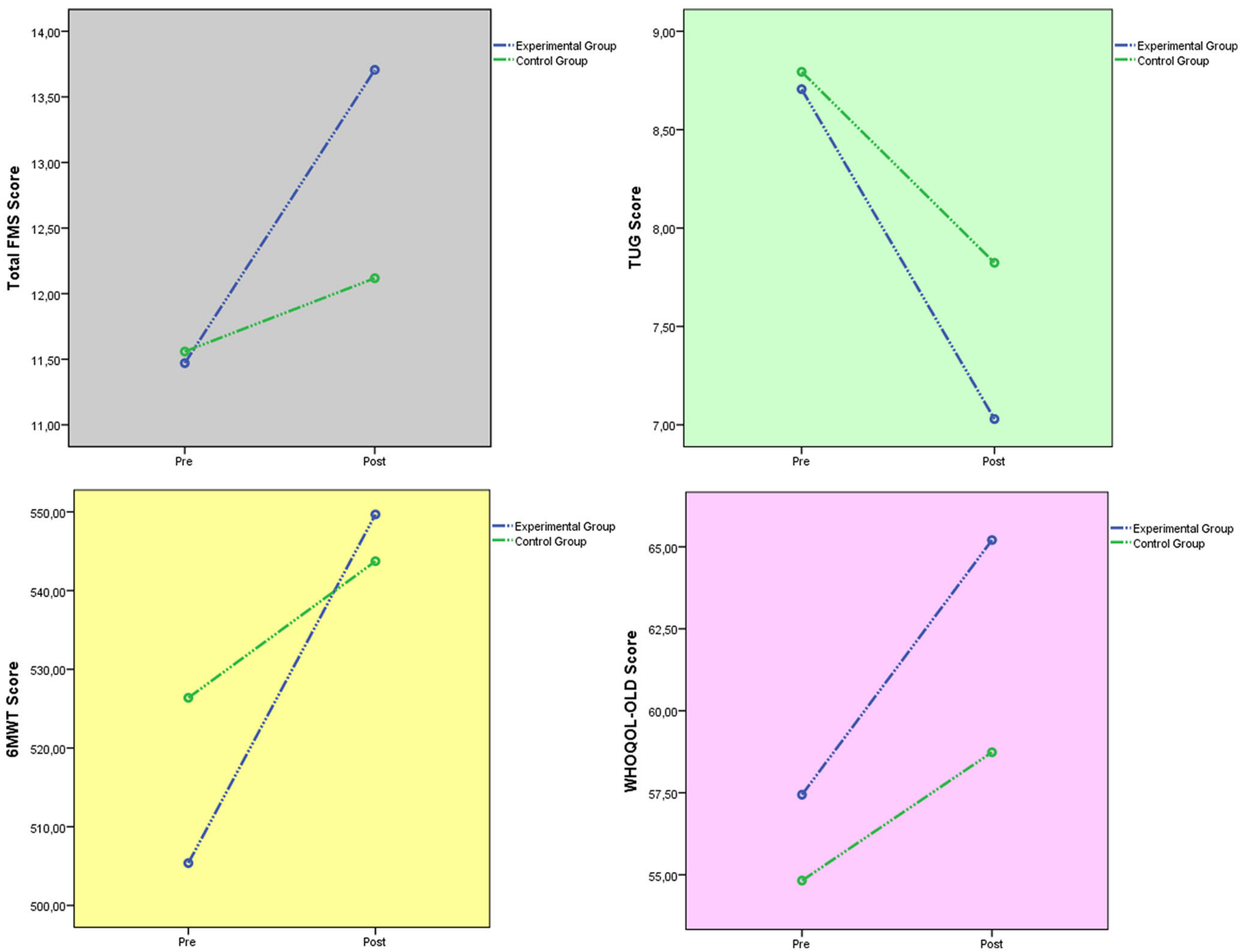

Figure 4. Comparison of the outcome measures between the groups.

on related parameters in older patients with CNSLBP. Therefore, it was difficult to compare our data with the relevant literature.

It is suggested that deterioration in QoM is a clinical feature in older patients with CNSLBP (Burnett. et al. 2004; O'Sullivan 2005; Gutknecht et al. 2015; van Baal et al. 2020). O'Sullivan reported that QoM impairment occurs secondary to chronic pain and can be a result of a lack of proprioceptive awareness, abnormal tissue loading, and potentially, the lack of a withdrawal reflex motor response (O'Sullivan 2005). Thus, patients with impaired QoM could benefit from a treatment program that focuses on restoring postural stability and movement control, correcting movement patterns, and eliminating pain-provoking postures. We administered such treatment within the scope of the "DNS approach."

Our findings suggest a positive effect of DNS on total FMS score and some of its items, namely deep squat, in-line lunge, hurdle step, shoulder flexibility, and rotary trunk stability in older patients with CNSLBP. It is difficult to compare the effectiveness of DNS on movement patterns to other interventions offered to older patients with CNSLBP and QoM (Aasa et al. 2015; Kent et al. 2015; Jacobs et al. 2016). This is mainly due to the diversity of the alternative interventions in the previous studies (e.g., motor control exercises, manual therapy, high-load lifting training, general exercises, or posture training) (Aasa et al. 2015; Kent et al. 2015; Jacobs et al. 2016). It was only possible to subgroup these studies based on active or non-intervention controls to compare the results, but this failed to reduce the observed heterogeneity.

The effectiveness of the DNS approach has been investigated in different neuromuscular pathophysiologies such as stroke (Lee et al. 2018; Yoon et al. 2020) and cerebral palsy (Son et al. 2017). The authors reported the superior effects of the DNS in improving diaphragm movement, abdominal muscle thickness, APA, and motor performances in standing, walking, and jumping. Despite the heterogeneity of the study protocols, the reported increase in neuromuscular activation following the DNS approach seems consistent with our results, indicating that the DNS is likely to be associated with improved QoM and functional balance performance (Son et al. 2017; Lee et al. 2018; Yoon et al. 2020). The present study is the first evidence demonstrating the effectiveness of the DNS in improving QoM and functional balance performance in older patients with CNSLBP.

The role of developmental kinesiology has been studied and discussed to describe the determinants of spinal stability for movement and musculoskeletal function (Son et al. 2017; Yoon et al. 2020). Older patients with CNSLBP demonstrate impaired stability suggesting that training the timing of both proximal and distal muscles should be considered when designing intervention programs. Alterations in anticipatory and reactive neuromuscular activation in both trunk and the extremities may interfere with the initiation and execution of coordinated movement. The DNS approach emphasises the importance of precise muscular timing and coordination for efficient movement as well as withstand compressive loading, which occurs in static or sustained postures. It has been reported that the DNS aims to alter movement behaviour, by means of a physical and cognitive learning processes (Son et al. 2017; Lee et al. 2018; Mahdieh et al. 2020; Yoon et al. 2020).

Research has shown that impairments in movement and motor control during postural adjustments seem to cause balance disorders in older patients with CNSLBP (Burnett et al. 2004; Gutknecht et al. 2015; van Baal. et al. 2020). To assess the functional balance of the participants, we used the TUG score, which is a gold standard measure (Tomita et al. 2015). Results revealed that the improvement in functional balance performance was more notable in the experimental group (conventional treatment + DNS) compared to the control group (conventional treatment only). Very low to high-quality evidence of the effectiveness of the DNS on functional balance performance is reported in different study protocols (Kolář et al. 2009; Kolar et al. 2010; Frank et al. 2013; Lee. et al. 2018; Yoon et al. 2020). As one of the strengths of the current randomized controlled trial with optimal sample size, we provide high evidence to support the positive effect of the DNS in improving functional balance in older patients with CNSLBP. In line with our results, the DNS approach is reported to reduce postural perturbation and spinal compression and improve postural control leading to higher levels of functional balance (Kolář et al. 2009; Kolar et al. 2010; Frank et al. 2013). Currently, balance problems in individuals with CNSLBP are generally treated using conventional core stabilization exercises (Inani and Selkar 2013; Paungmali et al. 2017; Ozsoy et al. 2019). Our results show that the DNS can be a better treatment option as it focuses on muscle coordination and stabilization required for an optimal movement pattern (Son et al. 2017; Mahdieh et al. 2020). Moreover, the TUG test necessitates a voluntary transition from a stable static support to an unstable posture during locomotion. This requires APA to replace the centre of mass to the supporting side (Tomita et al. 2015; Phu et al. 2019). The key role of the DNS on APA is through its marked motor control mechanisms (Mannion et al. 2008; Frank et al. 2013). The DNS emphasizes a subconscious feedforward mechanism and relevant exercises are mediated *via* relatively fast, short-loop APA latency (Frank et al. 2013). On contrary, the conventional core stabilization intervention focuses on a conscious feedback mechanism and relevant exercises are modulated *via* a relatively slow, long-loop APA latency (Mannion et al. 2008). The effects of these distinct methods should be investigated in further studies.

CNSLBP is reported to be an independent factor deteriorating functional performance, gait, and exercise capacity (Reid et al. 2005; Rudy et al. 2007). Patients with CNSLBP are reported to have lower exercise capacity compared to healthy individuals (Smeets et al. 2006; Hodselmans et al. 2010; Duque et al. 2011). To evaluate the exercise capacity of our participants, we used the 6MWT as an established exercise test for older patients (Enright and Sherrill 1998; Zhang et al. 2017). In both groups, 6MWT scores improved compared to baseline, however no noticeable intervention effect could be detected at the group level. In older individuals, different parameters (such as gender, age, weight, and height) seem to play a role in the variability of the 6MWT results (Enright and Sherrill 1998; Gouveia et al. 2013). Therefore, we used covariance analysis to increase the generalizability of our results. Alike exercise capacity, the DNS program was not helpful in improving QoL in our participants. Although post-intervention QoL was slightly higher in the experimental group, the difference between groups was statistically insignificant. We strongly recommend future studies to investigate these two measures within their study protocol.

Limitations of our study include: (i) The physiotherapist was not blind to the group allocation during treatment, (ii)

As this study is the only clinical trial highlighting positive effects of the DNS on measured parameters, it was difficult to compare our findings with previous reports, and (iii) Other than treatment sessions, we provided our participants with leaflets containing advice and recommendations regarding their daily activities, however, we did not measure their adherence nor patient satisfaction. A follow-up could enable us to assess the possible long-term effects of the program. It is unclear whether a higher or lower frequency of the DNS intervention could yield the same effects.

5. Conclusion

This is the first randomized controlled study investigating the impact of conventional treatment combined with the DNS in older patients with CNSLBP. Compared to the control group, the experimental group had greater improvement in balance performance and some functional movement patterns. The two groups had similar improvement in terms of the rest of the outcome measures. In conclusion, the DNS approach combined with conventional treatment seems to be a better choice in the treatment of CNSLBP in older patients.

Ethical approval

This study was approved by Selçuk University Medical Faculty Clinical Research Ethics Committee (2021/813).

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

The study was funded by the research team.

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