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Effectiveness of dynamic neuromuscular stabilization approach in lumbopelvic stability and gait parameters in individuals with idiopathic scoliosis

A randomized controlled trial

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Abstract

Background: Adolescent idiopathic scoliosis (AIS) is a common spinal deformity that leads to impaired lumbopelvic stability, gait dysfunction, and associated pain and psychological distress. This study evaluates the effectiveness of dynamic neuromuscular stabilization (DNS) in improving lumbopelvic stability and gait in AIS patients, comparing it to core stability exercises (CSE). This study evaluates the effectiveness of DNS in improving lumbopelvic stability and gait in AIS patients, comparing it to CSE.

Methods: This randomized controlled trial involved participants aged 18 to 25 years with mild to moderate idiopathic scoliosis, who were randomly assigned to either the control or experimental group. Both groups received 12 sessions of supervised exercises over 6 weeks, with the experimental group also incorporating DNS exercises alongside CSE. Lumbopelvic stability was assessed using the single leg squat, while core stability was evaluated with the stabilizer pressure Biofeedback in combination with the Sahrmann core stability test. Additionally, gait spatiotemporal parameters and pelvic dynamics were analyzed using the BTS-G-WALK system.

Results: Of 30 participants, 28 completed the study, comprising 12 males and 16 females, with 26 having mild right-sided thoracic scoliosis. Both groups showed improvement in the left single leg squat, with the control group reaching 93.3% "Good" performance and the experimental group achieving 69.2%. Gait analysis showed a significant reduction in duration for both groups, with the control group improving from 112.98 to 71.41 seconds ($P = .005$) and the experimental group improving from 112.33 to 67.68 seconds ($P = .021$).

Conclusion: This ongoing 12-week study shows that the combined DNS and CSE approach significantly improves lumbopelvic stability in individuals with idiopathic scoliosis. However, the impact on gait parameters was minimal, possibly due to the short duration of the intervention and the similar walking strategies of those with single-curve scoliosis and healthy individuals. These findings highlight the potential of integrating DNS into scoliosis rehabilitation and underscore the need for further research to optimize treatment duration and assess long-term functional outcomes.

Abbreviation: AIS = adolescent idiopathic scoliosis, CSE = core stabilization exercises, DNS = dynamic neuromuscular stabilization, IAP = intra-abdominal pressure, LM = lumbar multifidus, NGNP = neither good nor poor, PSSE = physiotherapeutic scoliosis-specific exercises, SCST = Sahrmann core stability test, SLS = single leg squat, TrA = transverse abdominis, UTAR = Universiti Tunku Abdul Rahman.

Keywords: adolescent idiopathic scoliosis, core stabilization exercises, dynamic neuromuscular stabilization

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The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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1. Introduction

Adolescent idiopathic scoliosis (AIS) is the most common type of spinal deformity, causing poor spinal mobility, structural weakness, respiratory dysfunction, chronic pain, and psychological involvement, such as poor body image, anxiety, and depression.[1–3] Early detection screening programs did play a role in the early detection of scoliosis, and this allows early conservative treatment, avoids unnecessary surgery, and preserves higher health-related quality of life scores.[2,4] If left untreated, the curvature can worsen, this progression increases the risk of experiencing more severe symptoms and complications, highlighting the importance of early intervention and management.[5] A corrective-based exercise regime helps reduce spinal deformity and improve quality of life as isolated treatment or as coadjutant treatment combined with other therapeutic resources.[6]

The principles of most physiotherapeutic scoliosis-specific exercises (PSSE) are based on individualized auto-correction and exercise contraction techniques, often combined with stabilizing exercises such as neuromotor control, proprioceptive training, and balance exercises depending on the specific PSSE school.[7–9] These exercises are typically incorporated into activities of daily living and practiced under supervision.[10] Corrective exercise-based therapy is the most effective treatment method for the spine and spinal stability to prevent the progression of the curve and reduce the neuromuscular imbalance of the spine and spinal mobility.[11,12]

However, the evidence for conservative management of AIS is not strong because the mechanism that leads to the improvement in such outcome measure is not known accurately, and the poor methodology quality.[9] Despite the lack of clear rationale for choosing which conservative treatment to use and the lack of evidence for the effectiveness of exercises in treating AIS, patients in many areas of the world are still expected to continue with these treatments. This can have a negative impact on their quality of life, as they may have to wear braces for long periods or undergo surgery, which may have significant risks.[11–13] Therefore, it is crucial to carefully consider each patient's individual needs and circumstances when determining the appropriate course of treatment for AIS.

A relatively new approach, the DNS exercise was developed based on neurodevelopmental kinesiology and reflex-mediated core stabilization concepts to stimulate subconsciously and reflexively, rather than consciously or cognitively, train deep core muscles such as the diaphragm and the transversus abdominis and internal oblique.[14,15] DNS utilizes the subconscious stimulation of special zones to reflexively mediate the diaphragm and other core stabilization muscles, which is highly effective for individuals with reduced somatosensory or movement awareness.[16] This approach focuses on reestablishing natural movement patterns and maintaining joint alignment through specialized exercises that prioritize proper breathing, dynamic support, and spinal alignment.[17,18]

In the context of AIS, maintaining lumbopelvic stability is crucial, as scoliosis can alter pelvis alignment and introduce abnormal pressure and torsion on the pelvic girdle. Lumbopelvic stability involves the ability to keep the pelvis steady while performing limb movements, which can be compromised in individuals with scoliosis due to excessive intervertebral movements and potential instability.[19,20] This instability can lead to changes in the gait parameters and affect overall functional performance.[21]

This study aims to address the gap by evaluating the effectiveness of DNS in conjunction with core stabilization exercises (CSE) to improve lumbopelvic stability and functional outcomes in individuals with AIS.

The objective of the study is to evaluate the effectiveness of the dynamic neuromuscular stabilization (DNS) approach in improving gait, lumbopelvic functional stability, and core strength in individuals with AIS and the difference between the DNS approach and CSE.

2. Methods

2.1. Study design and setting

The research design employed in this study was a randomized controlled trial. This study was approved by the Scientific and Ethical Review Committee (SERC) of Universiti Tunku Abdul Rahman (UTAR) (U/SERC/248/2023) and registered under the Australian New Zealand Clinical Trials Registry (ANZCTR12624000507583P). The study was conducted at the physiotherapy lab at UTAR. The trial was conducted and reported according to Consolidated Standards of Reporting Trails guidelines. Upon recruitment of participants, informed consent had been obtained from them. The objectives of the study, declaration of the participants, confidentiality of the information, and rights to withdraw from the study were included in the informed consent form and informed to the participant.

2.2. Study participants

The participants were selected through the spine screening program at UTAR by using a simple random sampling method. Block randomization was then employed to randomly assign eligible participants to either the experimental or the control group. The participants, aged limited between 18 and 25 years old and, voluntarily took part in the study program, both genders were recruited with mild to moderate idiopathic scoliosis with the single scoliotic curve (thoracic, thoracolumbar or lumbar) and voluntarily took part in the study. However, students will be excluded if they have: wearing a brace, a history of spine surgery, non-idiopathic scoliosis, and taking medication such as long-acting sleeping pills, beta-blockers, or opioid pain relievers or receiving any treatment for a related condition, double scoliotic curve.

2.3. Interventions

Both group participants have received a total of 12 sessions of supervised group exercises for a total of 6 weeks, 2 times a week. Each exercise session took 1 hour, including 10 minutes for warm-up and cool-down. The participants were required to perform home exercises for at least 40min for once a week. A simple punch card in calendar form was given to all participants to record their days of choice to perform their home exercise program.

The control group received 2 phases of CSE. Phase 1 exercises such as the abdominal drawing-in maneuver in sitting and prone lying targeted the isolated contraction of the lumbar multifidus (LM) and the isolated transverse abdominis (TrA) subsequently, bridging exercise, quadruped with single leg raise and progress to with the contralateral arm raise, and quadruped with knee off from the floor with the feet remain on the floor position. Phase 2 exercises consist of plank, plank with lower limb abduction, side plank, kneeling with weight and trunk rotation, and high kneeling with resistance exercises.

The experimental group received 20 minutes of CSE, the same as the control group, 20 minutes for the DNS exercise protocol, and another 10 minutes of warming up and cooling down. There is approximately 10 minutes for interval resting between CSE and DNS exercises. The experimental group received DNS exercises such as sitting, supine lying, side lying, low quadruped, oblique sit, tripod, bear, and squat position in phase 1 and phase 2 (4 patterns in each phase) subsequently. Before the DNS protocol, participants were required to engage the diaphragm breathing, engage the intra-abdominal pressure (IAP), and integrate the spinal stabilization pattern. Verbal cues and tactile cues were provided to the participants individually to reinstate the proper respiratory pattern and achievement of the targeted movement pattern. Exercise intensity and complexity will be progressively adjusted based on individual development to ensure continued improvement and prevent compensatory movements. Once participants have mastered the foundational techniques in each phase, the complexity of exercises will be gradually increased, along with the intensity, to challenge their core stability and neuromuscular coordination.

To prevent compensatory movements during home-based exercises, participants will receive comprehensive pictorial documentation detailing the precise execution of each exercise, facilitating adherence to proper movement patterns. During supervised sessions, they will be required to demonstrate the techniques they have acquired, enabling real-time assessment, corrective feedback, and reinforcement of optimal motor control. Furthermore, biweekly online discussions will be conducted to address challenges, provide expert guidance, and clarify uncertainties, ensuring continuous monitoring and adherence to prescribed exercise protocols.

2.4. Outcomes

2.4.1. Lumbopelvic stability. The Lumbopelvic Stability was assessed using single leg squat (SLS). In SLS, the participant was first instructed to cross the hands in front and squat down as far and as slow as possible with a single leg while maintaining the heel of the trial leg on the ground by transferring the weight to it and keeping the trunk erect.[22] The participant had been instructed to perform 5 consecutive squats with the same leg, then repeated on another leg. The clinical rating criteria assess 5 main components to categorize an individual's lumbopelvic stability. It includes the overall impression, weight transfer, lumbar and pelvic alignment, leg alignment, and foot alignment Perrott et al (2012). The participant was evaluated as having "neither good nor poor stability" if he or she did not fall into any of these 2 categories. The interrater reliability for the rating criteria of SLS has been reported with a weighted kappa of 0.73. Before the test began, each participant had been provided with a practice trial.[22]

2.4.2. Core stability. The core stability was assessed by using the stabilizer pressure biofeedback (The Stabilizer Pressure Biofeedback™) in conjunction with the Sahrmann core stability test (SCST).[23–25] It consists of 5-level tasks with a progression in difficulty and was evaluated using a 5-point scoring system, such that 1 point is given when the participant successfully completes each level task. To conduct the test, the participant was required to be in a supine crook lying position on a bed with the inflatable pad of a PBU placed under the natural lordotic curve and inflated to 40 mmHg. The participant was instructed to perform the SCST tasks while actively contracting their abdominal muscles to avoid pressure deviation of more than 10mmHg. Participants can only progress to the level 2 task when they complete the level 1 task with a deviation of <10 mmHg and so forth.[26]

2.4.3. Gait parameters. The spatiotemporal parameters of gait, such as total duration, cadence, speed and stride length, and pelvic tilt, obliquity, and rotation, were assessed during pre-post assessment using the BTS-G-WALK.[27] It is a single wearable device with a 3-axis 16-bit accelerometer, 3-axis 16-bit gyro, and 3-axis 13-bit magnetometer that is placed in the lumbosacral area while performing the 6-meter walk test.

2.4.4. Sample size. The sample size was determined using G*Power version 3.1.9.4, selecting "*F* tests" as the test family and "ANOVA: Repeated measures, within-between interaction" as the statistical test type. Input parameters included an effect size (f) of 0.30, an alpha (α) error probability of .05, and a desired power of .80, with 2 groups and 2 measurements.[28] G*Power calculated that 24 participants were needed for the study. To ensure sufficient participants despite potential dropouts, an additional 20% was added to the sample size. Therefore, the final sample size was determined to be 30 participants.

Core stability exercises training was conducted by a clinical physiotherapist with a minimum of 5 years of experience in musculoskeletal physiotherapy, and DNS sessions were conducted and supervised by a DNS scoliosis-certified physiotherapy researcher who has 5 years of experience in the related field.

Participants were assessed at baseline and week 7 of interventions by an independent therapist who was blinded to the group allocation and trained to conduct the standardized tests, including G-walk. The recorded baseline assessment data were not accessible to the assessor at posttrial assessment in view to avoid assessment bias.

2.5. Statistics analysis

The collected data was transferred and analyzed using IBM Statistical Package For Social Sciences software, version 26.0 (Chicago). Descriptive statistics was utilized to present the demographic data, pre-intervention, and post-intervention of the lumbopelvic stability results of the participants. Wilcoxon signed-rank test was used to evaluate the difference between the results of the lumbopelvic stability test for each group. The difference in lumbopelvic stability post-intervention results between the control and experimental groups was examined using the Mann–Whitney *U* test.

Paired t-test was used to analyze the difference in the mean score of the pre-intervention and post-intervention core stability performance in the control group and experimental group. An independent t-test was used to compare the mean score of the post-intervention core stability performance between the control group and the experimental group. The level of significant differences was set at $P < .05$, and data were expressed as mean and standard deviation (M ± SD).

3. Results

3.1. Demographic data

Table 1 presents the demographic data of all participants. Out of 30 initially enrolled participants, 28 completed the study, while 2 participants dropped out. The control group consisted of 15 participants, and the experimental group included 13 participants. The mean age of the participants was 20.82 years (SD = 1.36). The gender distribution included 12 males (42.9%) and 16 females (57.1%). The mean height was 1.66 m (SD = 0.07), and the mean weight was 55.36 kg (SD = 10.35). Regarding the side of scoliosis, 2 participants

Table 1

Demographic data of participants.

Variables	n (%)	Mean (SD)	*P*-value
Age (yr)		20.82 (1.36)	.47
Gender			
Male	12 (42.9)		.53
Female	16 (57.1)		
Height (m)		1.66 (0.07)	.12
Weight (kg)		55.36 (10.35)	.44
Scoliosis (side)			
Left	2 (7.1)		.37
Right	26 (92.9)		

SD = standard deviation.

(7.1%) had left-sided scoliosis, and 26 participants (92.9%) had right-sided scoliosis.

3.2. Single leg squats

Table 2 shows the pre and posttest results for the left-side SLS in both the control and intervention groups. The control group improved significantly, with 93.3% achieving "Good" performance posttest, up from 26.7%. The intervention group also showed improvement, with 69.2% reaching "Good" performance posttest, compared to 30.8% pretest. Both groups had no participants classified as "NGNP" (neither good nor poor).

In Table 3, the Wilcoxon Signed-rank Test shows a significant difference between the pre-post test results of the left-side SLS in the control group at the 0.05 level of significance ($Z = -3.162$, $P = .002$, 2-tailed)and in the intervention group ($Z = -2.236$, $P = .025$, 2-tailed).

Table 4 compares differences in posttest results for the Left-side SLS between the control and intervention groups. The control group had a mean rank of 16.07 and a sum of ranks of 241.00, while the intervention group had a mean rank of 12.69 and a sum of ranks of 165.00. The Mann–Whitney *U* test yielded a *U* value of 74.000, with a *P*-value of .103. Since the *P*-value is >.05, the difference is not statistically significant at the .05 level.

Table 5 presents the pre and posttest results for the Right-side SLS in both the control and intervention groups. In the control group, 73.3% of participants showed "Poor" performance in the pretest, with 26.7% classified as "Good." After the intervention, 93.3% achieved "Good" performance, while only 6.7% remained in the "Poor" category. In the intervention group, 53.8% performed "Poor" in the pretest, and 46.2% were classified as "Good." Posttest results showed 76.9% reaching "Good" performance, with 23.1% still in the "Poor" category. Both groups had no participants categorized as "NGNP" (neither good nor poor) at any testing point.

Table 6 compares the differences between the pre and posttest results of the Right-side SLS for the control and intervention groups. In the control group, there were no negative ranks (posttest SLS right < pretest SLS right), 10 positive ranks (posttest SLS right > pretest SLS right), and 5 ties (posttest SLS right = pretest SLS right). The *P*-value for the control group was .002, indicating a statistically significant difference. In the intervention group, there were no negative ranks, 4 positive ranks, and 9 ties, with a *P*-value of .046, also indicating a statistically significant difference.

Table 7 presents the comparison of differences in posttest results for the Right-side SLS between the control and intervention groups. The control group had a mean rank of 15.57 and a sum of ranks of 233.50, while the intervention group had a mean rank of 13.27 and a sum of ranks of 172.50. The Mann–Whitney *U* test yielded a *U* value of 81.500, with a *P*-value of .224. Since the *P*-value is >.05, the difference is not statistically significant at the .05 level.

Table 2

Pre and posttests results of left-side SLS.

Groups	Results	Pretest, n (%)	Posttest, n (%)
Left-side SLS			
Control	Poor	11 (73.3)	1 (6.7)
	Good	4 (26.7)	14 (93.3)
	NGNP*	0 (0.0)	0 (0.0)
Intervention	Poor	9 (69.2)	4 (30.8)
	Good	4 (30.8)	9 (69.2)
	NGNP*	0 (0.0)	0 (0.0)

*NGNP = neither good nor poor.

3.3. Sahrmann core stability test

Table 8 presents the pre-and post-intervention SCST scores for both the control and the experimental group. In the control group, the pre-intervention mean (M) score was 2.40 with a SD of 1.64, while the post-intervention mean score was 3.87 with a SD of 0.99. The mean difference was 1.47, with a *t*-value of 5.358 and a *P*-value of .001, indicating a statistically significant improvement. In the experimental group, the pre-intervention mean score was 2.08 with a SD of 1.66, and the post-intervention mean score was 3.15 with a SD of 1.28. The mean difference was 1.07, with a *t*-value of 4.070 and a *P*-value of .002, also indicating a statistically significant improvement.

Table 9 compares the post-intervention SCST scores between the control and the experimental group. The control group had a mean (M) score of 3.87 with a SD of 0.99, while the experimental group had a mean score of 3.15 with a SD of 1.28. The mean difference between the groups was 0.72, with a *t*-value of 1.659 and a *P*-value of .109. Since the *P*-value is >.05, the difference between the groups is not statistically significant.

3.4. BTS-G-WALK

Table 10 compares the pre and posttest results for various gait parameters in the control and experimental groups. In the control group, the duration decreased significantly from 112.98 (±50.73) to 71.41 (±7.58) with a *P*-value of .005, indicating a statistically significant change. Other parameters in the control group, such as steps per minute ($P = .706$), cadence ($P = .502$), pelvic tilt ($P = .479$), pelvic obliquity ($P = .907$), and pelvic rotation ($P = .945$), showed no significant changes. In the experimental group, the duration also decreased significantly from 112.33 (±59.82) to 67.68 (±2.67) with a *P*-value of .021. The steps per minute ($P = .929$), pelvic tilt ($P = .314$), pelvic obliquity ($P = .829$), and pelvic rotation ($P = .589$) did not show significant changes. The change in cadence approached significance with a *P*-value of .051. Data are expressed as mean ± SD and statistical significance is denoted by a *P*-value < .05 for paired tests.

Table 3

Comparison of difference between the pre and posttests results of left-side SLS.

Groups	Ranks	N	*P*-value (2-tailed)
Control	Negative ranks	0*	.002
	Positive ranks	10†	
	Ties	5‡	
Intervention	Negative ranks	0*	.025
	Positive ranks	5†	
	Ties	8‡	

* Posttest SLS Left < pretest SLS Left.
† Posttest SLS Left > pretest SLS Left.
‡ Posttest SLS Left = pretest SLS Left.

Table 4

Comparison of difference in posttests results of left-side SLS between control and intervention group.

Groups	Mean rank	Sum of ranks	Mann–Whitney *U*	*P*-value (2-tailed)
Control	16.07	241.00	74.000	.103*
Intervention	12.69	165.00		

* Level of significance: $P > .05$.

Table 11 presents the results of an independent t-test for various gait parameters. No significant differences were found for pretest and posttest measures of Duration, Steps per minute, Cadence, Pelvic tilt, Obliquity, and Rotation (all P-values > .05). The F-values ranged from 0.001 to 3.650, with none showing statistical significance. These results suggest that there were no significant differences between the groups for the measured parameters.

4. Discussion

This is a 12-week ongoing study, with results from the first 6 weeks being presented as early findings. This study included participants aged 18 to 25 years, with an average age of 20.82 years, all of whom met the specified inclusion criteria. Among the participants, 16 were females and 12 were males, all diagnosed with idiopathic scoliosis. The majority of participants had right-sided thoracic scoliosis.

In this study, there was a significant effect of the short-term DNS approach in addition to CSE in improving lumbopelvic stability in individuals with idiopathic scoliosis. This could be proved by the improvement of the SLS and dip test performance after a 6-week intervention in participants who received DNS in addition to CSE. This finding was similar to a previous study by Mahdieh et al,[16] which concluded that there was significant improvement in 5 functional movement tests, including the SLS performance in the DNS group after a 6-week intervention. Similar DNS exercises were conducted between the current study and this previous study,[16] which included deep breathing in crook lying, deep breathing in sitting, side lying, oblique sitting, tripod position, and squat position. A study by Ghagholestani[29] also revealed that DNS exercises were effective in improving lumbopelvic control in individuals with nonspecific low back pain. The improvement in lumbopelvic stability might occur due to the impact of improved core stability and spinal stability after DNS in addition to CSE.

Previous studies[16,29] showed similar results, as DNS exercises and CSE can improve core stability by regulating IAP through the integration of breathing techniques, especially in crook lying.[28] Besides, DNS exercises also target the co-activation of agonist and antagonist muscles in the torso, consequently influencing the activation of lumbar stabilizing muscles and avoiding undesirable movements. Through DNS exercises, muscle balance can be noted between the deep flexors and spinal extensors, as well as between the diaphragm and pelvic floor muscles, resulting in spinal stability via spinal stabilization system.[29] This statement is consistent with the results of the present study, in which the participants had improved lumbopelvic stability after 6 weeks of DNS in addition to CSE intervention.

Idiopathic scoliosis can cause alterations in muscles near the spine, particularly decreasing the lumbar muscle strength, which can lead to spinal and lumbopelvic instability.[30,31] Accordingly, CSE is often utilized to enhance neuromuscular control, strength, and endurance of the muscles around the spine to rectify and sustain the spinal alignment in the neutral position.[28,31] Based on the present study, there was a significant effect of short-term CSE in improving lumbopelvic stability in individuals with idiopathic scoliosis. A similar finding could be observed in many previous studies[32,33] in which the lumbopelvic stability had been improved in participants with low back pain caused by disc protrusion after receiving 4-week CSE.

This improvement in lumbopelvic stability could be explained by the findings of Bliven and Anderson[34] and Panjabi,[35] where CSE can restore normal muscle function to improve spinal stability and enhance neuromuscular control within the lumbopelvic area. Besides, CSE is commonly employed in scoliosis therapy to enhance core muscle capacity to reestablish dynamic control of external and internal forces over the spine and to improve spinal stability.[12,30]

DNS is rooted in the principles of DK, which asserts the existence of innate, genetically pre-determined movement patterns that form the foundation for motor development.[17] Individuals with IS face potential disruptions in movement patterns, which may contribute to altered muscle activation and poor core stability. By reinforcing these typical movement patterns, DNS aids in optimizing neuromuscular coordination, thereby promoting enhanced core stability. Moreover, DNS emphasizes the activation

Table 5

Pre and posttests results of right-side SLS.

Right-side SLS			
Groups	**Results**	**pretest, n (%)**	**Posttest, n (%)**
Control	Poor	11 (73.3)	1 (6.7)
	Good	4 (26.7)	14 (93.3)
	NGNP	0 (0.0)	0 (0.0)
Intervention	Poor	7 (53.8)	3 (23.1)
	Good	6 (46.2)	10 (76.9)
	NGNP	0 (0.0)	0 (0.0)

NGNP = neither good nor poor.

Table 6

Comparison of difference between the pre and posttests results of right-side SLS.

Groups	Ranks	n	P-value (2-tailed)
Control	Negative ranks	0*	.002
	Positive ranks	10†	
	Ties	5‡	
Intervention	Negative ranks	0*	.046
	Positive ranks	4†	
	Ties	9‡	

* Posttest SLS right < pretest SLS right.
† Posttest SLS right > pretest SLS right.
‡ Posttest SLS right = pretest SLS right.

Table 7

Comparison of difference in posttests results of right-side SLS between control and intervention group.

Groups	Mean Rank	Sum of Ranks	Mann–Whitney *U*	*P*-value (2-tailed)
Control	15.57	233.50	81.500	.224*
Intervention	13.27	172.50		

* Level of significance: $P > .05$.

Table 8

Pre- and post-intervention SCST score of control group and experimental group.

	SCST score				
	Pre-intervention M (SD)	Post-intervention M (SD)	Difference	*t*-value	Sig. (*P*-value)
CG	2.40 (1.64)	3.87 (0.99)	1.47	5.358	.001*
EG	2.08 (1.66)	3.15 (1.28)	1.07	4.070	.002*

CG = control group; EG = experimental group; M = mean; SD = standard deviation; SCST = Sahrmann core stability test.
* Level of significance: $P > .05$.

Table 9

Comparison of post-intervention SCST score between control group and experimental group.

	Control group M (SD)	Experimental group M (SD)	Mean difference	*t*-value	Sig. (*P*-value)
Post-intervention SCST score	3.87 (0.99)	3.15 (1.28)	0.72	1.659	.109

SCST = Sahrmann core stability test, SD = standard deviation.

Table 10

Pre- and posttest results of BTS-G-walk score in control and experimental group.

	Pretest (Mean ± SD)	Posttest (Mean ± SD)	*P*-value
Control group			
Duration	112.98 (50.73)	71.41 (7.58)	.005*
Steps_min	114.10 (8.07)	113.54 (5.91)	.706
Cadence	1.00 (0.14)	1.03 (0.13)	.502
Pelvic_tilt	64.80 (28.49)	60.62 (34.29)	.479
Pelvic_Obliquity	98.21 (0.76)	98.16 (1.61)	.907
Pelvic_Rotation	89.95 (12.00)	89.68 (19.16)	.945
Experimental group			
Duration	112.33 (59.82)	67.68 (2.67)	.021
Steps_min	110.51 (6.92)	110.35 (6.73)	.929
Cadence	1.05 (0.20)	1.13 (0.15)	.051
Pelvic_tilt	65.21 (26.73)	73.35 (14.31)	.314
Pelvic_Obliquity	97.84 (1.86)	97.95 (1.86)	.829
Pelvic_Rotation	93.81 (5.40)	92.50 (8.29)	.589

Data are expressed as mean ± standard deviations.
* *P*-value < .05 paired test.

Table 11

Pre and post-intervention BTS-G-walk score between control and experimental group.

	Sum of squares	Mean square	*F*	Sig.
Pre_Duration	2.935	2.935	0.001	.975
Pre_Steps_min	89.872	89.872	1.572	.221
Pre_Cadence	0.014	0.014	0.458	.504
Pre_Pelvic_tilt	1.158	1.158	0.002	.969
Pre_Obliquity	0.944	0.944	0.494	.488
Pre_Rotation	103.462	103.462	1.136	.296
Post_Duration	96.481	96.481	2.816	.105
Post_Steps_min	70.698	70.698	1.780	.194
Post_Cadence	0.075	0.075	3.650	.067
Post_Pelvic_tilt	1129.265	1129.265	1.552	.224
Post_Pelvic_Obliquity	0.296	0.296	0.099	.756
Post_Pelvic_Rotation	55.383	55.383	0.242	.627

Independent *t*-test.
* *P*-value < .05.

of deep stabilizing muscles, including the diaphragm, TrA, LM, and pelvic floor muscles, which provide anterior lumbopelvic stability by regulating the IAP. Similarly, the CSE is designed to specifically target the TrA and LM muscles that contribute to core stability.[36] The addition of DNS complements CSE by focusing on the selective activation of these muscles through developmental positions and movements. Therefore, it is believed that this dual emphasis can improve the precision of muscle recruitment, enhance the support and control of the core, and thus mitigate the effects of spinal curvature in individuals with IS.

Furthermore, DNS also employs the principles of neuroplasticity and motor learning, which proposed that repetitive practice of specific movement patterns can induce neuroplastic changes in the CNS, fostering the establishment of motor patterns that are not only more efficient but also inherently stable.[17] Hence, it is believed that by repetitively practicing the exercises of DNS, in combination with CSE, the ongoing neuroplastic changes aid in managing altered neuromuscular control associated with IS, ultimately improving core stability.

The gait pattern of adolescents with AIS is characterized by uneven translation and rotation, with the spinal curvature causing a noticeable change in spatial and temporal parameters of walking.[37,38]

The present study invested the combined CSE and DNS approach has any effect on gait parameters over 6 weeks of training, a small difference in the mean values was found in the present study pre and post-therapy.[39] The result of the current study is identical to previous studies,[40] and this could be due to the shorter period of management,[7] and patients with a single-curve used a similar walking strategy as healthy individuals.[41]

A few limitations of the study should be considered. First, the 6-week intervention period may be insufficient to observe significant changes in certain parameters, such as gait, which may require a longer duration for meaningful improvements to manifest. Additionally, while the study includes a diverse sample, the relatively small sample size limits the generalizability of the findings, particularly to individuals with more severe scoliosis or different demographic characteristics. Participant adherence to home-based exercises was self-reported, which could introduce bias in the evaluation of exercise execution and consistency. Since this is an ongoing study, the absence of a follow-up period to assess the long-term sustainability of the intervention's effects on stability and gait further limits the understanding of the lasting benefits of the combined DNS and CSE approach.

This study can conclude that the combined approach of DNS with CSE is theoretically positioned to improve core stability in individuals with AIS. The current research aims to explore the benefits of this combined approach in scoliosis and its influence on gait parameters, providing valuable insights into potential therapeutic strategies. Upon completion of the 12-week research period, the findings will offer a comprehensive understanding of the effects of the combined DNS and CSE approach on core stability and gait parameters in individuals with AIS.

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