Health Problems of Civilization
eISSN: 2354-0265, ISSN: 2353-6942

ORIGINAL PAPER

EFFECTS OF CORE EXERCISE ON SPINE POSTURE AND TRUNK NEUROMUSCULAR ABILITIES IN HEALTHY, RECREATIONALLY ACTIVE MALES: A RANDOMIZED CONTROLLED TRIAL

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Šćepanović T, Marinković D, Madic D. Effects of core exercise on spine posture and trunk neuromuscular abilities in healthy, recreationally active males: a randomized controlled trial. Health Prob Civil. https://doi.org/10.5114/hpc.2025.156408

Tables: 4
Figures: 3
References: 39
Submitted: 2025 Sep 12
Accepted: 2025 Nov 19

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Summary

Background. Postural misalignment and reduced trunk endurance are common even among healthy young adults. Although core exercise is considered a preventive strategy, scientific evidence remains limited. This study examined the effects of a six-week core exercise program on spinal alignment and trunk neuromuscular endurance in healthy, recreationally active males.

Material and methods. This randomized controlled trial was conducted over six weeks at the University of Novi Sad, Serbia. One hundred thirty-eight males (age 23.3±0.9 years) were randomly allocated to exercise (n=73) or control (n=65) groups. Outcomes included spinal posture variables measured with the CONTEMPLAS 2D/3D system and three trunk neuromuscular tests. Repeated-measures analysis of variance assessed time and interaction effects (α=0.05).

Results. Significant group × time interactions were observed for thoracic distance (p=0.02; 95% CI-3.24 to 0.37 cm), lumbar distance (p<0.001; 95% CI-1.58 to 0.47 cm), Thoracic Kyphosis Index (p<0.001; 95% CI-0.24 to 0.00), and cervico-lumbar angle (p<0.001; 95% CI-0.74 to 1.65°). Trunk endurance improved significantly for back extensor (p<0.001; 95% CI-11.26 to 36.70 s), flexor (p<0.001; 95% CI-41.41 to 83.95 s), and Double Leg Lowering (p<0.001; 95% CI-6.78 to 15.82°) tests.

Conclusions. A structured six-week core exercise program significantly improved spinal posture and trunk endurance, supporting its use as an effective, non-invasive strategy to promote spinal health in young adults.

Keywords: physical endurance, exercise therapy, randomized controlled trial, young adult, posture

Introduction

In the 21st century, humans have encountered significant climate, technological, and social changes affecting the growth and development of children and the health status of adults [1]. Furthermore, with all the assistance and support of modern technologies, the population has become less active [2]. These lifestyle changes have also affected musculoskeletal health, particularly by contributing to altered posture and decreased functional stability. Proper posture is essential to everyone and their static and dynamic functioning [3]. The strength of the muscles supporting the trunk, the flexibility of the joints, and the balance of the muscles in the front and back all point to favorable posture [4]. Prolonged exposure to external forces that exceed the muscular system's capacity to maintain alignment can disrupt normal postural control, ultimately resulting in postural abnormalities [5].

Postural abnormalities may be corrected by strengthening the weak muscles, whereas in the event of deformities, it is necessary to apply exercise, special individual techniques, manual techniques, or surgical treatments [6]. Researchers have utilized various methods and exercises to address posture and deformities. Thus, the application of an isometric treatment has yielded a statistically significant effect on the curvature of the thoracic and/or lumbar spine [7,8]. Corrective exercises that are appropriately planned and implemented, in addition to exercises for the trunk stabilization muscles, may positively affect the quality of the fundamental movement patterns [9]. Trunk stabilization treatment positively affects patients with idiopathic scoliosis by decreasing Cobb's angle and increasing the flexibility and strength of the muscles [10]. Core training positively affects the entire posture [4,11], and it is even possible to change Cobb's angle in the case of scoliosis [12]. Moreover, recent studies confirm that resistance and core training improve spinal alignment [13,14] and increase neuromuscular performance [15-17]. Core exercises are becoming more popular as a way to improve posture and spinal alignment. Recent research has shown that these treatments are effective at lowering thoracic kyphosis, lumbar hyperlordosis, and improving pelvic alignment, especially when performed consistently for 6 to 12 weeks [13,16]. Core training has been demonstrated to affect various neuromuscular and functional parameters, such as postural alignment, movement efficiency, trunk stability, respiratory mechanics, and muscular endurance. These adaptations indicate the enhancement of an individual's functional capacity and the manifestation of their genetic and neuromuscular potential rather than alterations in the genetic code itself. Research in exercise genetics indicates that targeted training may either activate or inhibit specific gene pathways, thus enhancing the body's adaptability and performance within its biological limitations [18,19].

Although the consequences of poor posture have been recognized for decades, the ability to objectively and accurately measure postural deviations remains a challenge in clinical and research settings. Observer bias and lack of scientific precision often influence visual assessments. Metric approaches offer quantification but often fail to reflect the complexity of human posture. More accurate evaluations are now possible thanks to recent technological developments, especially in 2D and 3D photometric imaging, which calculates angular deviations and postural indices and records the spatial relationships between anatomical landmarks. Among these, the CONTEMPLAS TEMPLO system has shown itself to be an effective postural analysis tool, providing a consistent, repeatable approach to assessing segmental deviations and spinal alignment [20].

While many studies examined core training in both athletes and the general population, most of the research that is being published currently has been done on clinical groups (e.g. people with low back pain, scoliosis, or postural instability) or athletes who attempt to improve their performance. There is a lack of research on recreationally active young adults, especially those without musculoskeletal disorders, regarding the combined effects of structured core training on spinal alignment and trunk neuromuscular endurance. Moreover, although posture-related research frequently utilizes visual or 2D observational instruments, there is a scarcity of studies employing integrated 2D/3D motion analysis systems to objectively measure spinal curvature and alignment within this population. These gaps underscore the necessity to investigate whether a structured core exercise regimen can induce significant postural and neuromuscular adaptations in a healthy, young adult demographic utilizing advanced biomechanical measurement instruments. Moreover, core exercises alone may be insufficient for structural spinal deformities, such as idiopathic scoliosis, without adjunctive interventions [14]. These considerations highlight the importance of investigating the effects of core training in specific populations, such as healthy, recreationally active young adults.

The majority of postural research has focused on children, largely due to the importance of spinal development during growth. Despite the increasing sedentary lifestyles and musculoskeletal imbalances in young adults over 20, there is limited research on postural alignment and corrective measures in this age group.

Based on previous findings, we hypothesized that a six-week core training program would result in significant improvements in spinal posture (specifically thoracic and lumbar alignment) and trunk neuromuscular endurance compared to a control group with no structured intervention.

Aim of the work

Core strengthening exercises that target the front and back muscles of the trunk can improve postural control by enhancing muscle balance and flexibility. The normalization of pelvic tilt, which directly affects lumbar alignment and, in turn, the positioning of the thoracic and cervical spine, is facilitated by the activation of deep stabilizing muscles in the abdomen and lower back. Correcting pelvic orientation is crucial for restoring the natural curvature of the spine and enhancing overall posture, as an anterior tilt is linked to lower back arching and a posterior tilt to a flattened back posture. This study aimed to determine the effects of a six-week core exercise program on spine posture and trunk neuromuscular endurance in recreationally active males.

Material and methods

Study design

This was a single-center, randomized controlled trial conducted over a period of six weeks between March and May 2023. All assessments and training sessions were carried out at the Faculty of Sport and Physical Education, University of Novi Sad, Serbia.

A priori power analysis was conducted using G*Power 3.1 (Heinrich-Heine-University, Düsseldorf, Germany) [21] to determine the minimum required sample size for a repeated-measures ANOVA (within-between interaction), assuming a small-to-medium effect size of f=0.25 (equivalent to η^2 p=0.06), α=0.05, power = 0.80, correlation among repeated measures = 0.50, and non-sphericity correction ε=1. The analysis indicated a required total sample size of 128 participants. Our final sample of 138 participants exceeds this requirement, confirming the study was adequately powered.

We divided the study sample into the groups: core exercise group (EG) and control group (CG) using simple randomization. The EG underwent six weeks of intervention training, while the CG did not exercise or use any training intervention or other habitual training during the two months. The researchers conducted the initial and final tests two days before and after the two-month treatment period. The EG completed four training sessions per week (excluding weekends), totaling 24 sessions over the course of the study interspersed with at least one day of rest. To guarantee the quality and correct execution of training protocols, a set of professional coaches with licenses and certificates and researchers supervised all training programs in small groups. Outcome measurements were conducted by an independent assessor who was blinded to the group assignments of the participants. The assessor was not involved in delivering or supervising the intervention and followed a standardized protocol for all testing procedures. This blinding was maintained throughout the pre- and post-test measurements to minimize assessment bias. Each testing session lasted approximately 60 minutes per participant and was conducted under standardized laboratory conditions. The study was carried out under stable laboratory conditions with no real-time constraints affecting data collection or intervention delivery. All sessions were conducted according to schedule, and the research timeline was fully maintained, minimizing any potential impact on the reported outcomes.

Participants

A total of 230 participants were randomized, with 115 allocated to each group. All participants were residents of Serbia and recruited from the University of Novi Sad, ensuring uniformity in country of residence and academic environment. Participants were randomly assigned to the EG or CG in a 1:1 ratio using a computer-generated randomization sequence created in Microsoft Excel by an independent researcher not involved in data collection. Block randomization with variable block sizes was used to ensure group balance. Allocation concealment was accomplished through the use of sealed, opaque, sequentially numbered envelopes, which were opened only after the participant finished baseline testing. While participants were aware of their group assignment due to the nature of the intervention, outcome assessors were blinded to group allocation to reduce assessment bias. This trial included only male participants to reduce potential sex-related variability in trunk muscle endurance, spinal posture, and hormonal effects on musculoskeletal performance. This homogeneity was designed to minimize inter-subject variability and enhance the internal validity of the results during this initial trial phase.

In the EG, 42 participants were excluded due to non-compliance (n=34 attended <80% of sessions), illness (n=2), or other reasons (n=6), resulting in a compliance rate of 63.5% (73/115). In the CG, 50 participants were lost to follow-up due to withdrawal (n=39), illness (n=6), or other reasons (n=5), resulting in a completion rate of 56.5% (65/115). No adverse events or injuries were reported in either group throughout the six-week intervention period. A total of 138 participants completed the study protocol (EG: n=73; age 20±0.5 years; height 1.80±0.05 m; mass 76±9.4 kg; CG: n=65; age 20±0.5 years; height 1.81±0.08 m; mass 78.6±4.7 kg). Figure 1 presents a flowchart illustrating the progression of the study. To reduce variability and potential confounding, inclusion and exclusion criteria were applied to ensure a homogeneous population of healthy, recreationally active males. All participants were instructed not to engage in any new physical activity programs, treatments, or lifestyle changes during the six-week study period. Inclusion criteria for this study were: (i) male university students aged 20-24 years; (ii) recreationally active adults [22]; (iii) no injuries within the past six months; (iv) no diagnosed medical conditions, including COVID-19; (v) no engagement in programmed physical activity, such as high-intensity anaerobic or resistance training during the study period; and (vi) completion of at least 80% of the training sessions; (vii) all participants were recreationally active but not involved in any structured core training, resistance training, or sport-specific conditioning programs for at least 3 months before the study. Exclusion criteria included: (i) history of neurological or musculoskeletal disorders; (ii) clinical conditions that could impair balance, such as motor impairments, cardiovascular disease, stroke, visual impairments, thyroid dysfunction, or problems related to the arteries and nerves; and (iii) other physical training activities in addition to the study protocol. In order to improve the study's internal validity and relevance to its goals, these criteria were put in place to guarantee participant safety, reduce confounding variables, and preserve sample homogeneity.

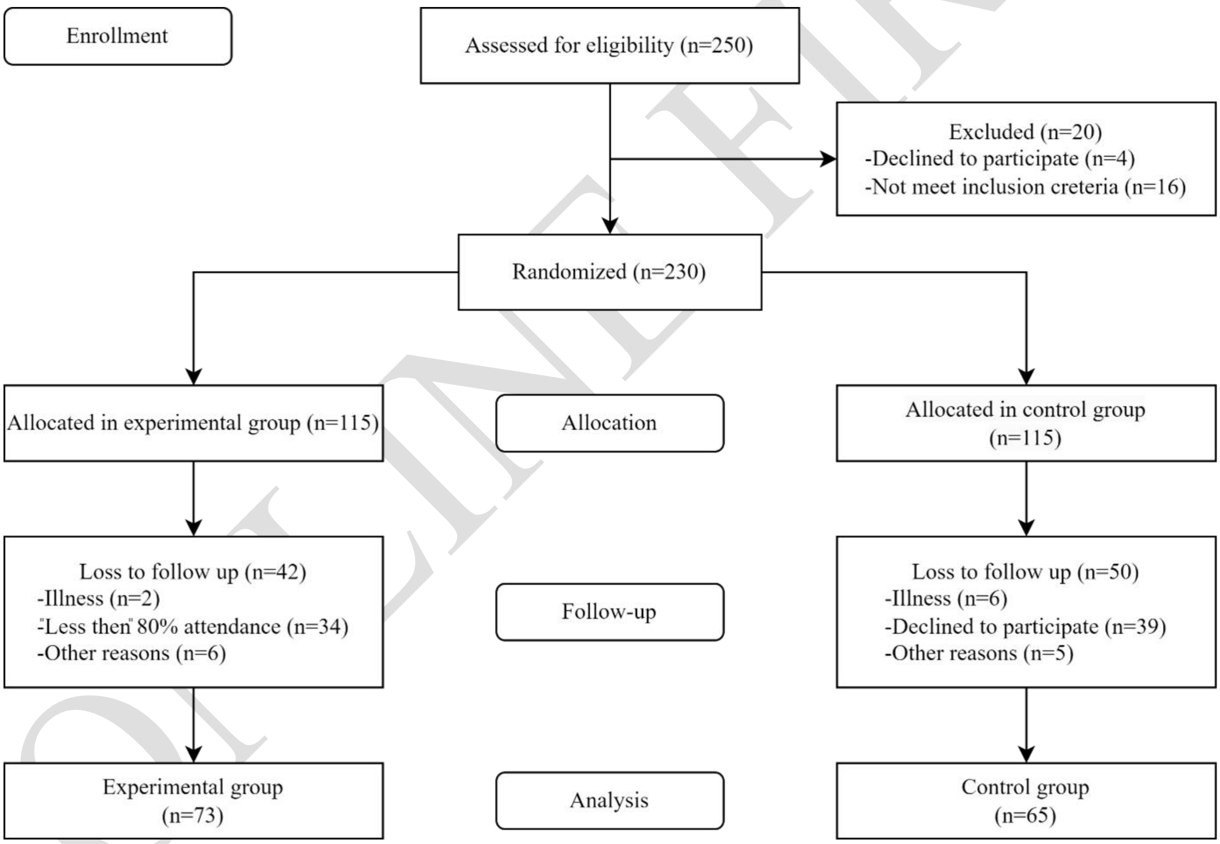

Figure 1. Flow diagram of participant enrolment, randomized group allocation, and final analysis

Values for age, body mass (kg), total body volume (cm³), and body mass index (BMI, kg/m²) are presented as mean ± SD. Total body mass and volume were included to describe anthropometric status and ensure initial comparability between groups. Baseline homogeneity between the EG and CG was assessed using independent t-tests for age, BMI, total body mass, and trunk volume (Table 1). No statistically significant differences were found ($p>0.05$), confirming comparable starting conditions across groups.

Table 1. Sample characteristics of the EG and CG

Characteristics	Total (n=138)	EG (n=73)	CG (n=65)	$T_{(136)}$	*p*
Age	23.3±0.9	23.3±1.0	23.4±1.0	-0.517	0.606
TM	772.8±100.3	760.8±94.9	786.3±105.1	-1.491	0.136
TV	1809.1±69.7	1807.2±54.2	1811.3±84.1	-0.334	0.732
BMI	23.6±2.4	23.3±2.5	23.9±2.4	-1.548	0.125

Notes: Baseline characteristics of the total sample and by group: experimental (EG) and control group (CG). Values are presented as mean ± standard deviation (SD). Independent samples t-tests were used to assess group differences. TM – Total Mass (kg); TV – Total Volume (L); BMI – Body Mass Index (kg/m²); T – t-test statistic; *p* – significance level.

Measurements – anthropometric variables

Anthropometric measurements were conducted twice, with a variation of less than 1% for both body mass and height, in accordance with the standards of the International Biological Program. A stadiometer (SECA Instruments Ltd, Hamburg, Germany) with an accuracy of 0.1 cm was used to measure body height, and a digital scale (Omron BF511, Japan) with an accuracy of ± 0.1 kg was used to measure body weight. We used the standard formula (weight/height² in kg/m²) to calculate the body mass index (BMI) based on the measurements received. The technical measurement error was less than 3%.

Measurements – spine posture parameters

The CONTEMPLAS 3D photometric system, which was calibrated in a laboratory, was used. To guarantee measurement accuracy, the equipment was placed on a perfectly level surface. The risk of measurement error was reduced as the system was firmly fixed to avoid any displacement during subject positioning. A 3D calibrator placed in the middle of the measurement board was used to calibrate the testing area. During calibration, a V-shaped frame containing three high-resolution Basler cameras (model acA645-100gm/gc) was positioned 2.5 meters from the board's center.

Data collection began after system configuration and calibration was completed. The evaluation followed the "2D protocol" and "3D Posture Compact" offered by the TEMPLO 7.0 software, which called for the positioning of reflective markers on particular anatomical landmarks (Figure 2). CONTEMPLAS 2D/3D Posture Analysis: a digital photometric system that uses camera-based tracking and software algorithms to look at posture in the sagittal and frontal planes. Previous research has demonstrated its validity and reliability in assessing spinal alignment and postural indices in standing individuals. The examiner placed the participants on the calibrated measurement board, standing with their feet shoulder-width apart and their backs to the cameras. By aligning the medial malleoli with the board's horizontal reference line, alignment was guaranteed. The participants were told to keep their arms relaxed at their sides, look straight ahead, and maintain a naturally upright posture.

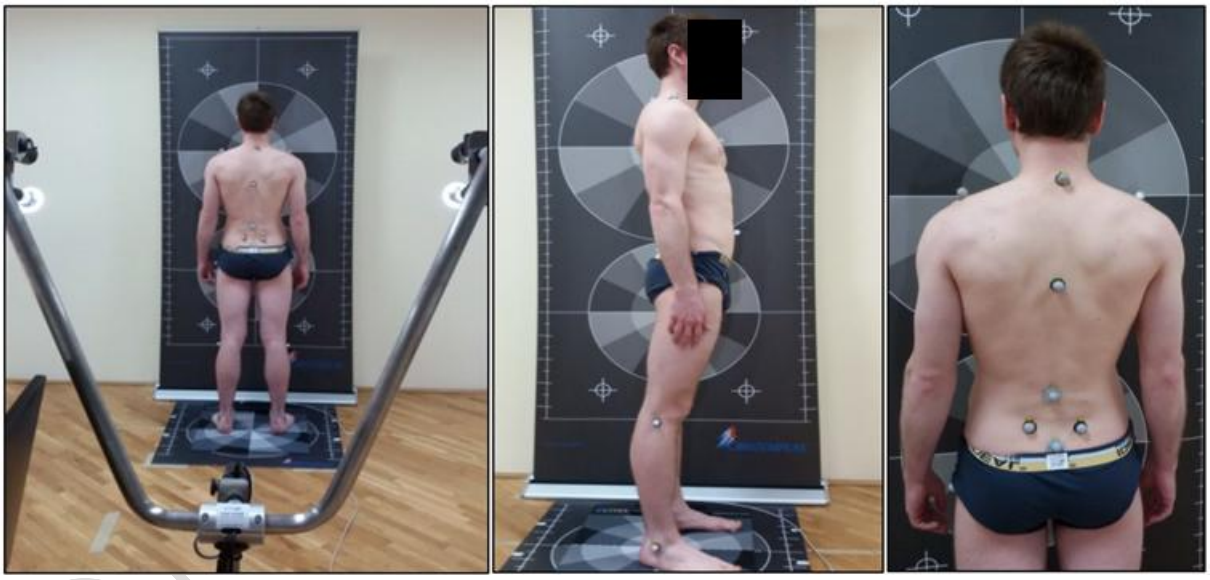

Figure 2. Measuring spine posture parameters with markers placed on reference points on the body

Following ten seconds of maintaining the position, measurements were taken three times, with two-minute breaks in between. While the "shading" criterion considered sufficient image illumination to remove ambiguity in the postural data, the "comfort" criterion guaranteed the subject's postural stability. This method of 3D posture analysis using the CONTEMPLAS system has been validated and previously applied in research [23]. Reporting on measurement properties, Greisberger et al. [20] found excellent intra- and inter-rater reliability for craniovertebral angle and trunk forward lean using the TEMPLO software (ICC=0.98-1.00).

Different spine posture parameters were evaluated using the CONTEMPLAS TEMPLO photometric system, which analyses body alignment-based 3D protocols. The system calculates:

- distance lumbar spine – sacrum. Markers were set on anatomical landmark: LV1 – lumbar level vertebrae 1 and SACR – sacrum. Distance indicates the lumbar (lower) spine regarding the vertical line projection of the sacrum (the bone at the bottom of spine). Values are presented in centimeters (cm);
- distance thoracic spine – sacrum. Distance indicates the thoracic spine in relation to the vertical line projection of the sacrum (the bone at the bottom of the spine) in the sagittal plane. Markers were set on anatomical landmark: MAI – midpoint between the inferior angles of most caudal points of the two scapula and SACR – sacrum. Values are presented in centimeters (cm);
- distance cervical spine – sacrum. Markers were set on anatomical landmark: CV7 – cervical vertebrae 7 and SACR – sacrum. Distance indicates the cervical spine in relation to the vertical line projection of the sacrum (the bone at the bottom of the spine) in the sagittal plane. Values are presented in centimeters (cm).

Moreover, postural disorders were additionally evaluated using the 2D CONTEMPLAS TEMPLO protocol, analyzing parameters of:

- Posture Index by Fröner (PI) – this evaluates the balance between thoracic kyphosis, lumbar lordosis, and abdominal protrusion, providing an objective indicator of spinal posture [24]. Markers were set on anatomical landmark: thoracic spine (T3-T5 region); sternum; lumbar spine (L3-L5 region); abdomen (navel level projection). Indexes were calculated: $PI = (a+d)/(b+c)$; a = thoracic kyphosis distance; b = sternal displacement; c = lumbar lordosis distance; d = abdominal protrusion. Interpretation of PI Fröner values: optimal posture: PI = 1.0-1.2; postural imbalance: $PI<1.0$ (reduced curvature) or $PI>1.2$ (excessive curvature); abnormal posture: $PI<0.8$ (hypolordotic or hypokyphotic posture) or $PI>1.7$ (hyperlordotic or hyperkyphotic posture).
- Thoracic Kyphosis Index (TKI) – TKI was used as a quantitative measure of sagittal thoracic alignment [25]. Markers were set on anatomical landmark: C – cervical vertebrae 7; D – midpoint between the inferior angles of most caudal points of the two scapula; L – lumbar level vertebrae 1; G – maximal present point of gluteus; D1 – vertical projection that connects the line from the cervical point to lumbar point. TKI =

(D*D1)*25/ distance from C to L; values: optimal: 2.3 to 3.0; acceptable: 3.1 to 4.0; marginal: 4.1 to 4.4; suspicious: 4.5 to 5.0; conspicuous: more than 5.0.

- Cervico-Lumbar Lead Angle (CCL) – markers were set on anatomical landmark: C – cervical vertebrae 7; D – midpoint between the inferior angles of most caudal points of the two scapula; L – lumbar level vertebrae 1; G – maximal present point of gluteus; D1 – vertical projection that connects the line from the cervical point to lumbar point. CLL angle was measured at point L. This presents the angle between the perpendicular and the connection line of point L and C and describes the sagittal inclination of the spine. Values: optimal: -2 to 1; acceptable: -2 to -6; marginal: -7 to -8; suspicious: -9 to -10.5; conspicuous: less than -10.5. Values are presented in degrees (°) [26].
- Lumbar-Gluteal Lead Angle (LGL) – markers were set on anatomical landmark: C – cervical vertebrae 7; D – midpoint between the inferior angles of most caudal points of the two scapula; L – lumbar level vertebrae 1; G – maximal present point of gluteus; D1 – vertical projection that connects the line from the cervical point to lumbar point. The LGL values representing lumbar lordosis were obtained at point G. The angle was calculated between the line connecting points L and G, and a perpendicular line drawn through point G. Values: optimal: -10 to -23; acceptable: -24 to -28; marginal: -29 to -31; suspicious: -32 to -35; conspicuous: less than -36. Values are presented in degrees (°) [26].

Trunk neuromuscular abilities

The Sorensen Back Extensor Test (BET) evaluates the endurance of the back extensor muscles. The iliac crest is in line with the edge of the table as the subject lies prone on it. While the upper body hangs over the edge unsupported, the lower body is strapped in place. For as long as possible, the subject keeps their arms folded across their chest. In the BET, the test was terminated when the participant could no longer maintain the horizontal position (≥ 5° deviation measured via visual alignment and angle markers) or upon voluntary withdrawal due to fatigue or discomfort. When the subject is too tired or in pain to maintain the position, the test is over. According to Dejanovic et al. [27], longer durations indicate greater endurance. The time is measured in seconds. The BET is used to measure how long the trunk extensor muscles can hold an isometric position. It has shown excellent reliability in healthy adults (ICC=0.88-0.99) and is a validated measure of lumbar endurance and presented as a dependable and valid assessment of lumbar endurance in both clinical and athletic cohorts [28,29].

Core endurance is evaluated by the Abdominal Flexor Endurance Test (FET). The subject sits with their arms folded across their chest, feet flat, and knees bent at a 90° angle. The upper body tilts back from the floor to a 60° angle. The subject must maintain this posture without shifting or arching after the support is removed. In FET, the trial ended when the participant's trunk deviated backward and could no longer be held at the target angle (typically ~60° from the floor) or if the feet lifted off the support. Longer durations indicate greater abdominal endurance. Time is measured in seconds [27]. FET assesses the endurance of abdominal muscles during prolonged trunk flexion. This test shows good inter-rater reliability and is often used to measure how well the core muscles work [30].

The Double Leg Lowering Test (DLL) evaluates core and lower abdominal strength. The subject is in a supine position with their legs raised to a 90° hip flexion and their arms at their sides. During the DLL, participants begin with their hips and knees flexed at 90°, and the knees remained flexed at 90° throughout the movement while both legs were actively lowered toward the table in a controlled manner. The subject gradually lowers both legs until they are unable to maintain lumbar stability or pelvic control while maintaining lower back contact with the floor. For the DLL, failure was defined as loss of pelvic stability (posterior tilt or arching) or if the legs dropped below the control point (measured at 45° from the table) without control. It is noted at what angle the control or rear arches are lost. Better core strength is indicated by a lower angle, whereas weakness is suggested by an early loss of control [31]. DLL evaluates how efficiently the lower abdominal muscles work and how strong they are. It is frequently utilized in postural and rehabilitation contexts, demonstrating established reliability in identifying lumbopelvic control deficits [32] (Figure 3).

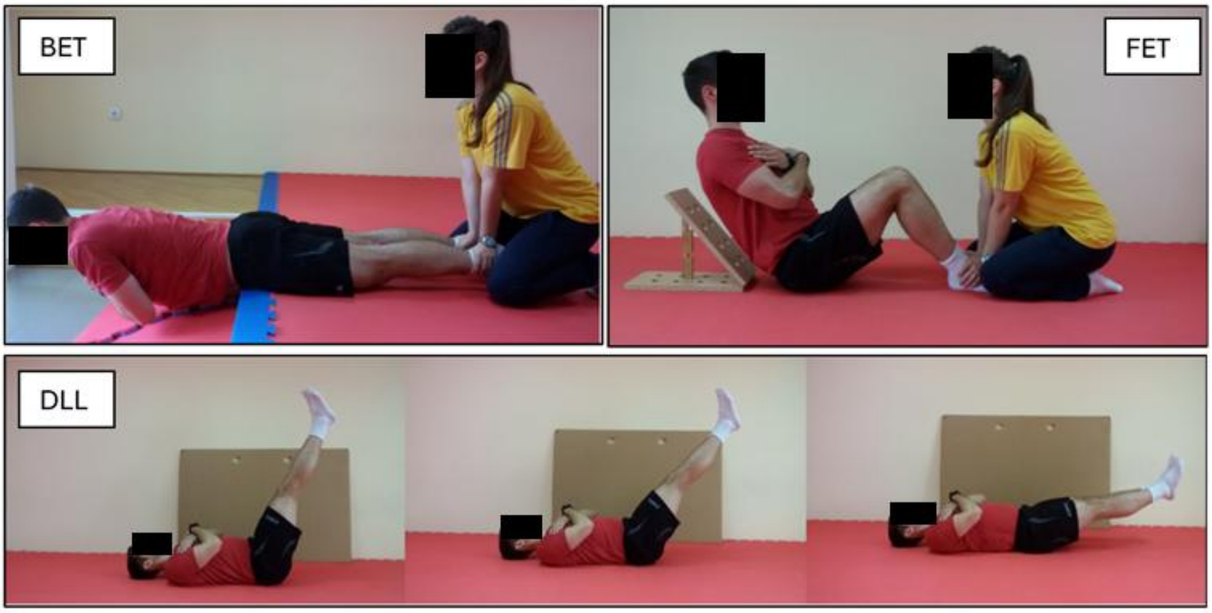

Figure 3. Measuring trunk neuromuscular abilities

Intervention

The CG received instructions to keep doing what they usually do every day and not start any new structured exercise programs. They could do light recreational activities like walking, but they were asked not to do any core, resistance, or sports training during the study period.

The experimental treatment lasted six weeks and was performed three times a week. This was a total of 18 introductory courses lasting 30 minutes each. The treatment included exercises to increase the mobility and strength of the neck, shoulders, pelvis, and hips, and anti-flexion, anti-extension, and rotation exercises were used to stabilize the spine [33]. McGill curl-up was performed during each treatment for all six weeks. In the first two weeks, the subjects did general and introductory exercises (all positioned planks, plank walking, forearm cranes, plank pad forearms, etc.); week three and four with additional movements and rotations (alternating hand and foot board holding, superman posture, faceplate switches, etc.). During the fifth and sixth weeks, the exercises were performed on unstable surfaces (one-handed board, ball stirring pot, feet raised sideboard, etc.). The intensity of the training courses varied for each individual, beginning at a submaximal level. The training program's intensity was adjusted for every participant based on their perceived exertion rating using the Borg CR10 Scale [34]. In two-week sprints, the intensity changed following the progress of each respondent. Table 2 presents a detailed plan of treatment for the EG.

eISSN: 2354-0265, ISSN: 2353-6942

Table 2. Experimental treatment

Week(s)	Exercise	Description	Sets/Reps/Time
1-2	All position planks	Isometric holds in various plank positions to activate core stabilizers	Hold ~50 s
	Plank walk	Transitioning between high and low planks to build dynamic stability	2-3 sets of 30 s
	Plank jacks	Lifting legs apart/together in a plank; adds cardio and challenge	2-3 sets of 15-20 reps
	Forearm to pushup plank	Moving from forearms to hands repeatedly to improve core/shoulder strength	2 sets of 10-12 reps
	Feet elevated side plank	The side plank, with feet raised, targets the obliques with added instability	Hold ~30-45 s
	3-point plank	Perturbation with limb from plank to challenge balance and control	2-3 rounds, hold ~20 s
	Bird dog	From quadruped, extend opposite limbs while keeping spinal alignment	2-3 sets of 10 reps/side
3-4	Alternating arm plank hold	Lift one arm in plank while maintaining hips stable	20-30 reps
	Alternating leg plank hold	Lift one leg in plank; targets glutes and core	20-30 reps
	Superman plank hold	Simultaneously lift arms and legs in a plank for coordination and stability	2-3 holds, 20-30 s
	Side plank star hold	Lifting the arm and leg of a side plank activates the full lateral chain	Hold ~20 s per side
	Alligator plank walk	Crawl in plank position; increases dynamic core demand	2 sets of ~5-10 m
	Plank barrel roll	Rotate hips while planking to engage obliques	2 sets of 10 reps
	Bird dog	Progression with longer holds or slower reps	As above
5-6	Plank down dog to toe tap	Transition from plank to downward dog and tap opposite foot	2 sets of 10-12 reps
	Plank with single arm fly (feet on ball)	Arm fly movement while feet are on Swiss ball to challenge core	2-3 sets of 8-10 reps
	Feet elevated side plank	Progressed side plank with feet elevated	Hold ~30-45 s
	Side plank hip adduction circle	Circle top leg during side plank; targets hips and obliques	2 sets of 10 reps/side
	Front plank plate switches	Move object side-to-side while planking; anti-rotation work	2-3 sets of 10 reps
	Side plank raises on ball	Side plank with dynamic hip raises on a ball	2 sets of 10 reps
	Swiss-ball stir the pot	Forearms on ball, make circular motions to resist extension	2 sets of 15-30 s

	Bird dog	Advanced variation with holds and resistance	As above
1-6	McGill curl up	Supine abdominal exercise minimizing lumbar flexion; builds endurance	20 reps/session

Statistical analysis

While Levene's and Box's tests revealed the absence of homogeneity of variances and covariance matrices, respectively, the Kolmogorov-Smirnov test validated the residuals' normality. Statistical analysis was performed on a per-protocol basis. Although 230 participants were randomized, only those who completed both pre- and post-intervention assessments with adequate adherence (≥ 80% attendance in the EG) were included in the final analysis (n=138). As such, an intention-to-treat (ITT) approach was not applied. This decision was made to ensure that the analysis reflected the actual effects of the completed intervention protocol. The effects of time (pre-test vs. post-test) and the interaction between time and group (EG vs. CG) on postural outcomes were investigated using a two-way repeated-measures analysis of variance (ANOVA). *P*-values were used to determine statistical significance; values less than 0.05 were considered significant. To ascertain whether there were differences between groups in the changes in trunk neuromuscular abilities and spine posture from the pre- to post-test, the time × group interaction effect was evaluated. When a significant interaction was discovered, post-hoc tests were used to evaluate within-group changes using simple main effects of time, with 95% CIs and Bonferroni-adjusted *p*-values. Partial eta squared (η^2p) was used to assess effect sizes; thresholds of 0.01, 0.06, and 0.14, respectively, indicated small, medium, and large effects. To complement the inferential analyses, effect sizes (Cohen's *d*) were calculated to determine the magnitude of observed differences for both within-group (time) and between-group (interaction) effects. Cohen's *d* values were derived from the mean difference divided by the pooled standard deviation, with thresholds interpreted as small (0.2), medium (0.5), and large (0.8) effects [35]. Additionally, to assess the clinical relevance of changes, the Minimal Clinically Important Difference (MCID) was estimated as 0.3-0.5 standard deviations (SD) of the baseline value, following established conventions for continuous physical performance and postural parameters in exercise science. Values exceeding these MCID thresholds were considered clinically meaningful improvements, while smaller effects were interpreted as negligible in practical terms. SPSS statistical software (SPSS 23.0, IBM, Chicago, IL, USA) was used for all statistical analyses.

Results

Table 3 shows the results of spine posture analysis. These results show only postural indicators of the sagittal plane. Results from repeated measures ANOVA showed a significant group (EG vs. CG) × time (Pre to Post) interaction for thoracic ($F_{(1,136)}$=5.51, p=0.02, partial η^2=0.03), lumbar ($F_{(1,136)}$=13.424, p=0.00, partial η^2=0.09), and cervico-lumbar lead angle ($F_{(1,136)}$=11.69, p=0.00, partial η^2=0.07). In addition to the significance mentioned above, the significant main effect of time was shown in the TKI ($F_{(1,136)}$=10.97, p=0.00, partial η^2=0.07). The analysis revealed varying magnitudes of effect across spinal posture and alignment outcomes. For the cervical region and PI Fröner index, changes over time and between groups were negligible (d<0.2), suggesting no meaningful adaptation. The thoracic region and TKI demonstrated small-to-moderate effects (d=0.35-0.55), indicating slight improvements in thoracic posture, particularly within the EG. The lumbar region showed moderate effects for both time and interaction (d=0.6), reflecting a noticeable enhancement in lumbar alignment following the intervention. The most pronounced change was observed for the cervico-lumbar lead angle, which exhibited a very large time effect (d=1.8) and a moderate interaction effect (d=0.6), indicating substantial postural realignment and a stronger training impact in the experimental condition. Finally, the lumbar-gluteal lead angle showed only small effects (d=0.2-0.3), implying minor but consistent adjustments. The postural outcomes showed more modest changes. The cervical and PI Fröner parameters remained below MCID thresholds, indicating negligible practical change. The thoracic and TKI demonstrated small-to-moderate effects (d=0.4-0.6) that approach or slightly surpass the lower MCID range, suggesting minor yet potentially meaningful posture adjustments. The lumbar and cervico-lumbar lead angles displayed moderate-to-large effects (d=0.6-1.8), clearly surpassing the MCID, and therefore represent clinically important improvements in spinal alignment. Meanwhile, the lumbar-gluteal lead angle (d=0.2-0.3) remained near or below MCID limits, indicating small, likely non-meaningful changes.

eISSN: 2354-0265, ISSN: 2353-6942

Table 3. Spine posture differences between pre- and post-test for the EG and CG

Outcome / **Group**	**Mean difference (pre-post) 95% CI [Lower, Upper]**	***p*-value, η^2p**	**Effect size (*d*)**
Cervical (cm)		Time: p=0.56, η^2p: 0.00 Interaction: p=0.65, η^2p: 0.00	Time: d=0.00 Interaction: d=0.00
EG	-0.82 [-4.30, 2.66]		
CG	-0.26 [-1.06, 0.55]		
Thoracic (cm)		Time: p=0.00, η^2p: 0.05 Interaction: p=0.02, η^2p: 0.03	Time: d=0.46 Interaction: d=0.35
EG	-1.43 [-3.24, 0.37]		
CG	-0.23 [-0.66, 0.20]		
Lumbar (cm)		Time: p=0.00, η^2p:0.09 Interaction: p=0.00, η^2p: 0.09	Time: d=0.63 Interaction: d=0.63
EG	-0.56 [-1.58, 0.47]		
CG	0.10 [-0.05, 0.25]		
PI Fröner		Time: p=0.16, η^2p:0.01 Interaction: p=0.32, η^2p: 0.00	Time: d=0.20 Interaction: d=0.00
EG	0.10 [0.06, 0.14]		
CG	0.05 [0.02, 0.08]		
TKI		Time: p=0.00, η^2p:0.07 Interaction: p=0.37, η^2p: 0.00	Time: d=0.55 Interaction: d=0.00
EG	-0.12 [-0.24, +0.00]		
CG	-0.20 [-0.36, -0.05]		
Cervico-lumbar lead angle (°)		Time: p=0.00, η^2p:0.44 Interaction: p=0.00, η^2p: 0.07	Time: d=1.77 Interaction: d=0.55
EG	1.20 [+0.74, +1.65]		
CG	2.37 [+1.85, +2.89]		
Lumbar-gluteal lead angle (°)		Time: p=0.07, η^2p: 0.02 Interaction: p=0.14, η^2p: 0.01	Time: d=0.29 Interaction: d=0.20
EG	-0.34 [-0.89, +0.21]		
CG	+0.86 [+0.24, +1.48]		

Notes: Pre- and post-intervention mean differences for posture-related outcomes in the EG and CG with confidence intervals (CI) [Lower, Upper] are reported. Results include time and interaction effects from repeated-measures ANOVA and corresponding effect sizes (Cohen's *d*). *d*-values were interpreted as small (0.2), medium (0.5), and large (0.8). Improvements exceeding the minimal clinically important difference (MCID; 0.3-0.5 SD) were considered clinically meaningful. *p*-values and partial eta squared (η^2p) are reported for the main effects of time and the group × time interaction. EG – Experimental Group; CG – Control Group; PI – Posture Index; SD – Standard Deviation.

Table 4 shows the results of trunk neuromuscular abilities between pre-and post-test for the EG and CG. The results of repeated ANOVA measurements showed a significant group interaction (EG vs. CG) × time (Pre to Post) for all three variables: BET ($F_{(1,136)}$=14.17, p=0.00, partial η^2=0.09), FET ($F_{(1,136)}$=33.03, p=0.00, partial η^2=0.19), and DLL ($F_{(1,136)}$=17.21, p=0.00, partial η^2=0.11). The results demonstrate clear and meaningful improvements across all three performance outcomes. For BET, medium-to-large effects for both time and interaction (d=0.6-

0.8) indicate notable gains in balance endurance over time, with a stronger response in the EG. The FET revealed large effects (*d*=0.9-1.0), reflecting a substantial enhancement in overall functional endurance and suggesting that the intervention had a pronounced impact on participants' physical capacity. Finally, the DLL showed a very large time effect (*d*=1.1) and a moderate interaction effect (*d*=0.7), pointing to significant improvements in core control and postural stability across time, with moderately greater progress in the EG compared to the CG.

For the functional outcomes, the observed effects in the BET (*d*=0.6-0.8), FET (*d*=0.9-1.0), and DLL (*d*=1.1) notably exceeded typical MCID benchmarks (= 0.3-0.5 SD), confirming that improvements were not only statistically but also clinically relevant.

Table 4. Trunk neuromuscular abilities between pre- and post-test for the EG and CG

Outcome Group	Mean difference (pre–post) 95% CI [Lower, Upper]	*p*-value, $\eta^2 p$	Effect size (*d*)
BET (0.1s)		Time: p=0.00, η^2p: 0.13 Interaction: p=0.00, η^2p: 0.09	Time: d=0.77 Interaction: d=0.63
EG	23.98 [11.26, 36.70]		
CG	2.58 [-4.49, 9.65]		
FET (0.1s)		Time: p=0.00, η^2p: 0.18 Interaction: p=0.00, η^2p: 0.19	Time: d=0.94 Interaction: d=0.97
EG	62.68 [41.41, 83.95]		
CG	-1.16 [-21.42, 19.10]		
DLL (°)		Time: p=0.00, η^2p: 0.24 Interaction: p=0.00, η^2p: 0.11	Time: d=1.12 Interaction: d=0.70
EG	11.30 [6.78, 15.82]		
CG	2.54 [-1.43, 6.51]		

Notes: Pre- and post-intervention mean differences for trunk neuromuscular endurance outcomes in the EG and CG with confidence intervals (CI) [Lower, Upper] are reported. Results include time and interaction effects from repeated-measures ANOVA and corresponding effect sizes (Cohen's *d*). *d*-values were interpreted as small (0.2), medium (0.5), and large (0.8). Improvements exceeding the minimal clinically important difference (MCID; 0.3-0.5 SD) were considered clinically meaningful. *p*-values and partial eta squared ($\eta^2 p$) are reported for the main effects of time and the group × time interaction. BET – Back Extensor Test; FET – Flexor Endurance Test; DLL – Double Leg Lowering test; EG – Experimental Group; CG – Control Group; SD – Standard Deviation.

Discussion

This study aimed to determine the effects of a six-week core exercise program on spine posture and trunk neuromuscular endurance in healthy, recreationally active males. The research aimed to prove the effect of core training on positive posture changes in the sagittal plane.

The analysis of sagittal-plane spinal posture revealed significant group × time interactions for the thoracic, lumbar, and cervico-lumbar lead angles, alongside a main time effect for the thoracic kyphosis index. The most pronounced improvements were observed in the lumbar and cervico-lumbar regions, which showed moderate-to-large effects (d=0.6-1.8) exceeding MCID thresholds, indicating clinically meaningful postural enhancements. Thoracic parameters demonstrated small-to-moderate effects (d=0.4-0.6), suggesting minor but potentially relevant adjustments, while cervical distance, Fröner index, and lumbar-gluteal angles showed negligible or small effects (d<0.3) without clinical significance. Overall, the results highlight region-specific adaptations, with the greatest improvements localized to the thoracic-lumbar segment following the core exercise intervention.

According to the 3D analysis protocol, the thoracic distance was drastically reduced in EG, from -2.52 to -1.65. In a study of adolescents up to 14 years of age, the average result was around -1.032 in healthy adolescents [36]. At the age of up to 12, measured with the same apparatus, average values of -0.64 for thoracic distance were obtained [23]. With age, in healthy subjects, the cervical spine decreases and the thoracic spine increases [37]. Our findings are in line with those of Marcos-Pardo et al. [13], who found that middle-aged and older adults who participated in an eight-week resistance-based training program had decreased thoracic and lumbar curvature in standing posture. This finding supports the idea that core training works by improving trunk muscle activation. This suggests that healthy individuals tend to move their heads forward while also increasing the curvature of the thoracic spine. Since we had a sample of respondents with pre-existing sagittal problems, any reduction in distance is an excellent result. The first lumbar treatment also had positive effects, as the trunk's center was the main focus. Moreover, previous research examined postural parameters in children and spinal curvature adaptations in middle-aged or older populations; however, our study concentrated on healthy young adults (mean age: 23.3 years). This age group represents a crucial stage where musculoskeletal maturity has reached its peak, but preclinical postural deviations remain susceptible to modification. To our knowledge, this study is one of the first to assess the impact of a structured core training intervention on spinal posture and trunk endurance in healthy adults in their early twenties, utilizing a validated 2D/3D digital analysis system.

According to the 2D analysis protocol, PI Fröner did not show statistically significant treatment effects. However, statistically significant changes were achieved in the variable cervico-lumbar lead angle by analyzing the effects according to the KIL scheme. This variable describes the inclination. Ideal values for inclination range from -2.0 to 1.0. The EG's

eISSN: 2354-0265, ISSN: 2353-6942

inclination shifted from -2.42 to -1.22, moving closer to the average values considered acceptable and ideal for physiological inclination. Through previous research according to the KIL scheme, it is possible to identify the effects after the treatment application [26].

The analysis of trunk neuromuscular abilities showed significant group × time interactions for all tests, confirming clear improvements in the EG. The BET demonstrated medium-to-large effects (*d*=0.6-0.8), indicating notable gains in trunk extensor endurance. The FET produced large effects (*d*=0.9-1.0), reflecting substantial enhancement of abdominal endurance and overall functional capacity. The DLL showed a very large time effect (*d*=1.1) and a moderate interaction effect (*d*=0.7), revealing marked improvements in core stability and lumbopelvic control. All three outcomes exceeded MCID thresholds (0.3-0.5 SD), confirming that the observed gains were both statistically and clinically meaningful. Overall, the six-week core exercise program significantly enhanced trunk muscular endurance and stability compared with the control condition.

Previous studies [38] have proven the positive effect of similar treatments. Previous research in transformation processes to increase the strength and endurance of trunk muscles has been effective in reducing lumbar lordosis and improving postural stability [39]. Similarly, following a 12-week core stability training program by Chaari et al. [16] found that athletes' trunk endurance and static postural balance significantly improved. In a healthy, recreationally active male population, the current intervention, although shorter in duration, led to similar improvements in postural and neuromuscular outcomes to these studies, indicating that even moderate-term core-focused interventions may produce significant functional benefits. Dynamic neuromuscular stabilization (DNS) also improved deep core muscle contractility and postural control in people with chronic low back pain, according to Huang et al. [14]. Because of incorrect posture, it is possible to show different torso stabilizer strength, where subjects with lordosis perform fewer BET and FET tests than subjects with kyphosis.

For certain postural parameters, the small effect sizes and wide confidence intervals indicate that corrective multisport training produced modest but variable improvements. These findings suggest that individual responses to the intervention may differ and that the overall practical impact, although favorable, remains uncertain and warrants confirmation in larger samples.

Limitations

This research has its limitations related to the choice of a measuring instrument that would more reliably verify changes in posture. The sample of available respondents could also be changed in one of the following research studies, including respondents not in the final stage of growth and development. Moreover, a limitation of this study is the use of a per-protocol rather than intention-to-treat analysis, which may limit generalizability. Future studies should consider using ITT approaches to account for attrition and better reflect real-world implementation. Additionally, our six-week core exercise program's duration was purposefully chosen to achieve a balance between intervention effectiveness and realistic viability for a population that engages in recreational activities. Although prior research by Chaari et al. [16] used a 12-week core stability training program and Marcos-Pardo et al. [13] used an eight-week resistance training program, both of which showed notable improvements in trunk function and posture, our findings suggest that significant neuromuscular and postural adaptations can also take place in a shorter six-week period. Additionally, while both groups were instructed to abstain from structured physical training, some variation in habitual daily activity could not be entirely controlled.

The practical contribution of the research is the correct choice of ET, which has proven to be suitable for creating muscle balance on the ventral and dorsal sides of the body and indicating proper posture. The importance of the research is reflected in the broad application of the proposed treatment in children, adolescents, recreationists, and people who are not involved in physical activity, and thus by applying exercises, they can maintain their working ability. Moreover, future studies should plan to replicate the intervention in female participants for broader generalizability.

Conclusions

The current randomized controlled trial revealed that a six-week core exercise regimen significantly improved spinal alignment and trunk neuromuscular endurance in healthy, recreationally active young males. The most noticeable changes in posture occurred in the thoracic and lumbar regions of the spine. Additionally, endurance performance (BET, FET, DLL) improved with moderate-to-large effect sizes that exceeded the MCID thresholds. However, the differences were primarily due to changes in the thoracic and lumbar parts. The

EG experienced a reduction in the thoracic spine, a result of the strength exercises employed during the treatment. These results indicate that core training protocols are potentially beneficial not just for kinesiology researchers and teachers but also for medical professionals who want to identify non-invasive ways to improve spinal health and functional stability in young adults.

Disclosures and acknowledgements

The authors declare no conflicts of interest with respect to the research, authorship, and/or publication of this article.

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

After explaining the experimental protocol, each subject provided written informed consent before participating in the study, per the Declaration of Helsinki and the University of Novi Sad Human Research Ethics Committee guidelines (ethical approval number: 20/2018). The study was fully registered at ClinicalTrials.gov under number: NCT06877806 and name: "Effects of Core Exercise on Posture and Trunk Endurance in Sedentary Males (Coremale)".

Artificial intelligence (AI) was not used in the creation of the manuscript.

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