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Research article

DIFFERENCES IN POSTURAL STABILITY BETWEEN ADOLESCENTS WITH SCOLIOSIS AND THOSE TYPICALLY DEVELOPED

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Abstract. *This study aimed to investigate differences in postural stability between adolescents with scoliosis and typically developed peers.*
Researchers conducted a cross-sectional study of 75 participants (53 male, 22 female) divided into two groups. The first group consisted of 35 adolescents with scoliosis (aged 17.15 ± 1.31 years; BMI 22.3 ± 2.6), while the second group consisted of 40 typically developed peers (aged 16.74 ± 1.3 years; BMI 22.6 ±2.5 females). The CONTEMPLAS 3D Kinematic System measured the level of scoliosis, while researchers used the Force Plate and double leg standing test to measure postural stability parameters.
Adolescents with scoliosis demonstrated significantly lower postural stability in the Center of pressure ($p<0.001$), Length function of surface ($p<0.001$) than typically developed peers. Furthermore, adolescents with scoliosis had higher Anterior-Posterior displacement of COP ($p<0.001$) and Medio-Lateral displacement of COP ($p<0.001$) compared to typically developed peers, indicating lower levels of postural stability.
This study suggests that adolescents with scoliosis have lower postural control and balance than typically developed peers. The findings highlight the importance of identifying and addressing these issues to optimize the health and well-being of adolescents with scoliosis.

Key words: *scoliosis, adolescent, 3d analysis, postural control.*

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INTRODUCTION

Scoliosis is a medical condition that affects the curvature of the spine. It is a common orthopedic disorder that can lead to postural instability, which is the inability to maintain a stable upright posture. The most prevalent form of scoliosis affects approximately 2-4% of adolescents, primarily impacting children aged 10 to 18 (Reamy & Slakey, 2001). This condition involves a three-dimensional distortion of the spine and ribcage, which can cause alterations in the coordination of body segments, spinal structure, and left-right symmetry of the trunk. These changes may result in a pathological gait pattern (Bruyneel et al., 2010; Syczewska et al., 2010, 2012).

Postural stability involves maintaining the center of mass (COM) within the base of support while minimizing postural sway. This requires proper functioning of the sensory systems (including visual, somatosensory, and vestibular), cognitive processing, and movement strategies (Horak, 2006). The mechanism responsible for this control adjusts the body axis based on bodily dynamics, resulting in small, yet continuous oscillations while standing (Winter, 1995). These oscillations are essential for pressure distribution on the soles of the feet and efficient venous return. Maintaining the center of pressure during standing requires keeping the support base unchanged without lifting or stepping the feet from the surface (Ivanenko & Gurfinkel, 2018). The central nervous system utilizes motor-sensory information and appropriate strategies to influence the stability of standing posture through internal representation.

During the period of rapid growth in puberty, different factors have an impact on the developing body, particularly the spinal region, having the potential to cause the development of the scoliosis deformity of the spine and ribcage characterized by altered body segment coordination, spinal anatomy, and body symmetry (Schlösser et al., 2015). The relationship between scoliosis and postural stability in the adolescent period has been the subject of considerable research interest in recent years. Studies have shown that individuals with scoliosis often have reduced postural stability and impaired balance control compared to those without scoliosis (Dufvenberg et al., 2018; Karimi et al., 2016; Wiernicka & Kotwicki, 2019). The reduced postural stability is believed to result from changes in the spinal alignment and muscle activation patterns associated with scoliosis (Osuka et al., 2022). Since scoliosis presents postural issues associated with spine deviation in the frontal plane, it can change the position of the center of mass (COM) and alter weight distribution on the lower limbs. As a result, individuals with scoliosis tend to exhibit poorer stability compared to those without the condition, particularly those of a similar age. Moreover, scoliotic patients may experience difficulties in maintaining an upright stance due to visual, vestibular, and somatosensory dysfunction of systems (Catanzariti et al., 2001; Gauchard et al., 2001).

In the past decade, research has aimed to determine whether adolescents with scoliosis have proprioceptive and somatosensory impairments that affect their balance control function. Different approaches and methodologies for assessing the degree of scoliosis and postural stability leave much room for debate. Understanding the relationship between these two factors can help clinicians develop more effective treatment strategies for individuals with scoliosis. Therefore, this study aimed to determine possible differences in postural stability parameters in a group of adolescents with and without scoliosis.

METHODS

Participants

A group of 75 (male: 53; female: 22) adolescents were enrolled in the study. The exclusion criteria were: (i) history of neurological or musculoskeletal disorders; (ii) clinical conditions that could impair balance. The study sample was divided into groups according to the values of the Scoliosis Index into the Scolio group (Scolio; n=35) including adolescents with Scoliosis Index ≥2 and Control group (Control; n=40) with values of Scoliosis Index ≤2 referencing as healthy adolescents. Each participant, after an explanation of the experimental protocol, provided written informed consent prior to participating in the study, in accordance with the Declaration of Helsinki and with the Novi Sad University Human Research Ethics Committee guidelines (ethical approval number: 234/2020).

Procedure

The testing was conducted at the Faculty of Sport and Physical Education, University of Novi Sad, Serbia. All of the participants were tested in the morning before the beginning of their training season in indoor environmental conditions (temperature: 18–21°C; relative humidity: 40–60%). Before starting a performance task, general information about the participants was recorded, including gender, age, height, and weight. To obtain height and weight measurements, the participants were directed to wear light clothing and take off their shoes. Furthermore, they were advised to consume and drink minimal amounts and use the restroom beforehand. A stadiometer (0.1 cm precision, SECA Instruments Ltd, Hamburg, Germany) was used to measure height and weight.

Scoliosis

The Scoliosis index was assessed using 3D Photometric Contemplas system - Templo® Posture Analysis (Kapo et al., 2018; Kovac et al., 2014). Using Templo software and Contemplas 3D posture compact mode, we detected the position of markers placed on anatomical landmarks: CV7 – Cervical Vertebrae 7; MAI – Midpoint Between the Inferior Angles of Most Caudal Points of the Two Scapula; LV1 – Lumbar Level Vertebrae 1; SACR – Sacrum. Following biomechanical posture parameters were measured for both groups: Distance cervical spine-sacrum (MLc), indicates the distance between CV7 and SACR in the frontal plane (cm); Distance thoracic spine – sacrum (MLt), indicate the distance between MAI and SACR in the frontal plane (cm); Distance lumbar spine-sacrum (MLl) indicate the distance between LV1 and SACR in the frontal plane (cm). Digital calculations were performed for distance as the sum of absolute value in centimeters (SI=ABS(Mlc+Mlt+MLl)). According to the Scoliosis index, a Scoliosis Index of ≤2.5 indicates good spine status; a Scoliosis Index of≥2.5 presents scoliotic posture (Madić et al., 2014).

Postural stability

The researchers conducted a static PS assessment using a laboratory-grade 0.5 m Footscan® plate (RSscan International, Lammerdries, Belgium) equipped with 4096 sensors and a scanning rate of up to 300Hz. The participant performed individual single and double-leg tasks with three trials, each lasting for 30 seconds, with a two-minute break between each trial. The researchers used this test, which is considered the gold standard for measuring balance, to obtain biomechanical parameters of static PS (Haas & Burden, 2000). All measurements were performed in triplicate, and the mean score was retained for subsequent evaluations and analyses. The sequence of performing the balance tasks was randomized. The software calculated the Double leg Center of pressure (COP), Medio-Lateral (ML) displacement (mm), Anterior-Posterior (AP) displacement (mm), and Length function of surface (LFS). The Length in the function of surface (LFS) is a measure of the correlation between the surface of the center of pressure (COP) and its length. It serves as a reliable indicator of the accuracy of postural control and the amount of energy expended by an individual to maintain stability while standing (Lion et al., 2014).

Statistical analysis

A priori, the G*power 3.1 power analysis software determined the minimum sample size (n = 40). The Kolmogorov-Smirnov test confirmed that all the data were normally distributed in anthropometric characteristics. Thus, for age, body mass, BMI, and height, descriptive statistics were calculated. In addition, the univariate analysis of variance (ANOVA) was performed to test the differences between groups on the selected variables. Moreover, the significance of the differences between subsamples was tested using and post-hoc Least Significant Difference (LSD) test. The effect size (ES) of each variable was assessed by calculating Cohen's d within each group, whereby 0.2, 0.2−0.6, 0.6−1.2, 1.2−2.0, 2.0, and 4.0 was defined as trivial, small, moderate, large, very large, and extremely large effect, respectively (Hopkins et al., 2009). Multivariate analysis of variance (MANOVA) was applied to determine the quantitative differences between variables system of Double leg stability test for two divided groups. Statistical Package for the Social Sciences (SPSS Inc., Chicago, IL, USA) ver. 22 was used for all statistical tests with the significance level set at $p \leq 0.05$.

RESULTS

The participants' characteristics within groups are presented in Table 1. On average, the participants' age, body height and mass, and BMI were similar in both groups. The Scoliosis index was significantly higher in the Scolio group (mean difference: 0.48 [-0.59, -0.37]).

MANOVA yielded that PS outcomes significantly differed between the groups to a medium extent (partial η^2 x100= 53.7%). The Scolio group's mean center of force (43.1%), Range COM Y (37.5%), Range COM X (32.9%), and Length of CoP displacement (16%), were lower than those in the Control group (Table 2).

DISCUSSION

The present study investigated the differences in postural stability between adolescents with scoliosis and typically developed peers. The results indicated that adolescents with scoliosis exhibited significantly lower postural stability in terms of the Center of pressure (COP) and Length function of surface (LFS) compared to their typically developed peers (p<0.001). Moreover, adolescents with scoliosis demonstrated higher Anterior-Posterior displacement of COP (p<0.001) and Medio-Lateral displacement of COP (p<0.001) compared to typically developed peers, indicating lower levels of postural stability.

Table 1 Characteristics of the participants

		N	MIN	Max	AS	SD	p
Age (years)		75	15	19	17.15	1.31	
	Control	40	15	19	17.50	1.24	0.10
	Scolio	35	15	19	16.74	1.29	
Body height (cm)		75	158.4	193.6	177.31	8.85	
	Control	40	158.4	192.4	176.03	8.81	0.62
	Scolio	35	161.4	193.6	178.76	8.80	
Body mass (kg)		75	48.4	98.6	70.74	11.13	
	Control	40	48.4	92.2	69.25	10.42	0.12
	Scolio	35	55.6	98.6	72.44	11.81	
Body Mass Index		75	17.2	30	22.43	2.54	
	Control	40	17.2	30	22.30	2.59	0.64
	Scolio	35	17.6	28.4	22.57	2.52	
Scoliosis Index		75	1.82	3.01	2.35	0.34	
	Control	40	1.82	2.65	2.13	0.23	0.00
	Scolio	35	2.09	3.01	2.61	0.25	

Legend: Min – Minimum; Max – Maximum; As – arithmetic mean; Sd – standard deviation; p – probability value; *, significant differences at $p < 0.05$.

Table 2 Group differences in Double leg static stability test

Outcomes	Group	AS±SD	f	p
Body center of pressure (cm)	Control Scolio	0.52 ± 0.32 1.52 ± 0.76	57.06	0.00
Length function of surface	Control Scolio	0.29 ± 0.06 0.37 ± 0.10	15.04	0.00
Range COP Y (cm)	Control Scolio	0.98 ± 0.3 1.8 ± 0.71	45.40	0.00
Range COP X (cm)	Control Scolio	0.62 ± 0.24 1.07 ± 0.38	37.20	0.00
			F	P
MANOVA			20.325	0.000

Data is presented as AS ± SD. Abbreviations: F, F-test statistics; p, p value of differences between groups

The findings of this study are consistent with previous research that has shown that individuals with scoliosis have diminished postural control and stability (Dufvenberg et al., 2018; Karimi et al., 2016; Wiernicka & Kotwicki, 2019). This is possibly due to the altered alignment of the spinal column and the resultant changes in muscle activation and proprioceptive feedback (Blecher et al., 2018). The period of rapid growth in puberty is a critical stage for the development of the neuromuscular system. During this period, various factors, some of which may be, developmental, or environmental affect the developing body, particularly the spinal region, have the potential to cause scoliosis, which is characterized by altered body symmetry and decrease stability.

Adolescents with scoliosis face unique challenges in maintaining postural stability, as spinal curvature disrupts the normal symmetry and biomechanics required for balance. Studies show that postural instability in scoliosis patients manifests as increased sway, a response to the body's attempts to compensate for structural imbalances (Radwan, Ibrahim, & Mahmoud, 2021). The severity of these balance issues can be influenced by the direction and location of the spinal curve, where asymmetry leads to disproportionate weight distribution, creating additional strain on balance mechanisms (Jung & Kim, 2017). Furthermore, comparative analyses indicate that children with scoliosis have greater instability and control difficulties than their typically developing peers. Increased sway parameters in scoliosis patients suggest a compromise in their ability to manage center-of-gravity shifts effectively, likely due to altered proprioceptive feedback from the spinal deviations (Valles et al., 2009). This condition not only affects static balance but also impacts dynamic postural control, which is essential for tasks involving movement and adaptability. As Amaricai and Sandu (2023) note, postural deviations in scoliosis patients impair dynamic balance, with severity varying by curvature, reinforcing the need for tailored interventions to address these unique challenges.

The greater displacement in both the anterior-posterior and medio-lateral directions seen in this study may also be attributed to the compensatory mechanisms employed by individuals with scoliosis to maintain their balance. Changes in spinal alignment and muscle activation patterns that are commonly associated with scoliosis are thought to contribute to the reduced postural stability observed in individuals with this condition (Osuka & Sudo, 2022). Research indicates that individuals with scoliosis exhibit greater COP excursions and speeds compared to their non-scoliotic counterparts, particularly in the medio-lateral direction, where they demonstrate a constrained and less adaptable control strategy (Gruber et al., 2011; Silferi et al., 2004). However, while scoliosis affects balance, some studies suggest that individuals may develop compensatory strategies to maintain stability, indicating a complex interplay between structural deformity and functional adaptation (Gruber et al., 2011).

The results of this study have important implications for the clinical management of scoliosis. The assessment of postural stability could aid in identifying individuals with scoliosis who are at a higher risk of falls and subsequent injuries. Furthermore, interventions that target the improvement of postural stability could help mitigate the negative effects of scoliosis on individuals' balance, functional mobility, and quality of life. Future research should explore the effectiveness of such interventions in improving postural stability and reducing the risk of falls in individuals with scoliosis.

The findings highlight the importance of assessing postural stability in individuals with scoliosis and the potential benefits of interventions that aim to improve postural stability in this population. However, the study did not control for potentially confounding variables such as age, sex, or physical activity levels, which could have influenced the results. Moreover, the sample size of this study was relatively small, which may limit the generalizability of the findings. It is possible that a larger sample size might reveal different results or provide more robust evidence. Another limitation is that the Scoliosis index did not indicate in which region of the spine participants have a deviation and this study did not indicate the type of scoliosis.

CONCLUSION

In conclusion, the observed correlation between scoliosis and reduced postural stability offers valuable insights with broad clinical implications. Adolescents with scoliosis show marked deficits in postural stability indicators—such as increased center of pressure displacement in both anterior-posterior and medio-lateral directions—pointing to the influence of spinal curvature on balance and neuromuscular control mechanisms. These findings align with prior research, supporting the notion that spinal asymmetry and altered muscle activation impact proprioception and increase sway.

These results underscore the importance of assessing postural stability in scoliosis patients to identify those at heightened risk of falls, and they emphasize the potential for targeted interventions to mitigate balance deficits. Tailored stability-focused interventions could enhance the patients' functional mobility and quality of life by reducing balance-related complications. Future studies should expand on these findings by exploring diverse assessment techniques and by evaluating specific interventions, such as Schroth exercises, for their efficacy in improving stability. Furthermore, addressing confounding factors such as age, sex, and physical activity levels in larger cohorts will enhance the robustness and generalizability of results. As research advances, a more nuanced understanding of scoliosis and stability will inform comprehensive approaches to managing this complex condition, ultimately guiding better clinical practices and patient outcomes.

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RAZLIKE U POSTURALNOJ STABILNOSTI IZMEĐU ZDRAVIH I ADOLESCENATA SA SKOLIOZOM

Ova studija je imala za cilj da istraži razlike u posturalnoj stabilnosti između adolescenata sa skoliozom i zdravih ispitanika. Istraživači su sproveli studiju na uzorku od 75 učesnika (53 dečaka, 22 devojčica) podeljenih u dve grupe. Prvu grupu činilo je 35 adolescenata sa skoliozom (starosti 17,15 ± 1,31 godina; BMI 22,3 ± 2,6), dok je drugu grupu činilo 40 zdravih ispitanika (starosti 16,74 ± 1,3 godine; BMI 22,6 ± 2,5 žene). CONTEMPLAS 3D Kinematički sistem merio je nivo skolioze, dok su Force Plate i test stajanja sa sa dve noge otvorenih očiju koristio za merenje parametara posturalne stabilnosti. Adolescenti sa skoliozom su pokazali značajno lošiju posturalnu stabilnost u varijabli koja opisuje kretanje centra pritiska (p<0,001) i funkciji površine oslonca (p<0,001) od zdravih ispitanika. Takođe, adolescenti sa skoliozom su imali veće oscilacije kretanja centra pritiska u smeru napred-nazad (p<0,001) i smeru levo-desno (p<0,001) u poređenju sa grupom zdravi ispitanika, što ukazuje na niže nivoe posturalne stabilnosti. Ova studija sugeriše da adolescenti sa skoliozom imaju nižu nivo balansa i posturalne kontrole od ispitanika čiji je kičmeni stub razvijen normalno. Nalazi naglašavaju važnost identifikovanja i predlaganja tretmana za optimizaciju zdravlja adolescenata sa utvrđenom skoliozom.

Ključne reči: *skolioza, adolescenti, 3d analiza, posturalna kontrola.*