Original paper

Sensory integration, balance deficits, and scoliotic posture in boys

Integracja sensoryczna oraz deficyty równowagi i postawa skoliotyczna u chłopców

Jacek Wilczyński[1], Natalia Habik-Tatarowska[2]

[1]Department of Physical Education, Posturology and Gerontology, *Collegium Medicum*, Jan Kochanowski University, Kielce, Poland
Head of the Department: Prof. Jacek Wilczyński MD, PhD
[2]*Collegium Medicum*, Jan Kochanowski University, Kielce, Poland Country
Head of the Collegium: Prof. Marianna Janion MD, PhD

Medical Studies/Studia Medyczne 2022; 38 (4): 330–335
DOI: https://doi.org/10.5114/ms.2022.122390

Key words: scoliotic posture, Diers Formetric III 4D, Clinical Test of Sensory Integration and Balance.

Słowa kluczowe: postawa skoliotyczna, Diers Formetric III 4D, Kliniczny test integracji sensorycznej i równowagi.

Abstract

Introduction: Proper development of posture is based on the integrative function of the brain and the body's ability to adapt to the changing conditions of the external environment. Disturbances in the processing of sensorimotor integration processes prevent the correct course of development of body posture. The processes of sensorimotor integration lead to the formation of appropriate postural tension, organization of alternating innervation, and the generation of correct postural and movement patterns. Scoliotic posture means the tendency of the spine axis to deviate from a straight line, which is associated with incorrect body posture. The postural system is based on the functioning of 3 senses: the balance system, vision, and proprioception.
Aim of the research: To assess the relationship between sensory integration and balance deficits as well as scoliotic posture in boys.
Material and methods: The study comprised 65 ten-year-old boys. Body posture was assessed using the Diers Formetric III 4D optoelectronic method. The Clinical Test of Sensory Integration and Balance (CTSIB), carried out on the Biodex Balance System platform, was used to analyse deficits in sensory integration and balance.
Results and conclusions: There was a significant correlation between the deficits of sensory integration and balance, as well as the angle of curvature of the spine, pelvic obliquity, and the direction of spine curvature. With increasing angle of curvature of the spine and pelvic obliquity, deficits in sensory integration and balance also worsened. Sensory integration and balance deficits significantly influence the formation of a scoliotic attitude.

Streszczenie

Wprowadzenie: Prawidłowy rozwój postawy opiera się na integracyjnej funkcji mózgu, czyli zdolności przystosowania się organizmu do zmieniających się warunków środowiska zewnętrznego. Zaburzenia przetwarzania procesów integracji sensomotorycznej uniemożliwiają prawidłowy przebieg rozwoju postawy ciała. Przetwarzanie procesów integracji sensomotorycznej prowadzi do kształtowania odpowiedniego napięcia posturalnego, organizacji unerwienia naprzemiennego oraz wytworzenia prawidłowych wzorców posturalnych i ruchowych. Postawa skoliotyczna oznacza tendencję osi kręgosłupa do odchylania się od linii prostej, co wiąże się z występowaniem nieprawidłowej postawy ciała. System posturalny opiera się szczególnie na funkcjonowaniu trzech zmysłów, tj. układu równowagi, wzroku oraz propriocepcji.
Cel pracy: Ocena związku między zaburzeniami integracji sensorycznej a deficytami równowagi oraz postawą skoliotyczną u chłopców.
Materiał i metody: Badaniami objęto 45 chłopców w wieku 10 lat. Postawę ciała oceniano metodą optoelektroniczną Diers Formetric III 4D. Do analizy deficytów integracji i równowagi sensorycznej wykorzystano *Kliniczny test integracji i równowagi sensorycznej* (CTSIB), który został przeprowadzony na platformie Biodex Balance System
Wyniki i wnioski: W badaniach zaobserwowano istotną zależność pomiędzy występowaniem deficytów integracji sensorycznej i równowagi oraz kątem skrzywienia kręgosłupa, kierunkiem skrzywienia i nachyleniem miednicy. Dla wszystkich podtestów CTSIB najważniejszym predyktorem był kąt skrzywienia kręgosłupa. Wraz ze wzrostem tego kąta narastały deficyty przetwarzania procesów integracji sensorycznej i równowagi. Deficyty integracji sensorycznej i równowagi znacząco przyczyniają się do powstawania postawy skoliotycznej.

Introduction

Scoliotic posture means a tendency of the spinal axis to deviate from a straight line, which is associated with inappropriate posture. We deal with scoliotic posture when pelvic skewness, lateral deviation, and spinal rotation are disturbed. All spontaneously developing cases of scoliosis, even those that are idiopathic, are, at the very beginning, low-grade curvatures, i.e. scoliotic posture, and only with time, usually during the so-called growth spurt, are their actual development tendencies revealed. Therefore, scoliotic posture should not be underestimated. When considering the subject of the pathogenesis and pathomechanics of the occurrence of scoliotic attitudes, 2 groups of views can be distinguished. According to one of the views, the passive support apparatus of the spine is responsible for the changes, namely the so-called "nucleus of curvature" contained in the vertebrae, as well as in the intervertebral discs or ligaments. However, the second view concerns the problem of muscle imbalance, which arises as a result of changes in the nervous system, including in the spinal cord, brain, and peripheral nerves [1].

In the aetiology of scoliotic posture and scoliosis, more and more attention is paid to discrete neurological changes. From an aetiopathogenetic point of view, these changes are merely a symptom, an external expression of an undiagnosed pathology. The concept of multifactorial, including genetically conditioned discrete changes in the central nervous system, causing dysfunctions in the postural system, has been gaining more and more supporters [2].

Proper postural development is based on the integrative function of the brain, i.e. the body's ability to adapt to the changing conditions of the external environment. Deficiencies in sensorimotor integration and balance affect the child's natural development, preventing the proper course of his/her body posture. Adequate stimulation of the nervous system by stimuli coming from the sensory systems is essential for proper psychomotor development and body posture. With proper sensorimotor integration, correct postural tension, appropriate organisation of reciprocating innervation, and the formation of correct postural as well as motor patterns then occur. All of the elements mentioned above are interconnected and integrated, creating a properly functioning anti-gravity system. This system allows for the harmonious and effective postural development of a child. Proper development of the anti-gravity system is the basis for all spheres of psychomotor development, i.e. posture, locomotion, eye-hand coordination, social contact, and speech [3].

The postural system is based on the functioning of 3 main senses: balance, vision, and proprioception. These systems, together with hearing and touch, lay the foundations for the development of complex functions, creating the first level of sensory integration. Due to the interaction of the above-mentioned systems, a properly functioning postural system can develop new skills that transform into psychomotor experiences [4].

Sensory integration processes play a significant role in maintaining proper postural stability, which affects the development of body posture. The task of the central nervous system is to organise sensory information to produce appropriate adaptive responses. Maintaining balance of the body in an upright position requires precise motor coordination, which is controlled by the central nervous system, and manifests itself in the form of an executive corrective response of the detected disturbance. This process consists of stimulating the work of motor units in specific temporal and spatial relationships. Deficits in the regulation and processing of sensory procedures may adversely affect the maintenance of vertical body posture and, to a large extent, can also impair postural stability, thus, leading to the formation of scoliotic posture [5].

Aim of the research

The aim of the study was to assess the relationship between sensory integration and balance deficits, as well as scoliotic posture in boys.

Material and methods

The study included 45 ten-year-old boys. The research was carried out in 2019 at the Posturology Laboratory of Jan Kochanowski University in Kielce (Poland). Prior to the trial, all the subjects provided informed consent for inclusion in the trial. The study was performed in accordance with the regulations of the Declaration of Helsinki. The University Bioethics Committee – Jan Kochanowski University in Kielce (Resolution No. 37/2018) provided approval of the research protocol.

Body posture and sensorimotor integration and balance were studied simultaneously. Body posture was assessed using the Diers Formetric III 4D optoelectronic method. It allows photogrammetric registration of the back surface using the raster stereography process. Based on the obtained data, a precise, 3-dimensional model of the back surface is created.

The Diers Formetric III 4D method is a contactless, automatic, and above all non-radiation method of measuring body statics, the purpose of which is to reduce the load that is caused by X-rays. The device allows a 3-dimensional diagnosis of scoliotic posture and postural defects, to assess spine mobility, analyse the shortening in the length of the limbs in the oblique position of the pelvis, and to control the course of the disease, among others. The examination consists of setting the child in a position of habitual posture. The measurement was carried out via the

Table 1. Variables of tested parameters

Variables		X	SD		V
Angle of curvature of the spine [°]		11.14	2.90		26.07
Lateral deviation [mm]		1.68	2.45		145.48
Pelvic obliquity [mm]		3.08	3.53		114.42
Pelvic rotation [°]		2.97	0.96		32.40
Location and direction of curvature of the spine					
Variables	**Thoracic**	**Lumbar**	**Thoracolumbar**	**Left-sided curvature**	**Right-sided curvature**
	9	15	21	21	24

X – arithmetic average, SD – standard deviation, V – coefficient of variation.

Table 2. The Clinical Test of Sensory Integration and Balance in boys with scoliotic posture

Variables	X	SD	V
CTSIB Open Eyes, Hard Surface	1.76	0.76	43.05
CTSIB Closed Eyes, Hard Surface	2.26	1.10	48.59
CTSIB Open Eyes, Soft Surface	2.84	1.28	45.24
CTSIB Closed Eyes, Soft Surface	3.30	1.32	40.12

DICAM program using the 'Average' test mode, which consists of taking a sequence of 12 photos, which, by creating an average value, reduced posture variance and thus improved the clinical value of the examination. The following parameters describing the posture of the child's body were analysed: angle of curvature of the spine (°), lateral deviation (mm), direction of curvature (mm), pelvic obliquity (mm), and pelvic rotation (°). Scoliotic posture was diagnosed when the pelvic skewness was within the range of 1–4 mm, lateral deviation was 1–4 mm, and the rotation pelvic was in the numerical range 1–4°. In cases for which these 3 requirements were not met, it was assumed that neither scoliotic posture was present [2, 6].

The Clinical Test of Sensory Integration and Balance (CTSIB) on the Biodex Balance System platform was used to analyse the deficits in sensory integration and balance. A diagram with 4 conditions was used: eyes open, hard surface, eyes closed hard surface, eyes open soft surface, and eyes closed soft surface. During the test conducted with open eyes on a hard surface, the integration of visual, vestibular, and proprioceptive elements was studied. The test performed with closed eyes on a hard surface examined the integration of vestibular and proprioceptive elements. The test with open eyes and on a soft surface was studied for the integration of visual and vestibular elements. However, during the test conducted with closed eyes and on a soft surface, the function of the vestibular elements was examined. All children were informed about how the Biodex balance System worked before going onto the device. During the eyes closed test, assistance from a physical therapist was provided in case of loss of balance. Before the test was performed, the child performed 3 preliminary attempts. The results are presented in relation to the upper limit of normal reference values. The higher the deflection index score, the more unstable the patient was. Complete instability, meaning having to grab onto the aid or stop the test, is referred to as a fall in the test results. During the m-CTSIB test, the following are measured: Deflection Coefficient and Stability Coefficient. The Variation Factor is the standard deviation of the Stability Index. The higher the Variation Index, the more unstable the person was during the test. The Stability Factor is the average distance from the centre of the platform.

Statistical analysis

The normality of distributions was checked using the Shapiro-Wilk test. Multi-variable regression models and ANOVA were applied. The homogeneity of variance regarding the variables was tested using Levene's test.

Results

The mean value of the angle of curvature of the spine was (x = 11.14°); lateral deviation (x = 1.68 mm); pelvic obliquity (x = 3.08 mm), and pelvic rotation (x = 2.97°) (Table 1). There were 9 thoracic curvatures; 15 lumbar; while the most frequent were thoracolumbar, equalling 21. The total of left-sided curvatures 21, while 24 were right-sided (Table 1). CTSIB open eyes, hard surface was (x = 1.76°); CTSIB closed eyes, hard surface (x = 2.26°); CTSIB open eyes, soft surface (x = 2.84°); and CTSIB closed eyes, soft surface (x = 3.30°) (Table 2).

For all CTSIB subtests, the most important predictor was the angle of spine curvature. The regression function in the open eyes, hard surface sub-test indicated that if the spine curvature angle increased by one unit, the CTSIB score increased by 0.07 ($p < 0.01$). For the closed eyes, hard surface sub-test, when the angle of curvature of the spine increased by one unit, the CTSIB score increased by 0.09 ($p < 0.02$). For the eyes open, soft surface sub-test, when the angle of curvature of the spine increased by one unit, the CTSIB score increased by 0.15 ($p < 0.01$). For the closed eyes, soft surface sub-test, when the angle of curvature of the spine increased by one unit, the CTSIB score increased by 0.18 ($p < 0.01$) (Table 3).

The regression function in the open eyes, hard surface sub-test indicated that the most important predictor was the direction of curvature ($p < 0.04$), while in the eyes closed, hard surface sub-test, the direction of curvature was also of significant importance ($p < 0.03$), as well as pelvic obliquity (°) ($p < 0.04$). On the other hand, for the eyes open, soft surface sub-test, the most important predictor was curvature direction ($p < 0.04$), and for the eyes closed, soft surface sub-test, the most significant predicator was curvature direction ($p < 0.02$), and pelvic skewness (°) ($p < 0.04$) (Table 4).

Table 3. CTSIB regression analyses in sub-tests and scoliotic variables

Variables	Beta	*B*	*P*-value
CTSIB Open Eyes, Hard Surface:			
Absolute term		0.18	0.88
Angle of curvature of the spine [°]	0.33	0.07	0.01
R_2 = 0.89			
CTSIB Closed Eyes, Hard Surface:			
Absolute term		2.10	0.01
Angle of curvature of the spine [°]	0.32	0.09	0.02
R_2 = 0.91			
CTSIB Open Eyes, Soft Surface:			
Absolute term		1.60	0.10
Angle of curvature of the spine [°]	0.43	0.15	0.01
R_2 = 0.94			
CTSIB Closed Eyes, Soft Surface:			
Absolute term		1.70	0.06
Angle of curvature of the spine [°]	0.51	0.18	0.01
R_2 = 0.92			

Beta – standardized regression coefficient, B – non-standardized regression coefficient, p – significance level, R_2 – coefficient of determination.

Table 4. CTSIB regression analyses in sub-tests and the remaining scoliotic variables

Variables	Beta	*B*	*P*-value
CTSIB Open Eyes, Hard Surface:			
Absolute term		0.61	0.16
Direction of curvature	0.25	0.38	0.04
R_2 = 0.89			
CTSIB Closed Eyes, Hard Surface:			
Absolute term		0.32	0.61
Direction of curvature	0.30	0.67	0.03
Pelvic obliquity [mm]	0.34	0.15	0.04
R_2 = 0.89			
CTSIB Open Eyes, Soft Surface:			
Absolute term		0.93	0.20
Direction of curvature	0.30	0.77	0.03
R_2 = 0.90			
CTSIB Closed Eyes, Soft Surface:			
Absolute term		1.25	0.11
Direction of curvature	0.27	0.72	0.02
Pelvic obliquity [mm]	0.32	0.12	0.04
R_2 = 0.90			

Discussion

In an aetiopathogenetic understanding, scoliotic posture and scoliosis are merely symptoms, an external expression of an undiagnosed pathology, that may appear in any section of the spine and at any age of the child [5]. Although they are clearly a deformation of posture, they are also an effect of the body's compensatory abilities, allowing the head and shoulder girdle to remain positioned above the pelvis. The final shape of the trunk is the result of deforming processes and the compensatory reaction, thanks to which the body maintains general orientation of at the expense of a huge disturbance to its own form. Scoliotic posture, appearing in the conducted research, is the result of deficits to the processing of sensory information. The correct integration of sensory-related processes, understood as the proprioceptive-vestibulo-visual complex, allows the force of gravity to be counteracted to an extent adequate for the current needs and possibilities, determined by the degree of central nervous system maturation [7].

Maintaining balanced body posture is a motor activity that requires precise cooperation of all body segments. The central nervous system acts as an intermediary in this recording and supervises the processing of sensory signals, which requires constant cooperation of the following sensory systems: proprioceptive, vestibular, visual, and auditory, which record the deviation of the centre of mass from the set point value to the executive system. A human maintains balance through the work of skeletal muscles under the control of the nervous system [8]. Postural tension is a form of perfect, automatic coordination between the stability and mobility of individual body segments depending on the type of performed physical activity. The degree of development concerning postural tension affects the type of antigravity action that forms the vestibular-proprioceptive complex. Based on the received sensory information, the nervous system recruits motor units, selects the thresholds of individual muscles, determines the rules of their coordination, and influences the nature of movements through appropriate stimulation and inhibition. The peak of functional possibilities is the full automation of adopting and maintaining a standing position, ensuring the optimal positioning of body segments, referred to as stereotypical body posture. The development of postural stability primarily depends on the quality of the anti-gravity system. The possibility of adopting higher and higher body positions is ensured by the compensatory anti-gravity system [9].

Body posture was assessed using the Diers Formetric III 4D optoelectronic method. Taking into account the anatomical and biomechanical assumptions of the model, it was possible to calculate fixed anatomical points, spinal curvatures, and parameters of the spatial form of the trunk and pelvis. The X-ray image provides direct and visualised information about the form and deviations from the norm, but only in 2-dimensional projection. In addition, the disadvantage of the X-ray examination is the harmfulness of radiation, which makes it impossible to take control images at shorter intervals.

In the conducted research, the most important predictor for all sub-tests of the CTSIB was spinal curvature angle, which means that the greater the angle of curvature, the greater the disturbance of sensory integration processes. The conducted research also shows that the direction of pelvic curvature and the oblique position of the DL-DR play a significant role in the development of scoliotic posture. The higher the parameters, the greater the degree of development of such posture.

The results of the author's own research are confirmed in the study conducted by Simoneau *et al*., who found that balance control depends on the availability and integrity of sensory signals, as well as on the ability of balance control mechanisms [10].

Also, according to Kutzner-Kozińska, maintaining correct body posture and spatial orientation depends on feedback, processing sensory information, and interpreting information from 3 sources: deep feeling receptors sensitive to stretching and tension, receptors of the balance organ – ensuring body balance when there is a change in centre of gravity, and the visual receptors responsible for reactions – enabling the adoption of correct posture after confronting the external environment. The basic condition for ensuring the balance of the body is the balance of the individual centre of gravity as part of the overall balance. If even one segment shifts its centre of gravity, the overall balance is disturbed, causing compensatory displacement of other segments [11].

According to Luo *et al.*, postural stability, i.e. proprioceptive-vestibular activation, is related to the forces of inertia acting on the body and the inertial features of body segments [12].

Khanal *et al.* also demonstrated a weaker ability to maintain balance in people with scoliotic posture compared to individuals demonstrating with normal posture [13].

Klavina and Galeja assessed the relationship between body posture and static balance among children with sensorimotor deficits. The results showed that the examined children had the highest number of abnormalities in both the sagittal and frontal planes. In the case of analysing balance reactions in the sagittal plane, the greatest instability in the open and closed eyes test was observed in children with closed eyes [14].

Nault *et al.* pointed to significant correlations between proprioceptive-vestibular disorders and postural defects [15].

In their research, Ludwig also demonstrated a relationship between vestibulo-proprioceptive deficits and posture parameters in children as well as adolescents [16].

On the other hand, Bourelle *et al*., assessed the relationship between body posture and static balance among children with sensorimotor deficits. The results indicated that children with sensorimotor deficits were diagnosed with the highest number of abnormalities in both the sagittal and frontal planes compared to other groups. In the analysis of balance reactions in the sagittal plane, the greatest instability in the open and closed eye test was observed in children with closed eyes [17]. In the research carried out by Walicka-Cupryś *et al.*, it was noted that increasing the angle of thoracic kyphosis reduced the value of stabilometric parameters, indicating the functioning of the vestibular-proprioceptive complex in the sagittal plane for both eyes open and eyes closed tests. Moving the trunk backwards causes a shift in the load on the forefoot, especially on the left foot, regardless of the flow of sensory information and deterioration of stabilometric parameters. At the same time, increasing anterior pelvic tilt causes increased deflections in the sagittal plane as well as loading the left forefoot. The authors also found that the asymmetric position of the pelvis, with the right side placed higher, unloads the right side. Conversely, a greater load on the left side is observed especially when maintenance of body posture is based only on information coming from deep feeling. In addition, it was noted that left-sided scoliosis in the studied children increased deflections in the frontal plane, which may have implications for maintaining postural stability in conditions of disturbed sensory information flow [18].

Conclusions

There was a significant correlation between the deficits of sensory integration and balance, as well as the angle of curvature of the spine, pelvic obliquity, and the direction of spine curvature. With increasing angle of curvature of the spine and pelvic obliquity, deficits in sensory integration and balance also worsened. Sensory integration and balance deficits significantly influenced the formation of a scoliotic attitude.

Conflict of interest

The author declare no conflict of interest.

References

1. Doménech J, Tormos JM, Barrios C, Pascual-Leone A. Motor cortical hyperexcitability in idiopathic scoliosis: could focal dystonia be a subclinical etiological factor? Eur Spine J 2010; 19: 223-230.
2. Wilczyński J, Karolak P. Correlations between electromyographic amplitude of the erector spinae and the location, direction and number of spinal curvatures in young school children. Medical Studies 2021; 37: 49-57.
3. Wilczyński J, Habik N, Bieniek K, Janecka S, Karolak P, Wilczyński J. Body posture and balance reactions in girls and boys aged 12-15 years. Modern Appl Sci 2018; 12: 89-97.
4. Wilczyński J, Habik N, Wypych Ż. Effect of sensory integration techniques on muscle tone in children after prenatal exposure to alcohol. J Educ Health Sport 2018; 8: 347-358.
5. Allen S, Casey J. Developmental coordination disorders and sensory processing and integration: incidence, associations and co-morbidities. Br J Occup Ther 2017; 80: 549-557.
6. Harzmann HC. Optischer Gipsabdruck hilft bei der Rückenanalyse Süddeutscher Orthopädenkongress. Kongressausgabe 1999; 2: 15.
7. Antoniadou N, Hatzitaki V, Stavridis S. Verticality perception reveals a vestibular deficit in adolescents with idiopathic scoliosis. Exp Brain Res 2018; 236: 1725-1734.
8. Bodison SC, Parham LD. Specific sensory techniques and sensory environmental modifications for children and youth with sensory integration difficulties: a systematic review. Am J Occup Ther 2017; 72: 7201190040p1--7201190040p11.
9. D' Hondt E, Deforche B, De Bourdeaudhuij I, Gentier I. Postural balance under normal and altered sensory conditions in normal-weight and overweight children. Clin Biomech 2011; 26: 84-89.
10. Simoneau M, Richer N, Mercier P. Sensory deprivation and balance control in idiopathic scoliosis adolescent. Exp Brain Res 2006; 170: 576-582.
11. Kutzner-Kozińska M. Proces korygowania wad postawy. Akademia Wychowania Fizycznego, Warszawa 2001.
12. Luo HJ, Lin SX, Wu SK, Tsai MW, Lee SJ. Comparison of segmental spinal movement control in adolescents with and without idiopathic scoliosis using modified pressure biofeedback unit. PLoS One 2017; 12: e0181915.
13. Khanal M, Arazpour M, Bahramizadeh M, Samadion M, Hutchin SW, Kashani RV. The influence of thermoplastic thoraco lumbo sacral orthoses on standing balance in subjects with idiopathic scoliosis. Prosthet Orthot Int 2016; 40: 460-466.
14. Klavina A, Galeja Z. Relationship between postural alignment in standing by photogrammetry and static balance in children with disabilities. Society. Integration. Education. Proccedings of the International Scientific Conference 2017; 3: 359-367.
15. Nault ML, Allard P, Hinse S, Le Blanc R, Caron O, Labelle H, Sadeghi H. Relations between standing stability and body posture parameters in adolescent idiopathic scoliosis. Spine 2002; 27: 1911-1917.
16. Ludwig O. Interrelationship between postural balance and body posture in children and adolescents. J Physl Ther Sci 2017; 29: 1154-1158.
17. Bourelle N, Dey D, Sifaki-Pistolla, Berge B, Gautheron V. Computerized static posturography and laterality in children. Influence of age. Acta Bioeng Biomech 2017; 19: 129-139.
18. Walicka-Cupryś K, Przygoda Ł, Czenczek E, Truszczyńska A, Drzał-Grabiec J, Zbigniew T, Tarnowski A. Balance assessment in hearing-impaired children. Res Dev Disabil 2014; 35: 2728-2734.

Address for correspondence

Prof. **Jacek Wilczyński**
Department of Physical Education,
Posturology and Gerontology
Collegium Medicum
Jan Kochanowski University
Kielce, Poland
E-mail: jwilczynski@onet.pl