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Body Posture and Balance Reactions in Girls and Boys Aged 12-15 Years

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Abstract

The objective of the study was analysis of the relationship between body posture and balance reactions in girls and boys aged 12-15 years. The study covered 503 girls and boys aged 12-15 attending randomly selected Primary School, and Junior High School in Poland. Body posture was examined by means of spatial photogrammetry using the projection moire effect. Postural reations were tested on an R50300 Cosmogamma platform by Emildue. In the saggital plane, 297 (59.05%) correct postures and 206 (40.95%) postural defects were observed. In the frontal plane, there were only 3 (0.60%) correct postures, 238 (47.32%) scoliotic postures, 262 (52.09%) residual scoliosis, and 46 (9.15%) idiopathic scoliosis >10°. A significant relationship was observed between anterior-posterior speed with closed eyes and lateral curvature of the spine, both with defects in the saggital plane and without these defects (p=0.044). Lateral curvatures of the spine and defects in the saggital plane are accompanied by a clear increase in the anterior-posterior speed. A significant relationship was found between the mean loading point Y with open eyes and lateral curvature of the spine, both with postural defects and without these defects (p=0.043). This parameter was the highest among the defects in the saggital plane, without lateral curvature of the spine. A significant relationship was also observed between the mean sway X (p=0.009) and the mean sway Y in the test with eyes open (p=0.046), and defects in the saggital plane, both with lateral curvature of the spine and without these defects.

Keywords: body posture defects, scoliosis, balance reactions, spatial photogrammetry, Cosmogamma platform by Emildue

1. Introduction

The causes of the development of postural defects and scoliosis have not been explained to date. There is no commonly accepted theory of etiopathogenesis of scoliosis. There is a consensus that idiopathic scoliosis is conditioned by multiple factors. Comprehensive relevant literature describes abnormalities at the level of systems, organs, tissues, cells and genes (CHD7), without prejudging their primary or secondary character. Recently, a mathematical theory of chaos has become popular in explaining the phenomenon of scoliosis. This theory assumes a change in the biological parameters of the body which is imperceptible to the contemporary researcher, and causes a cascade of slow, but consistent changes. Many physiological systems, including those which are postural, are partly chaotic systems (Gao et al, 2007). While aiming at an explanation of the etiopathogenesis of postural defects and curvatures of the spine, some theories are combined and new concepts created. Body posture defects and scoliosis are disorders related to disturbed static, adjustment reactions, as well as efficiency of balance reactions, which overlap onto the consciously performed programme of voluntary movements. Body posture is conditioned by many factors, primarily central regulation, the quality of which is associated with the posture habit gradually developing during ontogenesis. A normally functioning posture system contains mutually dependent components: normal postural muscle tone, correct reciprocal innervation, correct sensory information, correct postural reflexes and motor patterns. Postural defects are the consequence of sensory deficits, persistent primitive reflexes and spontaneous compensation of postural hypotonia. In the case of sensory deprivation, persistent primitive reflexes and decreased tone of postural muscles, posture habit does not develop normally, and children compensate for deficits by adjusting individual parts of the body in a way that facilitates functioning in conditions of gravity (Burwell, Dangerfield, Moulton & Anderson, 2008; Burwell, Dangerfield & Freeman, 2008; Burwell et al, 2009).The objective of the study was to analyze the relationship between body posture and balance reactions in girls and boys aged 12-15.

2. Method

2.1 Participant (Subject) Characteristics

The study counted 503 girls and boys aged 12-15, randomly selected from Primary School No.13 and Junior High School No. 4 in Starachowice (Poland), including 247 (49.11%) girls and 256 (50.89%) boys – 60 girls aged 12 (24.29%); 60 aged 13 (24.29%), 65 aged 14 (26.32%) and 62 aged 15 (25.10%); 65 boys aged 12 (25.39), 61 aged 13 (23.83%), 60 aged 14 (23.44%) and 70 aged 15 (27.34%) (Tab.1). The study was conducted from November to December 2005.

2.2 Research Design

Body posture was examined by means of spatial photogrammetry using the **projection Moiré** effect. This method consists in the use of refraction of a light beam passing through the raster. The obtained image of the back of the examined person is received by an optical system with a camera, and subsequently transmitted to an analogue monitor and computer. Thanks to an appropriate card and software, the computer performs proper analysis of posture. The measurement site consisted of a computer with an installed Frame Grabber card, with a monitor and printer, and a projection-reception device with CCD/f=8mm camera and an analogue monitor. On the back of the examined person, selected anthropometric points were indicated using a marker, i.e. spinous processes from C_7 to S_1, acromions, low blade angles and posterior superior iliac spines. Subsequently, the examined person assumed habitual posture, in the determined place, with his/her back to the device, at a distance of 3.2 m. Fringes were projected onto the back, and the setting of lens sharpness of the reception projector allowed to obtain the Moiré projection effect displayed on the monitor screen. The measurement and adjustment of image sharpness were performed automatically. The image was recorded, and further analysis took place without the participation of the examined person. Entering the image and indication of proper reference points with the mouse was followed by their processing for each plane of the body. The device allowed evaluation of the posture in three planes: sagittal, frontal and transverse. For this purpose, length, depth and angle parameters were determined. In this way, each selected segment of the spine was measured, and proper indicators calculated reflecting the inter-segmental relations. Measurements of the subsequent parameters of body planes also provided information concerning the spatial location of the entire spine and its individual segments. The computer determined a three-dimensional image of the back, and precisely analyzed 45 parameters. Selected angular and linear parameters, symmetries in the sagittal and frontal planes were used in the analysis (Wilczyński, 2006). Body postures in the sagittal plane were divided based on the Polish typology by Wolański into correct postures: (kyphotic type 1 (K_1), balance type 2 (R_2), lordotic type 1 (L_1), and postural defects (kyphotic types 2 and 3 (K_2), lordotic 2 and 3 (L_2) and flat back (R_1P) (Wolański, 1964). Postures in the frontal plane were divided into correct posture (angle of primary curvature = 0°), scoliotic posture (1-5°), residual lateral curvature of the spine (6-10°) and idiopathic curvature of the spine (>10°).

2.3 Measures and Covariates

Balance reactions were tested on an R50300 Cosmogamma platform by Emildue. The standard Romberg test was performed in free standing position. This consisted of two subsequent trials lasting 30 seconds each: the first with open eyes (OE), the second with closed eyes (CE). The measurements were performed in the morning. Each person was precisely informed about the course of the test. Silence was observed while performing the test because auditory stimuli which exert an effect on an individual in conditions of attention focus could considerably disturb postural reflexes. Each person participating in the test was informed that the performed test was totally harmless. During the test, the examiner stood behind the examined person the whole time, without providing any instructions. During the measurements with open eyes (OE), the examined person was asked to fix his/her eyes on a reference point located on the computer screen. The centre of macular vision was at a distance of 1 m from the examined person. Prior to the test with closed eyes (CE), the examiner ensured that the examined person was able to maintain an upright position without visual control. The examined person stood on the platform barefoot because shoes could disturb posture. The feet were set with careful precision: heels 2 cm apart, feet apart at a 30°angle. In order to facilitate the proper setting of the examined person, the platform was equipped with a standard for feet spacing. The examined person assumed the position with arms down along the side and head his/her held straight. The examiner first checked the coordinates of the foot centre of pressure (COP) on the monitor, and subsequently, after their stabilization, set the most appropriate sensitivity range. The test started at the moment of assuming stable posture by the examined person, and the pathway of deviation from the COP was displayed on the screen. The typical record of balance reactions registered by the posturographic platform resembled a random walk. However, analysis of the shape of the posturograme allowed the presumption that this signal, apart from the stationary, independent, fast-transient high frequency component (deterministically chaotic), contains stochastic trends (low-frequency components). The presence of the high frequency component is dictated by the presence of noise in the system of postural control, and occurs only during human nerve-muscle activity (Collins & De Luca, 1995). Balance reactions are described as a correlated random walk with two characteristic regions: a shorter region in which the trajectory of sways is positively correlated. i.e. the tendency from the past is continued in the future, and a longer region – with a negative correlation, i.e. without continuation of the trend. Each of these regions is ascribed a different type of control. In the shorter region, it is closed-loop control, while the other is ascribed open loop control. The threshold between these two regions is a sensitive indicator of the capacity of the postural system (synergetic theory – on the threshold of chaos, the new occurs – the order which spontaneously develops in the processes of self-organization) (Collins & De Luca, 1995; Błaszczyk, 2016). Balance reactions were described by means of: path length – the pathway of excursion of the COP in both planes during oscillation (mm); mean loading point X – provides lateral coordinates X (mm); mean loading point Y – gives anteroposterior coordinates Y (mm); lateral speed, i.e. the mean oscillation speed along the X axis (mm/s); anteroposterior speed, i.e. the mean speed of the COP along the Y axis (mm/s); mean sway X, i.e. the mean distance between the extreme sways of the foot centre of pressure in the lateral plane along the X axis (mm); mean sway Y, i.e. the mean distance between the extreme sways of the foot centre of pressure in the sagittal plane along the Y axis (mm). Distribution normality of the variables of posture and balance reactions was determined using the Kolmogorov-Smirnov test. Indices of postural defects were adopted as variables characterizing the quality of posture, and evaluated by means of tests for independence (χ^2 test, Fisher's exact test, and Likelihood Ratio χ^2 test), according to gender and age. For the assessment of relationships between body posture in the sagittal plane and balance reactions, one-way analysis of variance was applied, where the variables were balance reactions selected in factor analysis, while the independent variables – the types of posture. In order to determine the relationship between lateral curvature of the spine and balance reactions, one-way and two-way analyses of variance were performed, where the dependent variables were balance reactions selected in factor analysis, whereas the independent variables were types of posture (correct, scoliotic, residual scoliosis, idiopathic lateral curvature of the spine). According to the significance of the main effects and interactions, contrast analysis was performed as well as post hoc analysis. The *p* values were considered statistically significant at $p<0.05$.

3. Results and Discussion

The mean height of girls was 161.45 cm; mean body mass 50.84 kg, mean BMI 19.43. The mean height of boys was 165.41 cm, body mass 52.74 kg, BMI 19.08 (Tab. 1).

Table 1. Height, body mass and BMI of examined children

Gender Age	Body height	(cm)	Body mass (kg)		BMI	
	x	s	x	s	x	s
Girls	161.45	7.35	50.84	9.04	19.43	2.78
12	156.33	7.73	47.28	9.96	19.22	3.12
13	159.98	5.54	49.30	7.91	19.23	2.70
14	163.72	6.55	52.42	8.67	19.51	2.81
15	165.45	5.97	54.13	8.14	19.74	2.49
Boys	165.41	11.12	52.74	11.78	19.08	2.76
12	155.17	8.29	44.18	9.67	18.20	2.79
13	161.49	8.64	49.97	9.77	19.08	2.94

14	169.13	8.25	54.03	9.34	18.81	2.51
15	175.13	7.09	62.00	10.23	20.12	2.47
Total	163.47	9.66	51.81	10.56	19.25	2.77

In the sagittal plane, 297 (59.05%) correct postures were observed, and 206 (40.95%) postural defects. The $\chi2$ did not show any significant differences between girls and boys ($\chi^2 = 0.044$; $p=0.833$) (Tab. 2). In the frontal plane, there were only 3 (0.60%) correct postures, 238 (47.32%) scoliotic postures, 262 (52.09%) residual scoliosis, and 46 (9.15%) idiopathic curvatures of the spine (>10°). The $\chi2$ did not show any significant differences between girls and boys ($\chi^2 =2.119$; $p=0.346$) (Tab. 2). significant differences between girls and boys occurred for the path length (LP), mean loading point Y (MLPY), lateral speed (LS), anteroposterior speed (APS) and the mean sway X (MSX). Only the mean loading point Y (MLPY) was significantly higher in girls during both tests (OE, CE). Girls obtained lower values of the investigated parameters in both tests (OE, CE). A significant effect of age was noted for the mean loading point Y (MLPY) and anteroposterior speed (APS). In girls, in the open eyes test (OE), the mean loading point Y (MLPY) increased with age, and in the closed eyes test (CE), this parameter was the lowest in girls aged 12, followed by those aged 13, 14 and 15. In boys, in the open eyes test (OE), the mean loading point Y (MLPY) was the lowest among the 13-year-olds, followed by those aged 12, 14, and 15, and in the closed eyes test (CE), this parameter increased with age. Significant differences in the open eye test (OE) and closed eye test (CE) (Romberg test) were confirmed for the length of the path (LP), the mean loading point X (MLPX), lateral speed (LS), and the mean sway Y (MSY). Only the mean loading point X (MLPX) during the closed eyes test (CE) increased. In our other studies, it was found that children with scoliosis showed higher values of postural reactions compared to those with scoliotic posture. In the Romberg test with closed eyes (CE), a significant increase in postural reactions was observed. Balance reactions showing significant statistical relationships with the types of body posture are discussed below. In correct postures, the anteroposterior speed with closed eyes (CE) (mm/s) was 10.19; among defects in the sagittal plane without lateral curvatures of the spine – 10.16, and in defects in the sagittal plane and lateral curvatures of the spine – 10.70.

Table 2. Posture defects in the sagittal plane

Posture defects in the sagittal plane				
Gender	Correct posture		Posture defects	Total
Girls	147		100	247
%	29.22		19.88	49.11
Boys	150		106	256
%	29.82		21.07	50.89
Total	297		206	503
%	59.05		40.95	100.00
$\chi^2 = 0.044$; df = 1; $p=0.833$				
Postural defects in the frontal plane				
Gender	Correct posture	Scoliotic posture	Lateral curvature of the spine	Total
Girls	2	124	121	247
%	0.40	24.65	24.06	49.11
Boys	1	114	141	256
%	0.20	22.66	28.03	50.89
Total	3	238	262	503
%	0.60	47.32	52.09	100.00
$\chi^2 =2.119$; df=2. $p=0.346$				

The value of this parameter was the highest in lateral curvatures of the spine without defects in the sagittal plane – 11.06 (Tab. 3). Lateral curvature of the spine and defects in the sagittal plane were accompanied by a clear increase in anteroposterior speed. The mean loading point Y with open eyes (OE) in correct postures was 39.56, in lateral curvatures of the spine – 39.20, and among defects in the sagittal plane and lateral curvatures of the spine – 39.38. The value of this parameter was the highest among defects in the sagittal plane without lateral curvatures of the spine – 41.153 (Tab. 3). The mean sway X in the open eye test (OE) in correct postures was

2.76, among defects in the sagittal plane – 2.55, and defects in the sagittal plane and lateral curvatures of the spine – 2.48. This parameter was the highest in lateral curvatures of the spine without defects in the sagittal plane – 2.99 (Tab. 3). The mean sway Y with open eyes (OE) in correct postures was 3.80, among defects in the sagittal plane – 3.59, and in defects in the sagittal plane and lateral curvatures of the spine – 3.66. The value of this parameter was the highest in the lateral curvatures of the spine without defects in the sagittal plane – 4.00 (Tab. 3).

Table 3. Body posture and balance reactions

Posture defect (Note 1)	**Lateral curvature**	**Anteroposterior speed (CE)**		
		X	n	s
0	0	10.19	144	3.62
0	1	11.05	153	4.05
1	0	10.16	97	3.34
1	1	10.70	109	4.19
Total		10.56	503	3.84
Posture defect	**Lateral curvature**	**Mean loading point Y (MLPY) (OE)**		
		X	n	s
0	0	39.558	144	5.16
0	1	39.202	153	5.48
1	0	41.153	97	7.94
1	1	39.381	109	4.52
Total		39.719	503	5.80
Posture defect	**Lateral curvature**	**Mean sway X (MSX) (OE)**		
		X	n	s
0	0	2.76	144	1.52
0	1	2.99	153	1.84
1	0	2.54	97	1.39
1	1	2.47	109	1.11
Total		2.72	503	1.53
Posture defect	**Lateral curvature**	**Mean sway Y (MSY) (OE)**		
		X	n	S
0	0	3.80	144	1.53
0	1	4.00	153	1.75
1	0	3.59	97	1.30
1	1	3.66	109	1.38
Total		3.79	503	1.53

A significant relationship was observed between anteroposterior speed (PP) in the test with closed eyes (CE) and lateral curvatures of the spine, both with defects in the sagittal plane and without these defects (p=0.044) (Tab. 4). A significant relationship was found between the mean loading point Y (MLPY) with open eyes (OE), and lateral curvatures of the spine both with postural defects in the sagittal plane, and without them (p=0.043) (Tab. 4). A significant relationship was observed between the mean sway X (MSX) during the open eye test (OE) and defects in the sagittal plane, both with lateral curvatures of the spine and without them (p=0.009) (Tab. 4). A significant relationship was noted between the mean sway Y (MSY) with open eyes (OE), and defects in the sagittal plane, both with lateral curvatures of the spine and without them (p=0.046) (Tab. 4).

The balance system regulating postural sways, primitive reflexes, postural reflexes and free movements in posture defects and lateral curvature of the spine is often disturbed. The system of balance as the first fully developed begins to work in the sixteenth week of fetal life. Its myelination is complete at birth, which provides the child with a sense of direction and spatial orientation. It also facilitates dealing with the problem of gravity, which s/he experiences for the first time at birth. All living beings are in a relationship with gravity. It is gravity that gives us a sense of centre in space, time, motion, depth and self-awareness. The mechanism of balance allows to monitor all sense perceptions between the body and the brain. Problems with balance transfer to the other sensory systems, since all impressions pass through the vestibular system at brain stem level before they are passed on to higher levels of the CNS. The etiology of posture defects and lateral curvature of the spine more and more often draws attention to the discrete neurological changes. Considering the etiopathogenic meaning , posture defects and scoliosis are just a symptom, an outward expression of undiagnosed pathology. There is increasing support for the concept of multi-factorial, including genetically determined, "discrete changes" of the central nervous system, causing dysfunction in the postural system (Lowe et al, 2000).

Table 4. Analyses of variance (Note 2)

Anteroposterior speed (CE)						
Independent variables	**DF Effect**	**MS Effect**	**DF Error**	**MS Error**	**F**	***p***
Postural defect (1)	1	4.22	499	14.71	0.28	0.592
Lateral curvature (2)	1	59.72	499	14.71	4.05	**0.044**
Interaction (1-2)	1	3.30	499	14.71	0.22	0.635
Mean loading point Y (OE)						
Independent variables	**DF Effect**	**MS Effect**	**DF Error**	**MS Error**	**F**	***p***
Postural defect (1)	1	95.517	499	33.370	2.862	0.091
Lateral curvature (2)	1	137.39	499	33.370	4.116	**0.043**
Interaction (1-2)	1	60.913	499	33.370	1.825	0.177
Mean sway X (OE)						
Independent variables	**DF Effect**	**MS Effect**	**DF Error**	**MS Error**	**F**	***p***
Posture defect (1)	1	16.09	499	2.34	6.87	**0.009**
Lateral curvature (2)	1	0.76	499	2.34	0.32	0.568
Interaction (1-2)	1	2.66	499	2.34	1.13	0.286
Mean sway Y (OE)						
Independent variables	**DF Effect**	**MS Effect**	**DF Error**	**MS Error**	**F**	***p***
Posture defect (1)	1	9.38	499	2.34	4.00	**0.046**
Lateral curvature (2)	1	2.18	499	2.34	0.93	0.33
Interaction (1-2)	1	0.53	499	2.34	0.22	0.63

In body posture defects and scoliosis, the system controlling balance reactions, postural reflexes and voluntary movements is disturbed. As early as 1969, Yamada et al. reported dysfunction in proprioceptive postural reflexes in 57 scoliosis cases among the 70 individuals examined, and only one case in the 20-sucject control group. They confirmed a significant correlation between balance disorders and the angle of curvature, progression rate and the degree of skeletal maturity. According to these researchers, delayed development of balance may be an etiologic factor in idiopathic scoliosis (Yamada et al, 1969). The results of this study were confirmed by Sahlstrand, Örtengren & Nachemson (1978) and Lidström J., Friberg, Lindström L. & Sahlstrand (1988). These researchers observed considerably worse postural control in children with scoliosis compared to those who were healthy. They also noticed that with the smallest angle of the curvature, postural sways were clearly higher than in scoliosis with a considerable deformity. These researchers suggested that body balance disorders may be the causative factor in juvenile-type idiopathic scoliosis. In addition, they found an increase in the lateralization of patients with scoliosis. This increase was even higher with the distortion of perception caused by 'switching off' the sense of vision. Greater curvatures are accompanied by a considerably greater lack of balance. Herman, et al (1985), while using a simple force platform and rotary chair, observed that patients with scoliosis showed changes investibulo-ocular reflexes.

Gauchard, Lascombes & Kuhnast (2001) observed dynamic and static balance in idiopathic scoliosis, and according to him, scoliosis disturbs balance. In the static test, the site, number of arches and the size of curvature of the spine are important, while in the dynamic test, in multi-arch scoliosis with a large angle of curvature, the researcher observed deterioration of the capacity for maintaining balance.

Allard, et al (2004) evaluated static balance in a group of 13-year-old girls with idiopathic scoliosis, seeking relationships between the abilities to maintain balance and the body mass of the examined girls. He observed that those with a higher body mass had lower abilities to maintain static balance, compared to girls who had lower body mass. In turn, Eshraghi, et al (2009) investigated the parameters of static and dynamic balance in

14-year-old girls with kyphosis, and compared the results with children lacking defects. He found considerable differences between groups; the mean parameters of dynamic balance were worse in girls with hyperkyphosis. In recent years, many researchers have been engaged in posturographic studies in lateral curvatures of the spine (Bruyneel, Chavet, Bollini & Mesure, 2010; Gruber et al, 2011; de Abreu et al, 2012; de Santiago et al, 2013; Park et al, 2013). These researchers indicated significant relationships between balance reactions and postural defects (Pasha et al, 2014; Catanzariti et al, 2014; Gur et al, 2015; Nishida et al, 2016).

In Poland, this problem was undertaken by, among others, Ostrowska, Rozek-Piechura & Skolimowski (2006). The objective of their studies was an attempt to use the method of mathematical modelling to evaluate the motor characteristics of children with idiopathic scoliosis during the process of maintaining balance in a standing position, with the presence of external interferences. The study was conducted among a group of 42 children aged 13-18, with idiopathic scoliosis, and a control group comprised of 40 healthy children. Body balance was examined by the stabilographic method using a platform recording the COP signal. The examined person standing on the stabilograph was unexpectedly, lightly pushed. The result was the mean value from 10 measurements. Analysis of the results showed significant differences in the way of reacting to the balance disturbance. Persons with scoliosis were characterized by greater postural sways, compared to those who were healthy. In these individuals, the speed of losing balance after its disturbance was lower and depended on the value of the angle of spine curvature. The higher the angle of curvature, the slower the process of balance loss, the lower speed and acceleration, and the longer time required for stabilization of posture. In children with idiopathic scoliosis, the upright position is more susceptible to balance disturbances and is characterized by worse stability. In scoliosis, the reaction on the part of the nervous system to balance disturbance is clearly delayed, and characterized by lower impulsiveness. Postural defects and scoliosis are related with disorders of static and adjustment reactions, and the efficiency of balance reactions. There is a need for the application of exercises improving balance reactions in postural re-education using the biofeedback method on stabilometric and dynamometric platforms (Wilczyński, 2007).

4. Conclusions

1. A significant relationship was observed between anteroposterior speed with closed eyes (CE) and lateral curvatures of the spine, both with defects in the sagittal plane and without them. Lateral curvatures of the spine and defects in the sagittal plane were accompanied by a clear increase in anteroposterior speed.

2. A significant relationship was found between the mean loading point Y with open eyes (OE) and lateral curvatures of the spine, both with and without postural defects in the sagittal plane. This parameter was the highest among the defects in the sagittal plane without lateral curvatures of the spine.

3. A significant relationship was observed between the mean sway X (OE) and the mean sway Y during the open eye test (OE), as well as the defects in the sagittal plane, both with and without the lateral curvatures of the spine.

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Notes

Note 1. 0 – present, 1– absent.

Note 2. DF – degree of freedom, MS mean square, F – relation of MS effect to MS error, *p* – level of significance.