

Article

Monitoring the efficiency of equilibrium reactions during therapy in children with postural disorders

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Abstract:

Background: The aim of the study is to present the process of monitoring the changes in the efficiency of equilibrium reactions in the children with postural disorders, in the course of the therapeutic process.

Methods: The shape of spine and the efficiency of equilibrium reactions in standing posture and during gait were assessed in all the subjects. The subjects were put in 2 groups: with the shape of spine disorder and without one. The recommended set of therapeutic activities in home conditions lasted about 20 minutes and was performed by the child with parent's supervision. The therapeutic program was based on elements of the PNF and Vojta methods. The following parameters were measured: maximum movement of the center of pressure (CoP) in the frontal plane during gate, maximum movement of the CoP in the sagittal plane, movement of the CoP in the frontal plane in static conditions, movement of the CoP in the sagittal plane in static conditions.

(3) Results: Six statistically significant differences were recorded, all of them were related to measurement I. The Friedman test result was statistically significant for all the indexes. Post-hoc analyzes were performed using the Dunn-Bonferroni test.

(4) Conclusions:

1. The children with shape of spine disorders are featured by lower efficiency of equivalent reactions in relation to the children without disorders.

12. The therapy with the application of neurophysiological methods in the treatment of shape of spine disorders improves equilibrium reactions in these patients.

3. Long-lasting and thorough observations of the therapeutic process in the children with shape of spine disorders should include the monitoring of the efficiency of equilibrium reactions

Keywords: spine disorders; equivalent reactions; pedobarographic platform; neurophysiological methods

1. Introduction

The overview of literature and our own clinical observations point to an interesting aspect of the issues related to the shape of spine. A correct shape of spine allows, i.e. to keep the eyesight directed horizontally, in accordance with the guidelines of otoscopy, in order to maintain the eyesight in the transverse plane and to limit the movement of the center of gravity to the plane of support [1,2] It was found that children with shape of spine disorders are featured by balance disorders, weakened response to stimuli and a longer time of return to the starting position [3].

The abovementioned balance is a general term describing changes in the alignment of particular parts of the body against one another and in relation to space [4]. It is an important part of neuromuscular control of the mechanism preventing falls. It is a state characterized by vertical orientation of the body, maintained due to the balance of forces working on it [4]. It allows to regain the original positioning of the body while performing various motor tasks and after their completion [4]. The ability to maintain good, stable posture is a prerequisite for performing the majority of purposeful movements, including gait [5].

The efficiency of equilibrium reactions can be assessed by observing the movements of the center of pressure (CoP), which is the point of application of the ground reaction force vector. It is the weighted mean of all pressures on the surface in contact with the ground. Since the spontaneous movement of CoP is two-dimensional information, by analyzing the individual elements of a statokinesiogram path, i.e. separate sway in the sagittal plane and in the frontal plane, they can be used to determine the efficiency of equilibrium reactions [5-7].

It has been found that shape of spine defects are one of the causes of dysfunction in the reflex maintenance of static equilibrium, as well as of the possibility of corrective reflexes overlapping the free movement program [4]. Therefore, shaping the postural reflex is not only related to the muscular system, but also to improving its function in adjustment and equilibrium reactions. Along with the increase in the dysfunction of shape of spine, the extension of CoP path in a given time unit is observed, which means that the equilibrium reactions get weakened [4].

There is an interesting dependency between the shape of spine and the efficiency of equilibrium reactions during gait [8]. In the case of minor shape of spine defects, this dependency mainly concerns the sagittal plane; clinical observations of visible postural disorders indicate that in these cases the abovementioned dysfunctions also include the movement of the center of gravity in the frontal plane [9]. Shape of spine is related to the ergonomics of gait and its proper values are necessary for the correct movement of the center of gravity during the person's movement [4].

It is important to improve equilibrium reactions in order to improve the quality of life [10]. The process of improving balance disorders is based on the mechanism of neuroplasticity of the central nervous system, as a result of the processes of adaptation, habituation and substitution [11]. The aim of the therapy is to improve the visual-vestibular interaction during head movements and to stimulate proprioceptive functions, which translates into reduction in balance disorders [12]. The success of the treatment process depends mainly on systematic implementation of a personalized treatment plan [13] and this applies to both the therapy of shape of spine disorders and balance disorders.

The aim of the study is to present the process of monitoring the changes in the efficiency of equilibrium reactions in the children with postural disorders, in the course of the therapeutic process.

2. Materials and Methods

Subjects

The children (n = 312) aged 8-12 years underwent assessment. The study group consisted of the patients diagnosed with the shape of spine defect. The children in the study group underwent a four-month therapy conducted under the physiotherapist's supervision. The control group consisted of the children with no shape of spine defect in the preventive examination.

The study group consisted of 211 subjects (53% girls, 46.92% boys). The mean age in the study group was 10.72 years (SD = 1.25), body height 1.4 meters (SD = 0.16), body weight 34.7 kg (SD = 11.84), BMI 20.15 (SD = 2.35).

The control group consisted of 101 subjects (50.5% girls, 49.5 % boys). The mean age in the control group 10.69 (SD = 1.44), body height 1.39 meters (SD = 0.13), body weight 38.69 (SD = 8.03), BMI 20.02 (SD = 2.52).

Inclusion criteria:

- age 8-12 years
- diagnosed shape of spine defect
- good health ≤ 2 acc. to ECOG
- the legal guardian's consent for the minor's participation in the study.

Exclusion criteria:

- the presence of comorbidities which may affect the shape of spine disorder, e.g. Shneidermann's disease, genetic or metabolic diseases
- interruption or non-compliance with the orders included in the therapeutic procedure
- BMI below the 10th and above the 90th percentile.

Participation in the study was voluntary, with ensured anonymity in accordance with Ustawa o ochronie danych osobowych of 29.08.1997. (Dz.U.Nr 133 item 883).

Study project

The shape of spine and the efficiency of equilibrium reactions in standing posture and during gait were assessed in all the subjects. The individual elements of the statokinesio-graph path were analyzed in sagittal and frontal planes, which allows to objectively determine the efficiency of equilibrium reactions [5-7]. The subjects were put in 2 groups: with the shape of spine disorder and without one. Based on the functional assessment and the Diers computer analysis, a therapeutic program was fitted for the children in the study group. The program assumed that the child would perform preordered therapeutic activities at home twice a day, supervised by the parent, taking care of the proper correction of body posture with the use of a mirror.

The study conduct was approved by the Bioethics Committee, Approval No. 1/2016, issued 15.01.2016.

Intervention

The recommended set of therapeutic activities in home conditions lasted about 20 minutes and was performed by the child with parent's supervision or help if necessary. The therapeutic program was based on elements of the PNF and Vojta methods. The study protocol included 4 appointments at four week intervals. During each appointment, the analyzed parameters were measured and the functional test was performed, on the basis of which the individual therapy was fitted, based on the PNF and Vojta methods. The parents were thoroughly trained by the physiotherapist in the recommended techniques, which were then performed by them with their children at home until the next appointment.

The analysis of ground reaction forces and equilibrium reactions. In the study group, measurements were made four times at one month intervals, and in the control group, the measurement of the analyzed parameters as well as the functional test were performed once.

During the examination, the efficiency of equilibrium reactions during gait was analyzed. For this purpose, the DIERS Pedogait was used, consisting of a treadmill and a pedobarographic platform built into it [14]. The measurements were made while walking slowly at a speed of 2 km/ h. The following parameters were measured:

1. Maximum movement of the CoP in the frontal plane during gate - the parameter calculated in centimeters is the biggest CoP displacement in the frontal plane during gait over a distance of 16 m.
2. Maximum movement of the CoP in the sagittal plane - the parameter calculated in centimeters is the biggest CoP displacement in the sagittal plane during gate over a distance of 16 m.

Measurements of the movement of the CoP in a static position were made with the DIERS Pedoscan [14]. The examined person stood on the 80 x 100 cm platform, in its central part. The feet were placed forward in their natural relaxed position.

The following parameters were measured:

1. Movement of the CoP in the frontal plane in static conditions - the parameter calculated in centimeters, showing the biggest center of pressure displacement of the body onto the ground during 10 seconds in the frontal plane (to the left and right).
2. Movement of the CoP in the sagittal plane in static conditions - the parameter calculated in centimeters, exemplifying the biggest center of pressure of the body onto the ground during 10 seconds in the sagittal plane (forward and backward).

Statistical methods used

Statistical analyzes were performed with the IBM SPSS Statistics25 package. The basic descriptive statistics were analyzed: the mean, the median, standard deviation, skewness, kurtosis, the smallest and the biggest value of the distribution. In order to assess the normality of the distribution of variables, the non-parametric Kolmogorov-Smirnow test was used [15]. Percentage differences between the measurements were calculated.

To assess the significance of differences between the parameters in the study and control groups, the Mann-Whitney U test was used due to the fact that most of the analyzed variables took on different than normal distribution [16].

The analysis of changes occurring between further measurements in the study group was carried out with the Friedman test [17]. This test was used because it enables to determine the differences between four measurements at the same time.

Statistically significant scores of the Friedman's test were subjected to post-hoc tests with the Dunn-Bonferroni Test to counteract the problem of multiple comparisons, consisting in reducing the nominal significance level of each set of related tests [18].

3. Results

Basic descriptive statistics of the studied quantitative variables were calculated along with the Kolmogorov-Smirnow test checking the normality of the distribution of these variables. The analyzes were performed separately for the study and the control groups. The vast majority of measurements took on distributions different from the normal one. In this work, statistical analyzes were performed with non-parametric tests in order to keep the consistency of the scores.

The level of efficiency of equilibrium reactions in the test and control groups was verified. A series of analyzes which compared the two groups was performed with the Mann-Whitney U test. Due to one-time measurement in the control group, the scores obtained in the study group in measurement I and IV were compared to the same measurement in the control group, and then the strength of the observed effects was compared.

Six statistically significant differences were recorded, all of them were related to measurement I. The scores for the following variables - maximum movement of the CoP in the frontal plane and maximum movement of the CoP in the sagittal plane during gate, maximum movement of the CoP to the left and right - statically and maximum forward and backward movement of the CoP were statistically higher in the study group. The fact that the differences in measurement IV did not even come close to statistical significance indicates significant reduction in the differences between the groups as the result of the therapy. The detailed data are presented in Table 1.

Table 1 Comparison of the study and control groups in terms of the level of pressure distributions and the center of gravity in static conditions and during gait.

	Measurement	study group (n = 211)		control group (n = 101)		U	Z	p	r
		M	SD	M	SD				
Maximum movement of the center of gravity in the frontal plane - gait	I	10.46	2.50	9.87	1.92	9126.5	-2.051	0.040	0.12
	IV	9.80	1.94	9.87	1.92	10650.5	-0.007	0.995	0.00
Maximum movement of the center of gravity in the sagittal plane - gait	I	20.20	5.83	16.03	3.23	5542.5	-6.858	<0.001	0.39
	IV	16.38	3.68	16.03	3.23	10198.0	-0.614	0.539	0.03
Maximum movement of the center of gravity to the left - static	I	1.03	1.55	0.56	0.33	6846.5	-5.109	<0.001	0.29
	IV	0.61	0.41	0.56	0.33	9964.0	-0.928	0.354	0.05
Maximum movement of the center of gravity to the right - static	I	0.80	0.64	0.55	0.35	7445.0	-4.307	<0.001	0.24
	IV	0.55	0.36	0.55	0.35	10577.5	-0.105	0.917	0.01
Maximum forward movement of the center of gravity - static	I	1.18	1.01	0.83	0.41	7108.5	-4.758	<0.001	0.27
	IV	0.85	0.44	0.83	0.41	10273.0	-0.513	0.608	0.03
Maximum backward movement of the center of gravity - static	I	0.69	0.97	0.43	0.28	8145.5	-3.367	0.001	0.19
	IV	0.44	0.36	0.43	0.28	10587.5	-0.091	0.927	0.01
M – mean; SD – standard deviation; U – U Mann-Whitney’s test result; Z – standardised value; p – statistical significance; r - effect size.									

Six statistically significant differences were recorded, all of them were related to measurement I. The scores for the following variables - maximum movement of the center of gravity in the frontal plane and maximum movement of the center of gravity in the sagittal plane during gate, maximum movement of the center of gravity to the left and right - statically and maximum forward and backward movement of the center of gravity were statistically higher in the study group. The fact that the differences in measurement IV did not even come close to statistical significance indicates significant reduction in the differences between the groups as the result of the therapy. The detailed data are presented in Table 1.

The criteria for the level of the center of pressure displacement in static and dynamic conditions were analyzed in terms of changes occurring between subsequent measurements in the study group. A series of non-parametric Friedman analyzes of variance was performed and they were subjected to Post-Hoc tests with the Dunn-Bonferroni test (Table 2).

Table 2 Changes during therapy in the level of pressure distributions and center of gravity in static conditions and during gait. The Dunn-Bonferroni test.

	Measurement	M	SD	
Maximum movement of the center of gravity in the frontal plane - gait	I	10.46a	2.50	$\chi^2(3) = 9.67$ $p = 0.022$
	II	10.38a	2.51	
	III	10.15ab	2.30	
	IV	9.80b	1.94	
Maximum movement of the center of gravity in the sagittal plane - gait	I	20.20a	5.83	$\chi^2(3) = 42.60$ $p < 0.001$
	II	18.66b	5.78	
	III	18.96ab	4.94	
	IV	16.38c	3.68	
Maximum movement of the center of gravity to the left - static	I	1.03a	1.55	$\chi^2(3) = 38.21$ $p < 0.001$
	II	1.02a	1.26	
	III	1.05a	1.73	
	IV	0.61b	0.41	
Maximum movement of the center of gravity to the right - static	I	0.80a	0.64	$\chi^2(3) = 27.11$ $p < 0.001$
	II	0.89a	1.35	
	III	0.92a	1.16	
	IV	0.55b	0.36	
Maximum forward movement of the center of gravity - static	I	1.18a	1.01	$\chi^2(3) = 44.41$ $p < 0.001$
	II	1.18a	1.03	
	III	1.28a	1.28	
	IV	0.85b	0.44	
Maximum backward movement of the center of gravity - static	I	0.69a	0.97	$\chi^2(3) = 474.11$ $p < 0.001$
	II	0.65b	0.96	
	III	0.67b	1.14	
	IV	0.44c	0.36	
M – mean; SD – standard deviation,				

The Friedman test result was statistically significant for all the indexes. Post-hoc analyzes were performed using the Dunn-Bonferroni test. In terms of the index, the maximum movement of the center of gravity in the frontal plane during gait was re-corded at the lowest level in measurement IV. It was statistically significantly lower than in measurements I and II. Measurement III took on intermediate values. As regards the index of the maximum movement of the center of gravity in the sagittal plane during gait, the lowest score was recorded in measurement IV. It was statistically significantly lower than in measurements I, II and III. Also, a statistically significant difference in the level of this index between measurements I and II was recorded, and a difference close to statistical significance between measurements I and III was recorded. As regards the maximum movement of the center of gravity to the left, measurement IV was visibly the lowest. It was statistically significantly lower than the level in measurements I, II and III. Similar scores were recorded for the index of the maximum movement of the center of gravity to the right and the maximum movement of the center of gravity forward - a visible decrease in the level of these variables in measurement IV and significant differences between the last measurement and measurements I, II and III. In terms of the index of maximum backward movement of the center of gravity, the scores were similar, i.e. the lowest score in measurement IV was statistically significantly different from the level in measurements I, II and III, but additionally a statistically significant difference

between measurement I and measurements II and III was recorded. The detailed data are shown in Table 2.

4. Discussion

The shape of spine is susceptible to the influence of many factors, due to the complex system of its control [23]. The ability to keep a correct, stable posture is a prerequisite for most purposeful movements, including gait [5]. Therefore, monitoring the treatment process of patients with shape of spine disorders should take into account all the dysfunctions developing in their body [24], including the dysfunctions in the efficiency of equilibrium reactions.

Reliable monitoring of the treatment process enables the choice of a suitable, personalised rehabilitation program that gives a chance to achieve positive effects in the form of improving equilibrium reactions in patients with shape of spine defect [14,25]. The rehabilitation techniques used in our study affected the efficiency of equilibrium reactions in the children subjected to therapy. The parameters describing equilibrium responses assessed during gait have improved. The maximum centre of pressure displacement in the sagittal plane decreased by 3.82 cm (19%) and the maximum centre of pressure displacement in the frontal plane by 0.66 cm (6%). The static evaluation showed significant reduction in the movement of the center of gravity to the left by 0.42 cm (41%), to the right by 0.25 cm (31%), forward by 0.33 cm (28%) and backward by 0.25 cm (36%). During the analysis of the scores, the bigger shift of the center of gravity to the left, as well as the bigger effect of improving this parameter in relation to the right side are clearly visible. Similar observations were made by Bruyneel who analyzed the balance in a sitting position in the patients with spine deviation; this dependency is explained by the more frequent occurrence of deviation with concavity on the left side [26], which is reflected in the results obtained by the authors (125 subjects had a dominant concavity on the left side and 86 on the right).

It is worth noting that after 4 months of rehabilitation, all the parameters had improved, reaching the values typical of the control population. No deterioration from baseline value was registered. The improvement of the analyzed parameters trended from the second examination on, so the effect of the therapy on the values of the equilibrium parameters began at the latest after a month of its implementation, although the biggest effect was observed between the third and fourth appointments.

The analysis of the literature showed a small number of research papers describing the effect of the shape of spine correction on the efficiency of equilibrium reactions. Attention should be drawn to the work by Kinel et al., which describes the improvement of equilibrium reactions and motor coordination after using the Vojta method in patients with postural disorders. [25]. During the six-week program of rehabilitation with PNF, Lee noted decrease in the movement of the center of gravity in both static and dynamic examination, and the parameters describing the positioning of the spine in space also improved [14]. Winter [4] also points out that the improvement in balance can be expected along the improvement of the shape of spine. This involves shift in the center of mass in the upper torso, which is then shifted to the ground through the hip and ankle joints. Rougier [27] explains this phenomenon by the fact that the displacements change through the forces shifted to the feet and are partially reduced by the compensations occurring in the above mentioned joints. This causes a change in the load on the feet and disturbs afferent information, which affects the incorrect perception of one's own body in space, as indicated by Roll and Kavounoudias [28,29]. Carlsöö, on the other hand, attributes the improvement in the efficiency of equilibrium reactions resulting from the restoration of the physiological axis of the body to the reduction of tensions coming through the sacro-dorsal and calf muscles to the feet [30].

Based on the above findings, it can be concluded that the efficiency of equilibrium reactions is an important aspect in the process of shape of spine correction. Nalut points

out that it is the size of the deformity of the spine that determines the size of the equilibrium reaction disorders [9]. The quality and quantity of stimuli determine mutual dependencies between the dynamic and static parts of the musculoskeletal system, which are important components of the balance system [31,32,33,34].

As many as 5 out of 6 parameters determining the efficiency of the equilibrium reaction did not improve immediately, and even deterioration was observed. In the literature, we found the statement that it is the size of postural dysfunctions that determines the size of the disturbances of equivalent reactions, as reported by Naulut [9]. Winter [4] also points out that with the restoration of the physiological position of the spine, an improvement in balance can be expected. It involves a shift in the center of mass in the upper torso, which is then transferred to the ground through the hip and ankle. Carlsöö, on the other hand, attributes the improvement in balance resulting from the restoration of the physiological size of thoracic kyphosis to a reduction in tension flowing through the sacro-dorsal and calf muscles to the feet [30]. Lack of immediate improvement after the implementation of therapy restoring the correct shape of the spine may be the result of compensation in the form of torso tilt, changes in the angular position of the joints of the lower limbs, or foot loads, as reported by Rougier [27] and Suoza et al. [35]. This causes a change in the load on the feet and the disturbance of afferent information, which affects the incorrect perception of one's own body in space, as indicated by Roll and Kavounoudias [28,29]. This means that the brain perceives the body as vertical when it is tilted laterally. The process of improving balance disorders is based on the mechanism of neuroplasticity of the central nervous system, as a result of the processes of adaptation, habituation and substitution [11]. The observation of the subsequent results presented in the study indicates that this adaptation of the central nervous system to new parameters of body posture may take up to 4 months. However, this thesis requires verification in other groups of patients and with the use of other therapeutic methods.

When planning the treatment process, actions aimed at improving the ability to maintain body in space should be considered [36]. The disorder of physiological curves of the spine will always have a negative effect on balance, which should be taken into account when planning the treatment process.

6. Conclusions

The crucial issue in the therapeutic process is examination, observation and therapy. Research confirms, that the children with shape of spine disorders are featured by lower efficiency of equivalent reactions in relation to the children without disorders. Therefore the therapeutic process in the children with shape of spine disorders should include the monitoring of the efficiency of equilibrium reactions. What is more important, the observation should be long-lasting and thorough. Furthermore the therapy with the application of neurophysiological methods in the treatment of shape of spine disorders improves equilibrium reactions in these patients.

7. Limitations

The study protocol did not include angular measurements in the lower limb joints, nor the activity of postural muscles, and these are important components of the process of controlling the positioning of the body in space. In this work, only one of the components of the entire cause-and-effect chain aimed at keeping the body in balance was analyzed.

8. Clinical implications

The results presented in the work explicitly show that the efficiency of equilibrium reactions and the shape of spine are interrelated. Planning the treatment process, both in

the case of shape of spine disorders and deficits in equilibrium reactions, cannot focus on just one of these areas, but must be comprehensive.

Author Contributions: For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used “Conceptualization, A.Ż.; methodology, A.Ż., Z.S., W.K.; software, A.Ż., Z.S.; validation, A.Ż., Z.S., W.K.; formal analysis, A.Ż., W.K.; investigation, A.Ż.; resources, A.Ż., D.K., M.S.; data curation, A.Ż.; writing—original draft preparation, A.Ż.; writing—review and editing, A.Ż., W.K., M.S., D.K.; visualization, A.Ż., Z.S., W.K.; supervision, W.K.; project administration, A.Ż.; funding acquisition, D.K. All authors have read and agreed to the published version of the manuscript.”

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Institutional Review Board Statement: All participants gave their written consent to participate in the study. The research was conducted in accordance with WMA Declaration of Helsinki - Ethical Principles for Medical Research Involving Human Subjects.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

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