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Original paper

Assessment of the impact of orthotic gait training on balance in children with cerebral palsy

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The cerebral palsy symptoms are, among others, balance and gait disorders. The goal of this study was to assess balance capabilities in children with spastic diplegic cerebral palsy rehabilitated using Lokomat active orthosis. The experimental group included children with cerebral palsy, aged 6–14 years, independent standing, level II-III according to GMFCS classification. The cohort was randomly divided into two groups. The balance was assessed on a stabilometric platform. The experimental group was administered a rehabilitation program with the use of Lokomat active orthosis. Statistically significant improvement of balance was found in the experimental group; however, in the control group the improvement was also visible, but not on the statistically significant level. While comparing the results of both groups, significantly bigger improvement was achieved by the children from the experimental group. Lokomat active orthosis is one of the newest devices applied in the rehabilitation. The study shows that training with active orthosis can have positive influence on the balance improvement in children with CP and that further analysis of the impact of such training on locomotive functions is needed.

Key words: *cerebral palsy, balance, rehabilitation, stabilometry*

1. Introduction

Cerebral palsy (CP) is one of the most common causes of motor disability in children. Overall, the CP rate is between 2 and 3 per 1000 live births. This rate increases to 40–100 per 1000 live births among prematurely born babies or babies with very low birthweight [1]. CP belongs to the group of disorders of movement and posture which causes activity limitation and is attributed to non-progressive disturbances occurring in the developing fetal or infant brain [2]. The motor disorders of CP are often accompanied by the disturbances in sensation, cognition, communication, perception, and/or behaviour, and/or by a seizure disorder [3]. The motor disorders in children with CP are complex. The primary deficits include: muscle tone abnormalities influenced by position, posture and movement; impairment of balance and coordination; decreased strength; loss of selective motor control. Secondary musculoskeletal problems are muscle contractures and bone deformities. These develop progressively in response to the primary deficits and produce further motor dysfunction. For the time being, there is no specific therapy for the brain injury leading to the motor problems that characterize CP. In general, the rehabilitation of these patients requires the use of various physiotherapy techniques frequently adapted to the changing functional status of the patients. The goals of these interventions are: to minimize the development of secondary problems by reducing or normalizing the tone, facilitating adequate stretching of muscles, and increasing the active range of motion; to strengthen the weak muscles; to improve mobility and acquire functional motor skills; to promote functional independence at home, at school and in the community [4]. Recent advances in basic and clinical neuroscience raise hope that the implementation of effective functional therapies based on enhanced activity will be cru-

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cial in improving the level of functioning in patients with cerebral palsy [5].

Current concepts of motor learning assume that repetitive task-specific training can significantly improve motor function [6], [7]. Advancements in technologies, including computation, robotics, machine learning, communication, and sensor miniaturization, bring us closer to futuristic vision of compassionate intelligent devices and technology-embedded environments. One application of rehabilitation engineering that has recently received a lot of attention involves the use of technology, especially robotics, to enhance traditional physical and occupational therapy. One of the best-known systems is the Lokomat from Hocoma [8]. There is evidence that locomotor therapy for regaining walking capacity using the principle of enhancing neuroplasticity by task-specific training is effective in the rehabilitation process of patients with central gait disorders [9]. Postural control is an integral part of all motor abilities. Although stable control of posture and balance is automatic for healthy subjects, it is often a challenging task for vestibularly impaired patients, children with cerebral palsy, and others lacking balance stability due to pathology or injury. Dysfunctional postural control is one of the key problems in children with cerebral palsy. However, the exact nature of the deficits is only known to a limited extent. Postural stability is defined as the ability to maintain and control the body center of mass within the base of support to both prevent falls and complete desired movements. Maintenance of postural stability is a complex process which requires a proper function, and integration of the information from vestibular, visual and proprioceptive systems. In central nervous system (CNS), input signals from different sensory systems are integrated and information is sent to the musculoskeletal system in order to maintain balance [10]. Posturography methods are used to evaluate the active and passive regulation of balance under a variety of conditions. Fundamental elements of most posturography tests include the ability to actively manipulate posture or balance, and evaluate the subject's response to such interventions [11]. The goal of this study was to assess the balance, including foot loading symmetry, in the group of children with spastic diplegia treated with the use of active orthosis.

2. Material and methods

The experimental group included children with cerebral palsy aged 6–14 years. Inclusion criteria: children with spastic diplegia, independently standing and walking or walking with help, level II-III according to GMFCS classification, without disorders of higher mental functions, consent of parents or guardians. Exclusion criteria: children treated with botulinum toxin for less than 6 months, children treated surgically for less than one year before the date of the examination. Exclusion criteria were also active drug-resistant epilepsy; anatomical leg length discrepancy (because of Lokomat system limitations) exceeding 2 cm; fixed contractures; bone and joint deformities; bone-articular instability (joints dislocation); baclofen therapy using an implanted infusion pump; inhibitory casts during the last 6 months; significant amblyopia and hearing loss; inflammation of the skin and open skin lesions around the trunk or limb; contra-indications for training on a treadmill; the lack of cooperation from the patient, and the lack of consent by the patient or guardian. 18 children qualified for this study, and were divided randomly into two groups. The experimental group consisted of 9 children subjected to the program of rehabilitation and using the Lokomat system. All patients from the experimental group had physiotherapy and training with the use of Lokomat system once a day, five times a week for four weeks. The control group initially consisted of 9 children, 4 of them resigned from the participation in the project before its completion. The reason for their resignation was a lack of the possibility of participating in daily therapy (only distance, not medical problems). All patients from the control group received physiotherapy once a day, five times a week for four weeks.

The measurements performed twice, before and after the treatment, allowed us to assess balance with open and closed eyes by means of the stabilometric Zebris platform. Multifunctional platform for measuring the strength works with the 1504 capacitive force sensors organized in a matrix 32 × 47 cm. It allows for analysis of static and dynamic forces and underfoot pressure distribution. The length of motion path, confidence ellipse area, horizontal and vertical deviations of COG (Centre of Gravity), and percentage values of forefoot and rearfoot loading were analysed. The measurement was blind for the examiner and was performed by one person not knowing the manner of the division into the study and control group. Children from the experimental group used active orthosis Locomat from Hocoma company and completed a program based on individual exercises with a physiotherapist. Children in the control group participated only in individual exercises with a therapist. Children from the experimental and control groups participated in 20 therapeutic sessions. The total time assigned for exercise in both groups was the same. Locomat is a device which allows training in walking under conditions of dynamic unloading, and with the gait pattern simulation for the lower limbs, with the possibility of setting parameters of gait (velocity, step length). For each exercising individual, the parameters of the training were selected individually on the basis of the measurement of the length of limbs, the range of movement in the joints of lower limbs, the muscle tone and the body weight. The value of relieving the body weight was selected depending on the level of the child's walking capacity, his/her endurance, strength and commitment to walking. The time of the single training session was 45 minutes. While learning, the children constantly received additional outside information delivered verbally by the therapist conducting exercises, and in the form of graphic visualisation of his/her own walking shown on the screen of the monitor. Individual exercises in both groups were oriented towards the improvement in motor control, improvement in the stability in sitting and upright positions, learning to walk. The study was endorsed by the Bioethical Board.

3. Statistical methods

The statistical analysis was performed with the help of Statistica 9 software. In the evaluation of the significance of differences among both groups, we used the non-parametric Mann–Whitney *U* test (the version for small samples) and Wilcoxon test. Statistically significant level $p < 0.10$ was accepted. The assessment of the relation level for the feature studied was performed with the help of the Spearman's rank correlation coefficient.

4. Results

In the experimental group, the measurement in trials with opened eyes showed that the mean value of confidence ellipse width in the initial measurement was 23.2 mm (Mdn 26.0 mm) and in the follow-up measurement after the conclusion of rehabilitation it

Table 1. Medium value of test parameters and statistic test results in the experimental group tested with opened eyes

Parameters (opened eyes)	Before the rehabilitation		After the rehabilitation		Difference		p
	$\bar{x}$	Mdn	$\bar{x}$	Mdn	$\bar{x}$	Mdn	
Confidence ellipse width (mm)	23.2	26.0	18.3	15.1	–4.8	–3.9	0.0663*
Confidence ellipse height (mm)	45.2	31.5	40.1	23.6	–5.2	–2.6	0.7671
Confidence ellipse angle (deg)	10.6	26.0	–8.6	–18.4	–19.2	–46.0	0.5147
Confidence ellipse area (mm^2)	947.1	686.8	758.0	310.2	–189.1	24.1	0.6784
Total track length (mm)	1571.4	1647.1	1380.4	1354.4	–190.9	–241.8	0.1731
Horizontal deviation	16.0	12.2	15.1	8.0	–0.9	0.6	0.9528
Vertical deviation	12.3	11.8	9.0	8.2	–3.3	–3.8	0.0382*

$\bar{x}$ – arithmetic mean, Mdn – median, p – result of statistic test.

Table 2. Medium value of test parameters and statistic test result in the experimental group tested with closed eyes

Parameters (closed eyes)	Before the rehabilitation		After the rehabilitation		Difference		p
	$\bar{x}$	Mdn	$\bar{x}$	Mdn	$\bar{x}$	Mdn	
Confidence ellipse width (mm)	24.7	22.5	14.8	12.7	–10.0	–9.7	0.0284*
Confidence ellipse height (mm)	48.2	35.0	29.7	24.5	–18.5	–10.5	0.1097
Confidence ellipse angle (deg)	55.2	72.7	1.2	–0.6	–54.1	–46.8	0.1386
Confidence ellipse area (mm^2)	1145.1	660.5	251.0	181.3	–894.1	–225.1	0.0152*
Total track length (mm)	1691.0	1625.3	1322.8	1324.7	–368.2	–206.8	0.0077**
Horizontal deviation	18.2	11.3	10.6	10.0	–7.7	–4.2	0.1386
Vertical deviation	11.8	9.9	7.8	7.2	–4.0	–3.1	0.0209*

$\bar{x}$ – arithmetic mean, Mdn – median, p – result of statistic test.

was found to decrease to the value of 18.3 (Mdn 15.1). Similarly, the mean value of vertical deviation after the conclusion of rehabilitation decreased from 12.3 (Mdn 11.8) to 9.0 (Mdn 8.2). Mean values of the remaining test parameters also decreased (table 1).

In the trial with closed eyes, all measured mean values were higher, with the exception of the mean value for vertical deviation which was slightly lower, i.e. 11.8 (Mdn 9.9). Measurements in the control group, in the trial with closed eyes, also showed decrease in the values of all test parameters (table 2). The mean value of confidence ellipse width in the initial measurement was 24.7 (Mdn 22.5) and decreased to reach the mean value of 14.8 (Mdn 12.7). On average the mean value of confidence ellipse area decreased, after the conclusion of the rehabilitation, by 894.1 mm and was 251.0 (Mdn 181.3 mm). The average total track length in the initial measurement was 1691.0 mm (Mdn 1625.3) and decreased after the rehabilitation to reach the value of 1322.8 mm (Mdn 1324.7), (table 2).

In the control group, there was an increase in the mean and median values of confidence ellipse width in the trial with opened and with closed eyes (table 3). In the initial measurement with opened eyes, it was 23.2 (Mdn 20.2) and in the final measurement 25.3 (Mdn 25), while in the trial with closed eyes the respective results were 21.4 (Mdn 18.3) and 23.8 (Mdn 25). Similarly, the mean value of the total track length increased from 1252.0 mm to 359.7 mm (Mdn 60.5) in the trial with opened eyes, and from 1416.3 to 1496.5 (Mdn 1439.7) in the trial with closed eyes. The mean value of the vertical deviation in the trial with opened eyes increased by 2.8 (Mdn 0.3), to 14.4 (Mdn 13.8), while in the trial with closed eyes the final measurement showed a decrease in the mean value from 13.1 (Mdn 9.1) to 12.8 (Mdn 14.4). The follow-up measurement showed a decrease in the values of the remaining parameters of balance in the trials with both opened and closed eyes (table 3).

In the experimental group, the mean value of the difference in foot loading in the initial trial with opened eyes was 34% (Mdn 33) and decreased in the follow-up measurement to 19.9% (Mdn 20.4). The trials with closed eyes also showed an improvement in the symmetry of foot loading. The value of the difference in the initial measurement was 31.3% (Mdn 30.2) and decreased to 23.8% (Mdn 24.2). In the control group, the initial trial with opened eyes showed the mean value of the difference in foot loading to be 35.4% (Mdn 35.4) and in the follow-up measurement decreased to 33.0% (Mdn 33.0). In the trial with closed eyes, the difference in the initial measurement was 31.1% (Mdn 28.4) and increased to the mean value of 39.7% (Mdn 47.4).

5. Discussion

Deficits in postural control are one of the hallmarks of disability in children with cerebral palsy (CP). The balance and the stability of posture in children with CP being able to stand and walk independently, to a considerable degree, are disturbed [12]. Abnormalities observed in these children are caused by the child's improper control of movements and is the result of a brain damage and compensating mechanisms. As shown by LIAO and HAWANG [13] in their research, children with CP had worse static balance and dynamic balance compared to non-disabled children. The same researchers also revealed that this was connected with slower walking speed and greater physiological cost of walking. The correlation between dynamic balance and walking function was shown to be of significant value. It suggested that rhythmic weight-shift training should be encouraged to improve the walking performance of children with CP. SHUMWAY-COOK et al. [14] showed that intensive training of school-aged children with CP on

Table 3. Medium value of test parameters and statistic test result in the control group trial with closed eyes

Parameters (closed eyes)	Before the rehabilitation		After the rehabilitation		Difference		p
	$\bar{x}$	Mdn	$\bar{x}$	Mdn	$\bar{x}$	Mdn	
Confidence ellipse width (mm)	21.4	18.3	23.8	25.0	2.4	0.5	0.6858
Confidence ellipse height (mm)	47.0	30.1	45.4	40.5	–1.6	0.6	0.7874
Confidence ellipse angle (deg)	12.6	8.8	0.7	–12.7	–11.9	0.0	1.0000
Confidence ellipse area (mm^2)	1066.6	431.4	1057.4	795.7	–9.2	–0.7	0.8927
Total track length (mm)	1416.3	1549.2	1496.5	1439.7	80.2	119.0	0.4652
Horizontal deviation	15.1	9.2	15.8	10.9	0.7	–1.0	0.7150
Vertical deviation	13.1	9.1	12.8	14.4	–0.2	–0.4	0.7150

$\bar{x}$ – arithmetic mean, Mdn – median, s – standard deviation, p – result of statistic test.

a moveable forceplate system significantly improved their ability to recover stability as demonstrated by reduced center of pressure area and time to stabilization following training. The training improved the specificity of the adjustments, the speed of the postural muscles recruitment, increased the frequency of a bottom-up recruitment usage and improved the modulation of the degree of muscle contraction. These improvements were still present 30 days following completion of training and confirmed the thesis that postural control mechanisms in school-age children (7 to 13 years) with CP are modifiable [14]. There are a lot of methods and manners of treatment designed for the rehabilitation of children with CP. Automatic orthosis (Lokomat) is one of new devices applied in the rehabilitation [15]. BORGGRAEFE et al. assessed the effects of exercises with the application of the automatic orthosis Lokomat used in a group of children with CP and showed a significant improvement in balance, walking and general motor capacity. They noticed significant improvements in dimension D (standing) and E (walking) of GMFM [16]. In some cases (e.g., case study by Borggraefe), the dimension D in GMFM score can even double [17]. Also MEYER-HEIM et al. [18] carried out the assessment of automatic orthosis-driven task-specific training influence in children with central gait impairment. The results in dimension E of GMFM showed significant improvement, but in dimension D the differences were not so significant. CHERNG et al. [19] revealed that training with body weight support (TBWS) significantly improved the children's gait and showed a significant increase in dimension D and E scores in GMFM. The goal of this study was to assess the balance in CP children randomly assigned to the group exercising with the application of the automatic orthosis and to the group exercising conventionally. The exercise regime was designed to gradually increase the loading of lower limbs while walking, and it ensured the gait symmetry and phases while retaining the lowest possible muscle tone. The expected outcome of the exercises administered to a randomly selected group of children was an improvement in the static balance.

Due to the small size of the cohort the analysis of the results was limited to providing the mean and median values for specific parameters which were measured before and after the rehabilitation as well as the differences between those two measurements.

Both the experimental group and the controls showed differences between the results of balance assessment obtained in the trials with opened and closed eyes. This is a natural phenomenon which occurs as a result of detaching the visual analyzer from the balance control system. At the end of the program there was a decrease in all mean values of test parameters in the trial with opened eyes measured in the experimental group. During the trial with eyes closed, nearly all subjects showed a decrease in both the total track length and the confidence ellipse area. The significance of the changes resulting from the rehabilitation was assessed by means of the Wilcoxon test ($p < 0.10$). The outcomes related to the total track length and the confidence ellipse area were recognized to be statistically significant, but due to the small size of the batch the results of the statistical test cannot constitute the ground for conclusions.

The distribution of the values of test parameters for the 5 control subjects was described in the same manner as for the experimental group. Not all parameters related to balance were shown to decrease (balance improvement) in the final measurement after the conclusion of the rehabilitation, which was different than in the experimental group. This outcome relates to the trial with opened and closed eyes.

The comparison of the rehabilitation outcomes in the experimental group and controls was expressed as a difference between the measurements performed before and after rehabilitation. In the trial with opened eyes, a greater improvement was found in the control group with regard to the confidence ellipse height, confidence ellipse angle, confidence ellipse area and horizontal deviation. It should be noted that in the initial measurement in the trial with opened eyes, the children in the control group obtained higher values of the confidence ellipse height, confidence ellipse angle, confidence ellipse area and horizontal deviation compared with the children in the experimental group. The final results of examinations, in the trials with closed eyes, showed greater improvement of statistical significance in the experimental group. Statistically significant differences were found in the confidence ellipse area and the total track length. The results obtained can suggest an improvement in the control of the vestibular system because the final outcomes in trials with opened eyes do not show statistically significant improvement. The differences in the results between opened and closed eyes can be explained by the research results by CHERNG et al. [20] who suggest in a similar test that children with spastic diplegic CP may have difficulties in resolving intersensory conflicts for maintenance of standing balance, or the demands of motor control in the conditions of sensory conflict outweigh the motor ability of children with spastic diplegia CP.

For the parameters describing the foot loading symmetry we used the difference between the right and left feet loading (LAFT–RAFT (%)). In the initial measurement, the groups did not differ greatly in terms of asymmetry of foot loading. Upon the conclusion of the exercise program, the experimental group showed a significant improvement and a decrease in the foot loading asymmetry in the trial with opened eyes. The improvement in the control group was less pronounced. In the trial with closed eyes, the asymmetry decreased in the experimental group, while the controls showed an increase in the asymmetry. The analysis of the correlation between the change in the foot loading symmetry (LAFT–RAFT (%)) and the changes in the remaining parameters was performed for the data of both the experimental group and the controls combined. Significant correlations in the trial with opened eyes were found between the foot loading symmetry and the confidence ellipse height ($r = -0.56$), confidence ellipse area ($r = -0.54$) and horizontal deviation ($r = -0.55$). In the trial with closed eyes, a significant correlation was found for the total track length ($r = 0.58$).

6. Conclusions

The study suggests that exercising with the use of the automatic orthosis may have beneficial impact on the improvement of balance in children, it also points to the need of further assessment and analysis of the impact of such exercises on the change of locomotive function.

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