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The development of postural control in 6–17 old years healthy children. Part II Postural control evaluation – Limits of Stability Test (LOS) in 6–17 old year children

Authors' Contribution:
A – Study Design
B – Data Collection
C – Statistical Analysis
D – Data Interpretation
E – Manuscript Preparation
F – Literature Search
G – Funds Collection

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ABSTRACT:

Introduction: The ability to react quickly to changing external stimuli, to move the body rapidly and precisely in any direction and to maintain the center of gravity above the support base, all contribute to maintaining balance in dynamic conditions. The Limits of Stability Test (LOS) provides information on the state of dynamic balance in a standing position.

Aim: Assessment of dynamic postural control in developmental age.

Material: 127 healthy children (65 girls and 62 boys) aged 6–17 years.

Methods: All children underwent LOS test (NeuroCom posturograph) with registration of: reaction time (RT), movement velocity (MVL), directional control (DCL), maximum excursion (MXE), and endpoint excursion (EPE).

Results: At the age of 6–7 years, we observed not fully developed jumping strategy and visual feedback mechanism in the control of movement. All tested parameters were significantly worse in children aged 6–9 years. After this period, a significant improvement in TR and MVL was noted, with no significant changes in subsequent age groups while significant improvement in MXE up to 12 years of age, and EPE and DCL up to 13 years of age was found. No significant gender differences were found in the LOS test parameters.

Conclusions: (1) LOS test showed significantly lower dynamic balance development in children aged 6–7 years; (2) The study showed a significant improvement in all parameters of the LOS test up to 13 years of age, which supports the termination of the function at that time.

KEYWORDS: balance maturation, balance system in children, limits of stability, posturography, static and dynamic balance

ABBREVIATIONS

DCL – directional control
EPE – endpoint excursion
LOS – Limits of Stability Test
MVL – movement velocity
MXE – maximum excursion
TR – reaction time

INTRODUCTION

Correct function of the balance system is determined not only by reflex reactions, but also the mechanism of direct feedback regulation, which controls the state of individual receptors depending on changing external conditions. A characteristic of this system which controls the state of static and dynamic balance in humans is, on the one hand, high flexibility for destabilizing stimuli, while on the other the presence of automatic muscle reactions. It points to central software in the organization of postural control, so in the developmental age some functions of this control, especially in the youngest children, can be expected to not be fully developed [1–15].

Maintaining balance at rest and in motion is linked with the necessity to maintain a center of gravity within the limits of the support base. Both while standing, as well as in motion, we observe oscillations of the center of gravity from the axis of gravity. The condition for maintaining postural stability is to remain within the space defined by Nasher (1986) as the limits of stability, within which the maximum oscillations of the center of gravity are located, without causing a loss of balance [16–18, 1, 19–23]. Stability limit values change depending on the support base and the angular velocity of the body, which is related to the nature and duration of the stimulus [8, 11, 14, 16, 18, 22, 23].

A test determining the limits of stability (Limits of Stability Test, or LOS) provides details about the possibilities of the examined

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person to consciously move the center of gravity to given targets in different directions, allowing to assess the dynamic balance in the standing position [16, 17, 21, 24, 25]. Incorrect results in the limits of stability test may be an expression of various pathologies. A delayed time of reaction could result from cognitive and/or motor disorders. Decreasing the center of gravity's movement velocity could indicate deficits within the central nervous system, with the inability to reach a target and poor directional control – symptoms of motor control disorders. Reduction of the center of gravity's oscillation distance in relation to the appropriate limit results in a decrease in stability during movements in everyday life, with susceptibility to falls [12, 17, 18, 20, 26].

The presented paper which comprises a second part of a scientific report regarding the development of postural control in healthy children aged 6–17 (the first part regarding the results of the mCTSIB test in these children was qualified for printing in "Polish Otolaryngology"), concerns the assessment of the development of ability to maintain dynamic balance using visual feedback as a key aspect of postural control.

PURPOSE OF PAPER

Assessment of dynamic balance development with determination of stability limits (age norms) in healthy children aged 6 to 17 in the LOS test.

MATERIAL

The study group comprised 127 otoneurologically healthy children (65 girls and 62 boys) aged between 6 and 17. The inclusion criteria were: healthy physical development, functional musculoskeletal system, eyesight, as well as age-appropriate hearing with normal functioning of the eustachian tubes and no balance disorders in static and dynamic tests (Romberg test and straight-line walking test with eyes open and closed).

METHOD

The children were divided into 6 age groups of 20–23 subjects (an equal number of girls and boys, with the exception of the first group, where there were two more girls, and groups two and three, where there was one more girl). Particular age groups included children who were over a certain age and at the same time did not exceed it by more than 6 months (group I – 6–7 years, II – 8–9 years, III – 10–11 years, IV – 12–13 years), V – 14–15 years, VI – 16–17 years).

In line with the procedure, during the test the subject set his feet in a place marked graphically on the posturographic platform. The computer screen located at the height of the child's eyes presented an icon located centrally (square) and surrounded by eight target points (in the form of squares), each located relative to the previous one by 45°, constituting the limit of the center of gravity oscillations determined by the computer program in relation to the height of the examined person. The children were instructed to situate it in the central square while maintaining a straight posture and using the icon in the form of a human silhouette displayed on the screen, which portrayed their center of gravity. Next, they were advised to wait for an audio signal and a visual signal (blue circle) in the illuminated target point to move their body toward it as fast as possible and through the simplest way. Each part of the test was recorded for 8 seconds.

The following parameters were recorded:

1. RT (*Reaction Time*) – the time expressed in seconds from the appearance of the visual signal and the audio signal to the beginning of movement towards the target;

2. MVL (*Movement Velocity*) – the average speed of the center of gravity to the target in degrees per second, recorded between 5% and 95% of the distance to the first endpoint;

3. EPE (*endpoint excursion*) – the furthest distance from the starting point after the first movement toward the target, expressed as a percentage of the stability limit;

4. MXE (*maximum excursion*) – expressed as a percentage, assuming that the theoretical limit of movement in a given direction meant reaching 100%;

5. DCL (*Directional Control*) – the ratio of the number of coordinated moves toward the target to the number of moves not following the direction to the goal, expressed as a percentage.

The study used a NeuroCom VSR Basic Balance Master posturograph with diagnostic, analytic and training software in version 8.0 VSR [25]. The compatibility of studied variables with the normal distribution was evaluated using Kolomogorov-Smirnov and Chi-square tests. Statistica software was used for statistical analysis. The statistically significant value was $P < 0.05$.

RESULTS

All qualified children were otoneurologically healthy, and body weight and height values in all age groups ranged between the 50th and 70th centile.

LOS test results

Upon the initiation of body movement toward the target, children from group I were found with a reflexive move of the torso forward with flexion of the hip joints (hip type strategy), which required special control of the course of study in this age group. According to the instructions, the respondents from the older groups used the jumping strategy without difficulty. Furthermore, the youngest children experienced great difficulty in maintaining the center of gravity in a central position visible on the monitor screen.

Reaction time

Tab. I. summarizes the average reaction times by age group.

The recorded reaction time for all subjects in individual directions ranged from 0.56 (± 0.11) to 0.92 (± 0.4) seconds. Analysis of the average reaction time values in all studied directions in relation to age showed a significantly longer reaction time in children from the two youngest age groups compared to older subjects. There were no significant differences in reaction time over 9 years of age or by gender.

The average center of gravity velocity (MVL) to the first EPE endpoint

Tab. II. Summarizes the MVL values in age groups in all studied directions.

Regardless of age, higher MVL values were noted in the lateral and forward directions compared to backward directions. There were no significant differences between the velocity of the center of gravity in right and left directions in any age group.

Group I children showed significantly lower MVL values for targets located in all directions compared to other age groups. These values increased linearly to the age of 10–11 (III group). Group II children obtained values of the studied parameter that did not differ from older children in the case of forward movements, while for backward and lateral movements, as in group I, MVL values were significantly lower than for other older children (10–17 years).

Analysis of the average total velocity achieved during movement of the center of gravity to the first endpoint in all tested directions showed significantly lower MVL values in the youngest children (groups I and II) in comparison with the other subjects. However, there were no significant differences in this respect due to gender.

Control of the center of gravity movement to the target (DCL)

Tab. III. presents the average DCL values for particular age groups.

Depending on the direction of movement and the age of the children, differences in its control were found. All subjects had the highest DCL values for forward-located targets, but it was significantly lower than the others in the youngest. These values increased slightly with age from an average of 71.5% in group I to an average of 82.3% in the oldest group. All patients had significantly worse control of backward movements compared to other directions toward the target, but also showed the greatest improvement with age (from 30.4% in children 6–7 years old in group I to 59% in the oldest group). In lateral directions, DCL also increased with age from 57.5% and 58.6% in group I to 73.4% and 76.2% at the age of 16–17 (group VI). There were no significant differences in right or left direction control.

Tab. IV. shows the significance of differences in total DCL values in all directions and age groups. In the youngest, directional control was significantly lower than in all other age groups, while in groups II, III and IV it was lower than the control value of children from groups V and VI. It is noteworthy that there are no significant differences in the two oldest groups in all tested directions, which suggests that the ability to control the direction of intentional movements has reached its final development by the age of 13.

Analyzing DCL values by gender, no significant differences were found between boys and girls in controlling any direction.

Tab. I. Average reaction times in seconds in children (in age groups) when performing intended body movements to a given target (in different directions). The standard oscillation included in brackets.

AGE GROUPS	FORWARD	BACKWARD	TO THE RIGHT	TO THE LEFT	TOTAL AVERAGE REACTION TIME
I	0.69 (0.28)	0.78 (0.38)	0.84 (0.28)	0.85 (0.25)	0.79 (0.2)
II	0.92 (0.4)	0.68 (0.25)	0.88 (0.27)	0.84 (0.23)	0.82 (0.19)
III	0.79 (0.25)	0.66 (0.22)	0.7 (0.19)	0.61 (0.16)	0.69 (0.12)
IV	0.89 (0.31)	0.8 (0.21)	0.66 (0.17)	0.73 (0.27)	0.77 (0.14)
V	0.78 (0.26)	0.66 (0.25)	0.66 (0.22)	0.66 (0.2)	0.69 (0.19)
VI	0.82 (0.32)	0.67 (0.21)	0.64 (0.19)	0.56 (0.11)	0.67 (0.15)

Tab. II. The average values of the center of gravity velocity in °/s in children (in age groups) when traveling the distance to the first EPE endpoint towards the target in different directions. The standard oscillation included in brackets.

AGE GROUPS	FORWARD	BACKWARD	TO THE RIGHT	TO THE LEFT	TOTAL AVERAGE REACTION TIME
I	5.1 (1.6)	2.3 (1.1)	5.5 (2.05)	5.56 (2.24)	4.64 (1.34)
II	6.6 (2.05)	2.26 (1.16)	6.5 (2.5)	6.4 (2.28)	5.42 (1.4)
III	7.3 (1.9)	3.3 (1.3)	8.8 (3.5)	9.5 (2.77)	7.29 (1.7)
IV	6.1 (1.5)	2.8 (0.84)	9.21 (2.8)	8.3 (2.9)	6.66 (1.5)
V	6.4 (2.7)	3.06 (0.9)	8.02 (2.8)	8.07 (2.8)	6.36 (2.02)
VI	6.9 (1.9)	3.28 (1.2)	8.87 (2.4)	9.06 (2.2)	7.04 (1.4)

Tab. III. Average direction control values – DCL (in%) of the center of gravity's movements toward particular targets in different directions. Standard oscillation in brackets.

AGE GROUPS	DCL FORWARD	DCL BACKWARD	DCL TO THE RIGHT	DCL TO THE LEFT	AVERAGE CONTROL VALUE OF ALL DIRECTIONS
I	71.5 (12.8)	30.4 (16.4)	57.5(11.6)	58.6 (14.3)	52.5 (13.7)
II	76.3 (7.6)	39.2 (16.7)	61.8 (10.6)	63.6 (9.2)	60.2 (8.6)
III	77.5 (11.1)	35.7 (16.2)	63.8 (13.7)	65.6 (11.1)	60.8 (10.3)
IV	74.8 (12.2)	46.4 (19.1)	66.2 (11.1)	69.8 (9.7)	64.4 (9.7)
V	82.4 (6.2)	60.1 (13.1)	74.2 (8.4)	71.6 (9.8)	72.3 (8.08)
VI	82.3 (6.7)	59.0 (17.6)	73.4 (9.1)	76.2 (7.01)	72.8 (8.1)

EPE test

Tab. V. summarizes the average distance values (in%) covered by the respondents in age groups from the moment of initiating body movement to reaching the so-called first EPE endpoint.

Regardless of the direction of movement, an increase in distance to the first endpoint with age was noted in all children, however it was dependent on the direction of movement, mainly in the case of backward movement. Backward distance to EPE reached an average of 32.2% ± 12.5 in children in group I, to 47.2% ± 15.8 in the oldest group, while forward movement reached an average of 78% ± 24.5 in the youngest, increasing to 85% ± 15.0 in children aged 16–17 (group VI). Similar values were noted in lateral directions, in which in children from group I they were 68.9% ± 18.1 to the right and 78.5% ± 17.5 to the left, reaching respectively 94.7% ± 14.6 and 104,9% ± 15.5 in the oldest group.

Analysis of the significance of differences in the average EPE values in all directions and study groups showed that the distances achieved

Tab. IV. Summary of the significance of differences (p) of the mean sum values of body movement control (DCL) in all given directions in age groups. Statistically significant differences are marked in red.

AGE GROUPS DCL %	I P	II P	III P	IV P	V P	VI P
VI		0.01	0.009	0.0002	0.000000	0.000000
p			0.85	0.182	0.0002	0.0001
VI				0.24	0.0004	0.0002
p					0.014	0.008
VI						0.88
p						

Tab. V. Summary of the average distances (%) to the first EPE endpoint in individual directions and in all directions combined, in age groups (reaching endpoint = 100%). Standard oscillation in brackets.

AGE GROUP	FORWARD %	BACKWARD %	TO THE RIGHT %	TO THE LEFT %	IN ALL DIRECTIONS %
I	78.0 (24.5)	32.2 (12.5)	68.9 (18.1)	78.5 (17.5)	64.4 (9.2)
II	91.3 (17.7)	30.1 (10.8)	76.0 (16.3)	79.3 (18.0)	69.2 (9.4)
III	79.1 (17.5)	34.2 (9.3)	86.0 (20.1)	87.2 (18.9)	71.9 (12.3)
IV	76.2 (23.2)	41.5 (12.9)	84.8 (22.8)	93.8 (16.5)	74.1 (13.6)
V	91.5 (13.8)	47.8 (16.4)	89.5 (16.6)	99.4 (20.0)	83.1 (9.5)
VI	85.9 (15.0)	47.2 (15.8)	94.7 (14.6)	104.9 (15.5)	83.2 (9.2)

Tab. VI. Average MXE values achieved in individual directions and age groups. Total MXE - -average MXE values in all directions combined. Standard oscillation in brackets.

AGE GROUP	MXE FORWARD %	MXE BACKWARD %	MXE TO THE RIGHT %	MXE TO THE LEFT %	MXE TOTAL %
I	104.7 (15.8)	41.5 (17.5)	90.5 (11.80	96.5 (17.3)	83.3 (8.2)
II	105.2 (13.4)	39.9 (17.1)	94.0 (18.7)	93.6 (18.5)	83.2 (9.9)
III	97.6 (14.8)	47.1 (13.1)	104.0 (15.9)	105.5 (17.3)	88.2 (9.0)
IV	92.7 (17.5)	55.6 (13.8)	106.9 (13.3)	111.2 (13.7)	91.6 (7.3)
V	102.1 (7.8)	61.0 (13.2)	106.8 (12.3)	111.5 (15.6)	95.8 (5.6)
VI	97.5 (12.3)	57.7 (17.1)	110.9 (10.0)	114.8 (12.9)	95.3 (5.9)

before the age of 13 (groups I–IV) were significantly lower than in older children, but due to the systematic increase in the distance covered towards the set target, with age and from the age of 14, no significant changes are observed in this respect. No differences in EPE values were found in relation to gender. EPE in all directions was 73.2% ± 13.3 in boys and 74.9% ± 12.8 in girls (p = 0.46).

MXE test

The values of the maximum intended excursion (MXE) in different directions are presented in Tab. VI. The ability of controlled excursion of the center of gravity in forward and lateral directions was well developed in the youngest children. However, the maximum backward movement in all children slightly exceeded the EPE value (EPE in children aged 6 years – 20%, MXE – 24%, in seventeen-year-olds EPE – 55%, MXE – 60%).

Maximum distances to the target located forward to children from groups I and II are significantly lower only than children from group IV, while in the backward direction, significantly lower distances were covered by children from groups I-III compared to older children. From the age of 12 (group IV), no significant changes in this respect were observed. With lateral movements, significantly lower maximum distances were achieved by children from the two youngest groups compared to the other respondents. From 10 years of age changes in this area were not significant.

MXE analysis in all studied directions showed significantly lower values in children from the three youngest groups (6–11 years). Above 12 years of age (groups IV–VI) no significant changes were found.

There were no significant differences in MXE values due to gender (on average 88.5% ± 10.7 in boys and 90.3% ± 8.2 in girls, p = 0.3).

Research results and discussion

Maintaining balance in dynamic conditions is determined by: the ability to react quickly to changing external stimuli, fast and precise body movement in any direction, and maintaining the center of gravity above the base of support [5, 18, 15]. Developmental disorders in the form of poor motor coordination, lower and inadequate motor skills and inferior postural control are one of the most common neurodevelopmental disorders in about 6% of typically developed children in early school age [20]. As a dynamic test, LOS permits the assessment of the subject's ability to move in different directions without losing balance, which is necessary when performing numerous daily activities (e.g. walking, running or jumping). Due to developmental changes occurring with age, the reference point in the assessment of postural control in children must be normative values based on studies of otoneurologically healthy children of different ages. Publications regarding postural control in healthy children based on the stability limit test are scarce, refer to a limited age range or the control group comprises healthy children in the study of children with various diseases [1, 16, 17, 20, 24, 27]. Often the subject of reports is the assessment of repeatability of LOS test results in the context of follow-up examinations after the rehabilitation of injuries acquired by young athletes, which confirm the value of the test on the one hand, while on the other hand indicate the occurrence of a learning result in relation to some parameters [21–23, 26, 28].

In the course of the study, during initiation by children of movement of the body towards the target, we observed a tendency to lean the torso forward with simultaneous flexion of the hip joints (hip strategy) in the youngest group at the age of 6–7, suggesting that the jumping strategy is not fully developed in this period [5, 20]. In older age groups, the jumping strategy was easily applied by children according to the study procedure, i.e. a motor reaction whose axis were the ankle joints [29].

Performing the LOS test required functional visual and proprioceptive feedback from the subjects, which are substantial mechanisms of postural control, especially in dynamic conditions [4–6, 8, 11, 14, 18, 30]. In the youngest group there were significant difficulties in maintaining the center of gravity in the center of the monitor screen, which was not observed in older children. This may be due to differences in the share of visual and proprioceptive

information in postural control in the youngest children, as some authors point out, but also to the incomplete development of central sensory integration in the nervous system [4, 10, 11, 14, 18, 30].

One of the tested parameters of the LOS test was reaction time, which is significantly related to the ability to notice and process visual information, which results in the activation of a conscious motor reaction towards the target. Its value also depends on the degree of attention and concentration, and multisensory-motor integration associated with the development of higher nervous function [4, 7, 10, 11, 14]. The mean reaction time values ranged from 0.79 ± 0.2 s in six-year-old children to 0.67 ± 0.15 s in seventeen-year-olds, while in the 6–9 age range they were significantly longer compared to older children. In a study by Fong et al. who conducted studies in children aged 5–11, but did not assess this parameter in age groups, the average reaction time for all children was 0.78 ± 0.28 s [20]. According to Geldhof et al., the average reaction time in the LOS test in children between the age of 9 and 10 is 0.70 ± 0.15 s [24].

No differences in reaction time depending on gender were found [13].

The velocity of the center of gravity (MVL), distance to the first endpoint (EPE) and the final largest move achieved by the children towards the target (MXE) showed differences due to direction and the age of subjects.

Even the youngest children were capable of controlling the center of gravity in the intended direction, showing a well-developed function of anticipation of movement (feed-forward), although the aggregate value of MXE associated with visual feedback in all directions achieved by children aged 6–9 years was significantly lower than in older children [6, 10, 29]. In respect of forward moves, only the subjects aged 6–7 achieved significantly lower values of postural speed than the others. In the case of lateral moves before the age of 9, a linear increase in speed was noted, followed by no significant changes in older children. Lateralization (all right-handed children) had no effect on the speed of lateral moves, as no significant speed differences were found depending on moving to the right or to the left, similar to the study by Fong et al. [20]. The speed of movements towards the target located to the back was significantly lower than in other directions in all children, while in the children from the two youngest groups it was significantly lower than in older children. At the same time, large instability of all subjects was observed during backward movement of the body. Similar observations were made by other authors who noted nearly 50% lower speed of movement in this direction in children [20, 24]. With age, the increase in postural speed in backward direction was small and did not even reach similar values of speed in other directions. Similar results were reported for EPE and MXE values, which was also stated by Geldhof et al. in his study [24]. The analysis of these parameters in relation to age showed a mediocre increase in the EPE value in all directions (already the youngest subjects showed high values of these parameters), however, until the age of 13 (groups I–IV) in subsequent age groups this increase was significant in forward movements and in relation to the total EPE, in lateral directions and backwards until the age of 11 (groups I–III).

In the study of the maximum movement of the center of gravity, even children aged 6–7 years were able to achieve the set target and the indicated stability limit (value 100%) in forward and lateral directions, while in the reverse direction its value ranged from 41.5% in group I up to 57.7% at the age of 17 years. However, significant differences in this respect were shown in the youngest age groups. In the case of forward movement, children aged 6–9 reached significantly lower maximum distances to the target than children aged 12–13 (group IV), and in lateral directions – significantly lower values than other age groups. In the case of backward movement and considering total values in all directions, a significant increase in the achieved distance to the target was noted until the age of 11 (group I–III).

The increase in the value of directional control with age illustrates the development of the child's ability to precisely control movement in the intended direction. Already the youngest examined children presented the best control of forward movement compared to other directions (although still significantly worse than children aged 14–17). The control values in this direction increased to a relatively small extent with age (from 71.5% in group I to 82.3% in group VI). Control of right and left movements in children aged 6–7 was lower and did not exceed 60%, reaching a value of 76.2% at 16–17. Movement of the center of gravity to the target located behind the body was not only characterized by lower speed, but also poorer control of direction. Similar observations regarding inferior control of backward direction were provided by Geldhof et al. in children of 9–10 years old – 57.65 ± 16% and Fong et al. in children 5–11 years old – 49.13 ± 23.95% [20, 24]. At the same time, it was in this direction that we recorded the greatest improvement in control with age (from 30.4% in group I to 59% in group VI), which occurred most frequently up to the age of 14. Sum values of all directions in children aged 6–7 years were significantly worse than the other age groups, and significantly lower in children aged 8–13 (groups II–IV) than in those from groups V and VI. It was only from the age of 14 (groups V and VI) that no significant differences were observed in this area, which indicates the achievement of sensory integration, allowing adequate control of any movements performed in the base of support [4, 5].

The LOS test showed that in the scope of the studied dynamic equilibrium function in standing position, there is further development in children aged 6 to 17 years, which is in some respects completed only after 13 years of age. However, there were no significant differences in parameters due to gender. Schedler et al. have meta-analyzed scientific reports on differences in the development of static and dynamic balance due to age and gender in children aged 6-18 years. These studies show a significant improvement in age-related postural control, while they present inconclusive results regarding gender differences [13].

SUMMARY AND CONCLUSIONS

1. The stability limits test showed further development in the field of postural control in dynamic conditions in children above 6 years of age, which is completed in terms of all tested parameters up to 13 years of age;

2. The development of the studied function is not monotonic. Children aged 6–9 show significantly lower development in terms of dynamic balance compared to other age groups, with significant improvement after 9 years;

3. Stability limits values developed on the basis of healthy Polish children aged between 6 and 17 may be the basis for assessing this function in the diagnosis of balance disorders in children.

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