

Computerized static posturography and laterality in children. Influence of age

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Purpose: The present study aims to explore relationships between footedness and posturographic assessment in children aged from 4 to 10. A real-time computerised device was used on a force plate for movement analysis. It requires a static posturography to assess postural control of children with the same handedness and footedness. *Methods:* Thirty eight right-handed and right-footed children organized in three age groups of 4 to 6 years old, 6 to 8 years old and 8 to 10 years old participated in the study. Two static tests, the Unilateral Stance (US) and the Weight Bearing Squat (WBS) were performed, jointly with a dynamic balance examination (Limits of Stability (LOS)). All these tests were executed to explore the body capability of the right/left side. *Results:* The study demonstrated significant differences involving the right/left side among the three age groups. Better performance on the youngest children's right part and on the oldest children's left part was observed. Differences between the left and right sides of the body were noticeably revealed by posturographic assessments in right-handed and right-footed children. *Conclusions:* Age seemed to be a determinant for these outcomes. Maturation of the vestibular at the ages of 6 or 7 years might explain the observed differences between the youngest children and older children.

Key words: children, balance platform, biomechanical response

1. Introduction

An active sensorimotor control system is required for maintaining the postural balance [28]. Human balance and adequate postural control determine the effective performance of daily living activities. The most common and complex daily activities that require balance and propulsion are those of bipedal movement (e.g., walking, running and hopping). Normal human gait is considered to be symmetrical in most visual and computerized gait analyses. However, asymmetries in the walking cycle have been found in several studies

[8]–[26]. Furthermore, other studies [2], [30] noted that an asymmetric relationship between functional gait and laterality in the lower limbs is often observed. Diop et al. [8] conducted a study on the ground reaction forces asymmetry of the normal gait in children and noted that several dissimilarities between the left/right sides among children aged 4–6 years were identified. They assumed that the right lower limb is more responsible for propulsion among children in this age group. Another study [11], revealed that the same individuals could often be right-footed during attributions of movement (e.g., ball kicking) and left-footed during postural stabilization. Peters [20] de-

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defines the dominant foot (or preferred foot) as the one that is used to control an object or to lead out in stepping or kicking, whilst the foot that is used to support the actions via lending postural and stabilizing support of the preferred foot is referred to as the “nonpreferred” limb.

Therefore, the above-mentioned evidence in the literature raises a range of questions. For example, if there is one preferred lower limb to pilot the movement while the other foot is in favour of postural stabilization, then does postural control need to obtain distinction between left and right sides? As Diop et al. found asymmetries in gait analysis among children aged 4–6 years but not among older children, then does the postural control of the right and the left side are considered to be affected by age-related factors and vary among the different age groups? Lateral preference behaviour has already risen the interest of the scientific community [23], but there are only a few studies that focus on children’s footedness behaviour [10]–[17]. According to our knowledge and based on the literature review, the link between footedness and posturography has never been investigated in children.

This study aims to explore whether or not the asymmetry between the right/left side among the children with the same footedness and handedness could be identified by posturographic assessment. Another objective of the study is to observe any age-related significant differences.

2. Materials and methods

The present study was approved by the ethical committee of the Champaign Ardenne Region (CERCA). The ethical committees of the Institutional Review Boards (IRBs) approved the consent procedure. Furthermore, all parents (kins, guardians or caregivers) and children were informed about the aim and objectives of the study and agreed to participate through a written consent form. The authors declare no funding source.

2.1. Study sample: children

Setting of the study was the Saint Etienne hospital. A total of 45 healthy children aged from 4 to 10 years old, comprised the study sample at 22 boys and 23 girls. Apart from the age criteria, one more inclusion criteria was set; only children that were right-

handed and right-footed would be included in the final study sample. Furthermore, children with preceding medical history of neurological or musculoskeletal problems were excluded from the study. Thus the parents filled a questionnaire about children’s medical history of diseases (locomotion early pattern, motor system diseases, physical activities and frequent otitis) that might influence balance and postural control. All children that were finally enrolled in the study went through physical examination that included neurological examination and measurement of body weight (kg) and height (cm in standing position). All the examined children had regular ability of understanding the instructions and no shortage in the sensory-perceptual was observed. Children were grouped in 3 age-groups, as follows. Group 1: 15 children aged from 4 to 6 years old (mean age = 5.3 ± 0.6 years, mean weight = 19.5 ± 1.7 kg, mean height = 112 ± 5.4 cm), group 2: 15 children aged from 6–8 years old (mean age = 6.9 ± 0.6 years, mean weight = 26.5 ± 3.8 , mean height = 122 ± 6.4 cm), group 3: 15 children aged 8–10 years old (mean age = 8.8 ± 0.6 years, mean weight = 31.6 ± 4 kg, mean height = 133.8 ± 6.2 cm).

2.2. Methods

2.2.1. Limb preference assessment

All children were tested on the basis of three foot activities, namely kicking a ball, foot-stamping an imaginary bug, foot-tracing letters during standing and three hand activities: writing, throwing a ball, stacking cubes. Partial tasks were scored and recognized as left, right mixed-handed and footed, as it was reported in studies on children footedness. Only 38 out of the 45 were included in the final study sample according to the inclusion criteria (right-handed and right-footed).

2.2.2. Posturographic assessment

Posturographic evaluation was performed using the Balance Master® (version 7.0 from NeuroCom International Inc. 1997). This is a computerized device that has the ability to operate at the participants’ facility while they are performing particular balance tasks that are vital in daily living and assess their ability real time. This device [33] has been used extensively in adults and elderly [7] rather than in children, with little evidence for children in the literature [3].

The following posturographic tests that assess laterality were chosen. They were two static tests: i) Uni-

lateral Stance (US), ii) Weight Bearing Squat (WBS) and one dynamic balance test entitled Limits of Stability (LOS). The posturographic assessment was performed for all children after the end of a normal primary school day.

2.2.3. Description of the 3 tests

1. WBS

The Weight Bearing Squat test measures the body weight borne's percentage by each leg in several positions: with the knees fully extended and with the knees at 30, 60 and 90 degrees of knee flexion. Squatting positions considerably increase the stress on the knees and ankles. In addition, the weight bearing differences may be identified even though they are not measurable in a less challenging position. The trial length (duration) is instantaneous. Expressing the results as a percentage of body weight allows comparisons between patients of different weights.

2. US

The Unilateral Stance test measures the postural bend velocity when the patient is standing stable on the force-plate on one foot, while opening-closing the eyes. Duration of each trial is 10 seconds and each of the four conditions consists of three traces. The quantity of sway is measured in degrees per second for all three trials of each condition.

3. LOS

The Limit of Stability is the individual's maximum distance to bend in a specified direction that is determined in terms of the angular distance from the vertical; without misplacing balance, stepping or reaching for assistance. The limits of stability test quantify various movement types related to the patient's capability to bend speedily and precisely from a center target to eight peripheral targets and temporarily preserve stability at those positions. During this assessment the situation of the individual's center of gravity is demonstrated on a screen as a cursor that provided a visual feedback to the individual. The duration of each trial is 8 seconds. Five parameters are automatically measured, namely directional control, reaction time, endpoint excursion, sway velocity and maximum excursion. The reaction time is defined as the time between the command to move and the action starting in seconds. Movement velocity is the average speed of the center of gravity movement in degrees/second. Endpoint excursion is known as the distance travelled by the gravity center on the primary

effort to reach the target, expressed in percentage of stability limits. At this point the primary movement in the direction of the target ceases and corrective movement begins. The maximum excursion is expressed as the farthest distance attained during the trial, also known shown as percentage of stability limits. It indicates the best subsequent movement accuracy endeavour after the primary one. Directional control is a comparison of the amount of movements in the envisioned direction to the movement from the target amount, defined as a percentage, where a directional control score of 100% can be given to a patient's movement directly towards the target as a straight line. To demonstrate a hypothetical difference between the right and the left side with this dynamic test, the authors combined the three right directions (right front, right, right backward) to afford an average right score and the same was done for the three left targets.

2.2.4. Statistical analysis

All tests were conducted at a significance level of 0.05 using the SAS v9.1.3. The Sign test was used to explore any potential asymmetry between the left/right side within each group. Then the Kruskal–Wallis test was performed to compare the three age groups of children. In case any significant variations were identified between the three groups, a post-hoc test was run to compare each pair of groups by means of Wilcoxon–Mann–Withney test with Holm's correction of p -values.

3. Results

As it was mentioned previously, thirty eight children were identified as right-handed and right-footed after the limb-preference assessment and included in the final study. The mixed-footed children were not included, while there weren't enough left-handed children to constitute a reliable sample. Therefore, 13 children constituted the first and youngest age group (4–6 years old), 12 children were included in the second age group (6–8 years old) and 13 children in the third one (8–10 years old).

3.1. Main findings

1. WBS

The youngest group favoured the right side: the youngest children bore, on average, the main part of

body weight on the right side at any degree of knee flexion. The two other groups favoured the left side: they bore, on average, on the left side where the main part of body weight at any degree of knee flexion. Knees in extension are presented in Fig. 1.

Significant variations were identified through the Sign test ($p = 0.043$) showing an irregularity between the right and the left side in the age group of 4–6

years, while no significant asymmetry was found in the two other groups. The Kruskal–Wallis test and the post hoc test established a significant difference between the age group of 4–6 years and the two other age groups ($p = 0.006$). Results for 90° of knee flexion are illustrated in Fig. 2.

No significant asymmetry was found in each group, but the Kruskal–Wallis test was significant

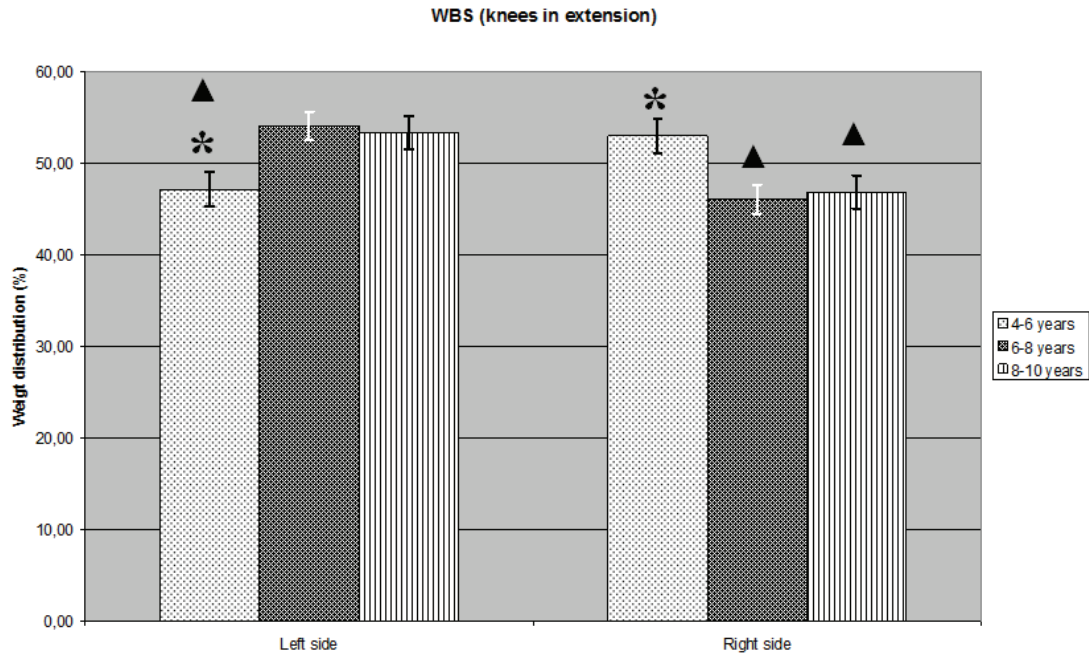


Fig. 1. WBS Knees in extension (statistics; %, pvalue). * Significant difference ($p < 0.05$) between the right and left side. ▲ Significant difference ($p < 0.05$) between the youngest group and the two others

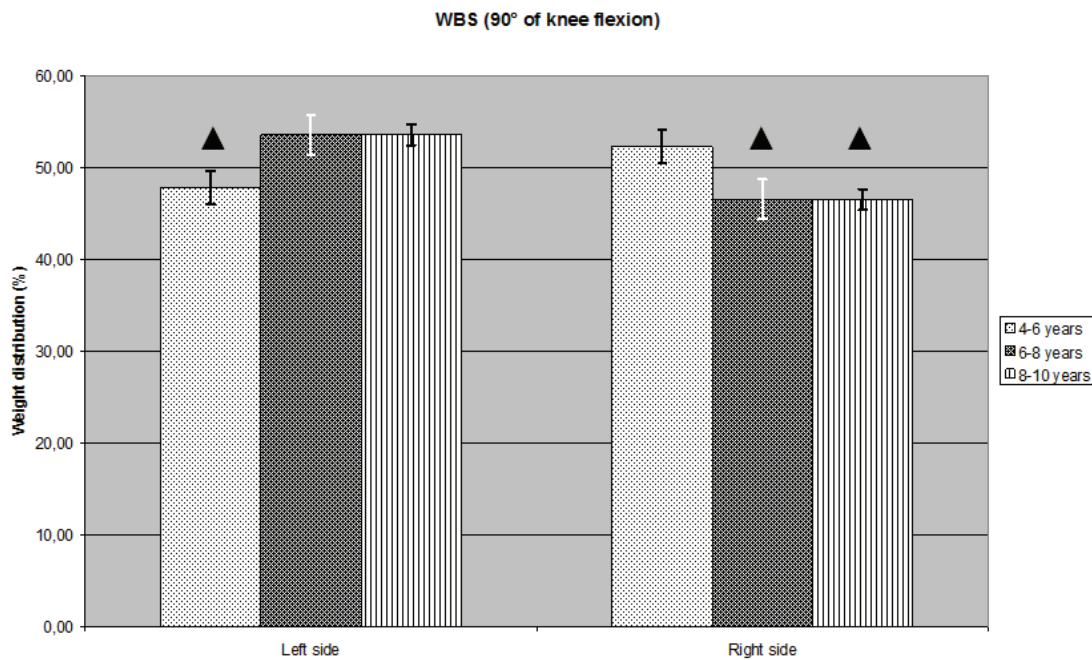


Fig. 2. WBS 90° of knee flexion (statistics; %, pvalue). ▲ Significant difference ($p < 0.05$) between the youngest group and the two others

($p = 0.039$) and the post hoc test determined a significant difference between the age group of 4–6 years and the two other groups.

2. US

The age group of 4–6 years swayed more on the right foot in the case of opened eyes and more on the

left foot in the case of closed eyes. Additionally, the age group of 6–8 years swayed more on the right foot with opened eyes and more on the left foot with closed eyes. The age group of 8–10 years swayed more on the right foot with eyes open and more on the left foot with their eyes closed. Overall, a decrease of the sway velocity between the youngest group and the two other groups was observed (Fig. 3).

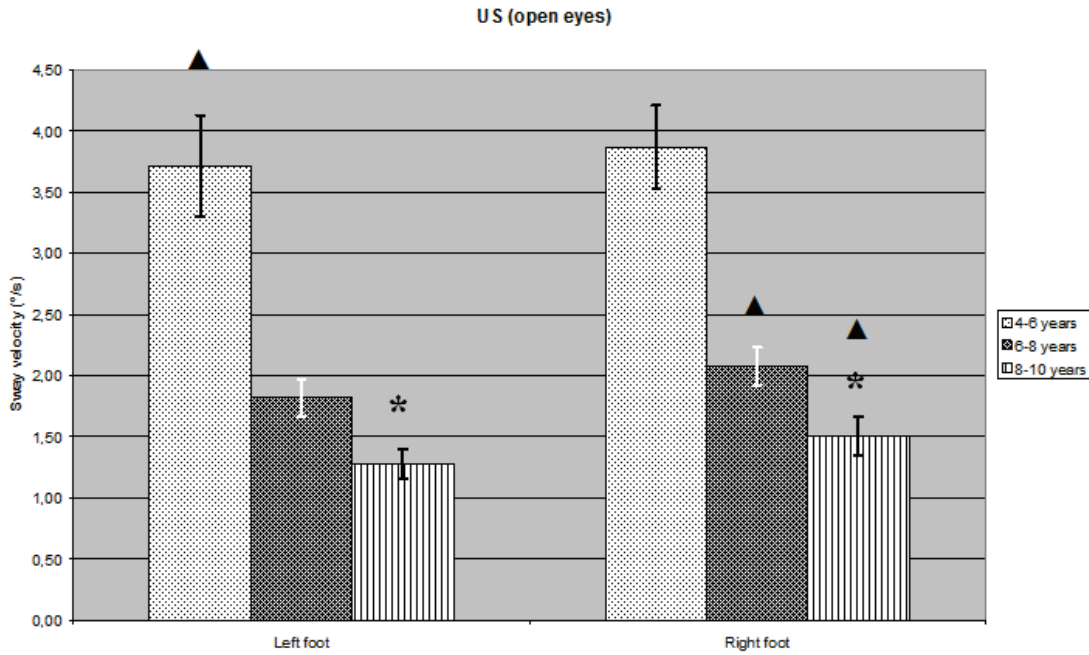


Fig. 3. Sway velocity (US) between age groups, with eyes open. * Significant difference ($p < 0.05$) between the right and the left foot. ▲ Significant difference between the youngest group and the two others for both sides

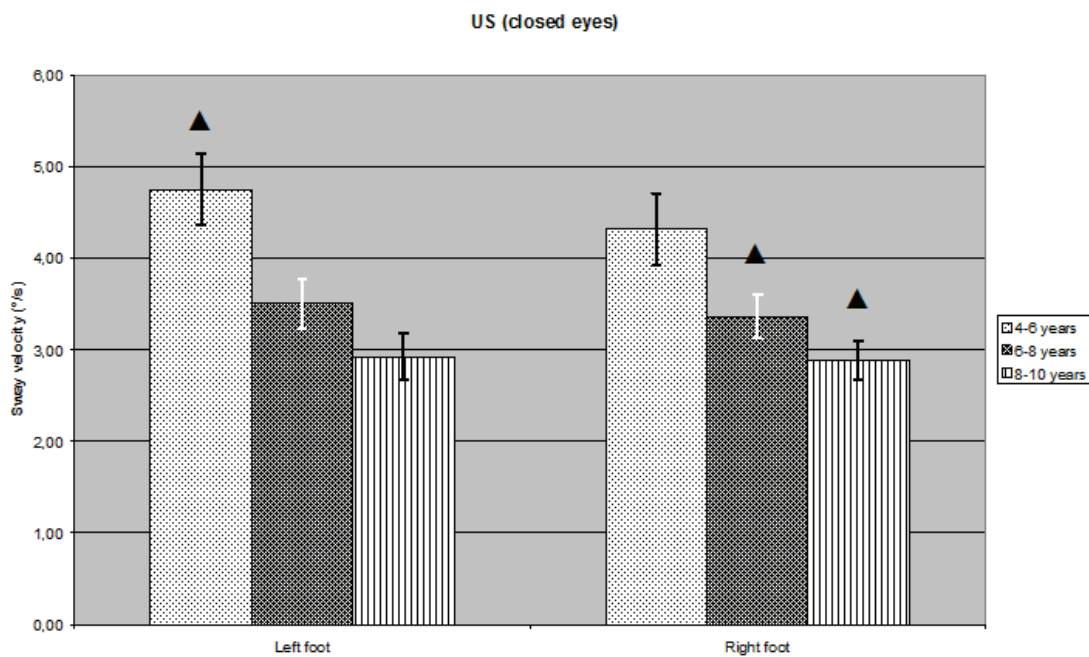


Fig. 4. Sway velocity (US) between age groups, with eyes closed. ▲ Significant difference ($p < 0.05$) between the youngest group and the two others for both sides

A significant difference ($p = 0.030$) was found in the age group of 8–10 years, pointing out that the oldest group swayed more on the right foot and that balance was better on the left foot. In the two other groups there was no significant difference between the left and right sides. However, significant difference of $p < 0.01$ was revealed between the age group of 4–6 years. In addition, the two other groups presented even higher signifi-

cant difference with the sway velocity in the youngest group on right and left foot (Fig. 4).

No significant difference was observed between right and left foot in each of the three age groups. There was a significant difference comparing the age group of 4–6 years and the two other groups meaning that sway velocity was significantly higher in the youngest group on right and left foot.

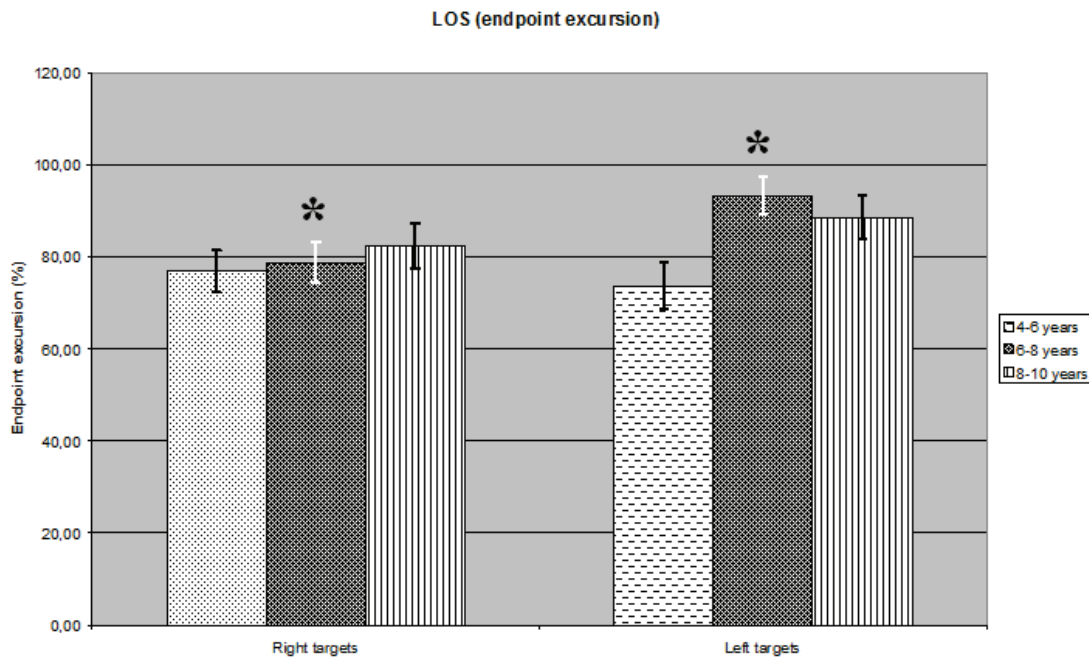


Fig. 5. LOS endpoint excursion (statistics; %, p -value). * Significant difference ($p < 0.05$) between the right and left targets

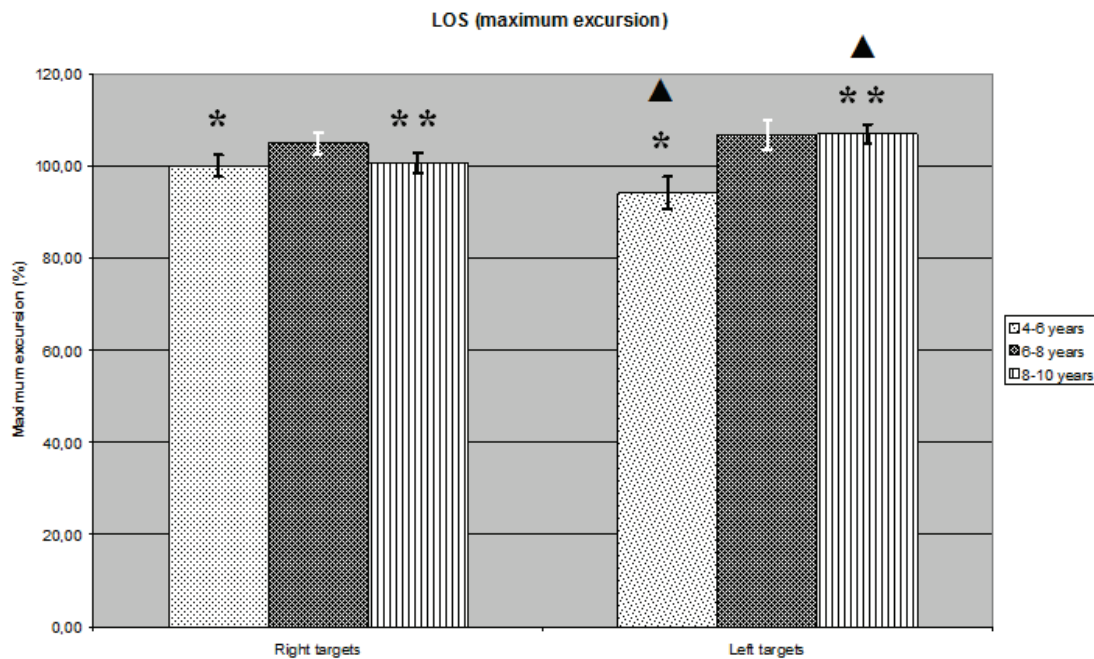


Fig. 6. LOS Maximum excursion (statistics; %, p -value). * Significant difference ($p < 0.05$) between the right and left targets. ** Significant difference ($p < 0.05$) between the right and left targets

3. LOS

A significant difference ($p = 0.034$) was found between the right and the left targets in the age group of 6–8 years indicating that the left side has superior results. The results were also better on the left side for the age group of 8–10 years, though no significant differences were observed. Better results with no statistical difference were gained on the right side with the youngest group. However, comparing the three age groups, no significant difference was obtained.

Furthermore, significant difference between the right and left targets in the age group of 4–6 years ($p = 0.019$) and in the 8–10 years ($p = 0.034$) was revealed through the Sign test. The youngest group had better results on the right side and the oldest group on the left side. The age group of 6–8 years had better results on the left side though it was not statistically significant. Between the three groups for the right targets, there was no significant difference based on the Kruskal–Wallis test. Significant results were observed for the left targets, while the post hoc test demonstrated a significant difference only comparing the youngest and the oldest group.

The right and left targets in the age group of 4–6 years varied significantly ($p = 0.001$). The youngest group had better directional control for the right targets. Directional control was better on the left side for the age group of 6–8 years and 8–10 years, although no significant differences were observed. For the three

groups for both sides there was a statistically significant difference. For the right targets between the age group of 4–6 years and the two other groups, there was a significant difference, while for the left targets, the significant difference was only comparing the youngest group and the oldest group.

4. Discussion

The lower margins are engaged in different posturo-motor, locomotor and operant activities such as operating a control pedal, crushing something or kicking a ball [30]. During standing upright tasks, they require major mechanical and neuromotor adjustments. For example, as the body center of gravity transfer above one leg provides this leg full dependability of body supporting duties, and tolerating the other leg to employ in operant activity [30]. Laterality in lower limbs expresses the limb dominance existence that denotes the leg that is used for mobility (operant activity). At the same time, the non dominant limb supports the other [26]. For postural supporting, one foot is used to engage the antigravity muscle extension on the same side while flexion of the support muscles occurs on the other side for most voluntary activities [24]. The majority of the individuals favour the foot on the same side as the dominant hand for

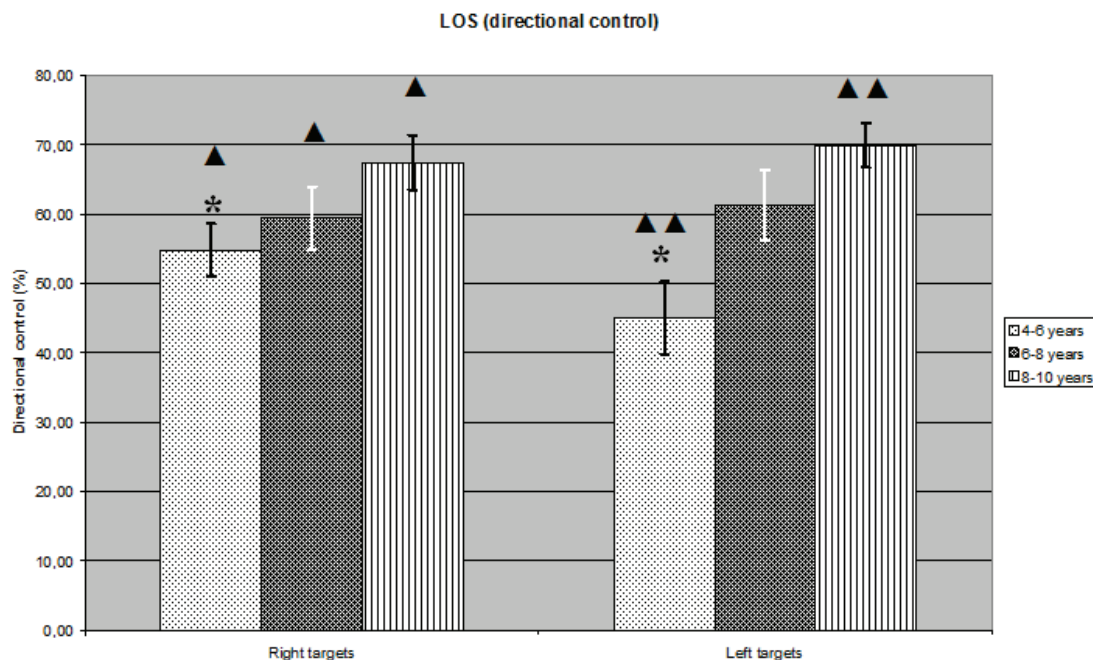


Fig. 7. LOS Directional control (statistics; %, p -value). * Significant difference ($p < 0.05$) between the right and left targets. ▲ Significant difference ($p < 0.05$) between the youngest group and the two others. ▲▲ Significant difference ($p < 0.05$) between the youngest group and the oldest group

operant activities, especially right-handers [8], with the contralateral leg for the postural maintenance. Thus, as right-handedness is the most frequent due to the fact that most individuals are right-footed for mobilization action and left-sided for postural control [11]. An explanation concerning the stabilizing features of footedness is proposed in general theory of cerebral lateralisation in the literature [24]. About two thirds of the human population has a left otolithic advantage that motivates a reliance on the body left side for postural control and the right side for voluntary (mobilizing) motor functioning according to Previc [24]. These arguments are based on the observations on asymmetric prenatal ear progress, labyrinth and foetus position (cephalic-leftward-right ear facing out) through the final trimester. This theory's fundamental significance is the ipsilateral association between the labyrinth and the antigravity extensor muscles (mainly the gastrocnemius and soleus). Compatible with Pompeiano [22], while the labyrinths apply bilateral control over the antigravity reflexes, their excitatory effect is greatest for the ipsilateral muscle groups. For instance, the left labyrinth stimulation leads to greater extension of the left antigravity muscles and diminished extension on the right side. Consequently, along with Previc, lateral asymmetries in antigravity excitatory strength arise from an imbalance in vestibular functioning (i.e., an expansional advantage on the left side owing to asymmetric prenatal progress). However, laterality in lower limbs seems to establish progressively as children get older. Gentry and Gabbard [11] reported a lifespan study classifying trichotomously (right-footedness, left footedness and mixed-footedness) in a large group of children, adolescent and young adults from 4 to 20 years old. They observed a significant incidence of mixed-footedness in 4 and 8 years olds, afterwards a significant shift towards greater right-footedness by the age of 11. Later there preferences remained comparatively stable. During childhood (especially early ages), right-side domination is not as pronounced in foot preference actions and more children appear not to establish a favoured limb (i.e. they are mixed-footed). This right-sidedness shift with increasing age has been well demonstrated by Porac [23].

Research studies that deal with the symmetrical or asymmetrical issue behaviour of the lower limbs are numerous but, according to our knowledge, posturographic assessment of children of the same handedness and footedness is uncommon. Right-sidedness recognizes individuals who are robustly lateralized, thus, reveal more pronounced functional asymmetries in comparison to their inconsistent and left-sided peers

[17]. A limb preference pattern was not eventually a significant factor in gross-motor agility in the Iteya et al. [17] study about young boys aged 4 to 6 years and Gabbard [10] found no correlation between foot dominance and motor skill in 4-year-old. This suggests a lack of foot preference in this age group. We would have expected asymmetries that would be easily detectable by posturography in our study for those strongly lateralized children aged from 4 to 10.

An obvious difference of weight bearing between the right and the left side was expected in the WBS; i.e. the main part of the body weight would be on the left side in charge of the supporting and postural maintenance in right-sided children. According to our expectations, we found some asymmetries between the right and left side. The older children (6–8 and 8–10 years old) bore, on average, the main part of body weight on the left side at any degree of knee flexion but none of our results were significant. On the contrary, in the 4–6 years old children, the present study revealed that they favoured the right side at any degree of knee flexion. The only significant difference was at 0° of knee flexion. Weight bearing asymmetries were significantly different between the youngest group and the two other groups at 0° and 90° of knee flexion. Then the question was how those results can be explained. Weight bearing asymmetries could be explained by the different weight of the right and left side of the body. In right-sided individuals, the result of greater reliance upon the left leg for antigravity expansion is its greater overall size and, muscle and bone weight [5]. As reported by Previc [24], this evaluation is based on the fact these physic asymmetries are not present at birth but carry on to grow during adolescence and that the greatest asymmetry in muscle weight occurs for the gastrocnemius and soleus muscles that are the principal ones are used in antigravity support. In literature no other anatomical asymmetries were demonstrated, i.e., the relationship between limb dominance and foot width was scrutinized and no significant relationship was reported [8]. The greater weight of antigravity muscles (gastrocnemius and soleus muscles) might be explained by greater muscle activity on the left side. Tan [29] demonstrated, in right-handed adults, a greater extensor tonus (tested in the soleus muscle) on the left or “nondominant” leg. The results in the older children weren't significant, consistently with the literature. What could explain the difference between the three groups of children? According to the literature, the process of maturation between the right and the left side in the growing child might be hypothesized. First, there is a common agreement that the main motor

cortex of each hemisphere manages most phases of the voluntary movement mainly in the body contralateral side and ontogenesis data suggested that right cerebral hemisphere development precedes the left one [30]. Second, according to Previc's theory, antigravity expansion on the body left side that appears before voluntary motor dominance on the right side. Thus, perhaps, over time, experience of the utilizing the body left side for postural maintenance (in a bilateral context) may affect strength of laterality and so the weight asymmetry among the body right and left sides. This notion of maturation has been mentioned in Gabbard and Hart's study [10] on young children (4–6 years old), in which, contrary to adults, only right-handers demonstrated better performance (on a speed-tapping task) with the right hand while for use of either foot no bias was noted, and left-handed children did not show significant performance bias for hand or foot. The authors attributed the difference between young children and adults to experience (mainly foot pedal controls in automobiles) or maturation. Nevertheless, in this study, a solid explanation for the significant right bias of weight-bearing in the 4–6 years-olds is still lacking.

The US is a typical unipedal task. In reference to Previc's theory, better postural control (lower sway velocity) on the left side in those right-footed children should be expected. The three groups swayed more on the right side with eyes were opened but the only significant results were for the 8–10 year-old children who swayed significantly more on the right side with eyes were opened, which means that those children are more stable on the left side. Thus Previc's theory constitutes an explanation for this result and we can speculate that the difference between the 3 groups may be attributed to experience (the use of the left limb for postural stabilization) or maturation (of antigravity extension on the left side). Nevertheless, our results are quite disappointing considering others publications. Some authors [14] described that foot partiality for kicking (the operative limb) was not intimately associated with limb choice for unipedal stability tasks, for example balancing on one foot. For Hart and Gabbard [13], limb favoured for stabilization in the bilateral context is independent of the limb choice in a unilateral condition for example a one-leg static balance. Thus, most individuals switched limbs for stability in the unilateral situation and favoured the right side for stabilisation on the one-leg balance task. This activity was based on the apparent complexity of the task, so that the dominant (favoured) limb possibly was reserved for the more complicated phase of a behavioural action [12] and it appears with most bilateral

evaluations that the stabilization is easier than the mobilizing conditions, e.g., standing while performing a task with a foot. Furthermore, Hart and Gabbard [13] in their study on mobilizing feature of footedness found that right-footed individuals choose 98% of the time the right foot for unipedal task (drawing their initials in a sand box and rolling a golf ball around a circle) execute while the subject was settled on an amendable chair with knee angle at approximately 90°. Contrary to their conclusions, as they exclude the need of standing postural maintenance, their results seem to be in agreement with the theory of the predominant left side for postural balance while performing an operant task with the right lower limb in a bilateral context. Also, Peters [20] mentioned that the difference between the manipulated foot and the one that maintain stability can be only established if the subject is standing, forcing a choice of the leg for support and the leg for manipulation.

The LOS is a dynamic test assessing the ability to lean in different directions without losing balance: this ability is necessary for many daily activities such as taking clothes from a wardrobe, picking items from the floor or putting on shoes, for example. Comparing this ability between right and left side could be interesting in right-sided children. In the present study, some difference between the right and the left side were found and were unequal among the three groups. The endpoint excursion was significantly better on the left side for the 6–8 years-old children while the maximum excursion was better on the right side for the youngest children and on the left side for the oldest children. Significant "preference" for the right side in the youngest children and the left side in children over 6 years old was revealed through the present study. The Previc's theory offers a possible explanation. According to Previc [24], antigravity extension of the left side relies on the predominance of the left vestibular and it emerges before voluntary flexion (control) on the body right side. Furthermore, lateral whole body tilt, a very effective stimulus for the otoliths (that react to linear acceleration and continuous head tilt relative to gravity), shifts the body's center of gravity and thus requires a strong activation of the ipsilateral antigravity responses to prevent a fall. Evidently, all the children had the capacities of leaning on the left and the right side but those capacities were different according to age. For Shumway-Cook and Woollacott [27], the 4–6 years-old period signifies a period of transition where children are developing adult-like sensory integration strategies for managing redundant sensory inputs and determining multimodal sensory inconsistency. While in Forsberg and

Nashner [9] study it was proposed that the performance of children below the age of 7¹/₂ resembled that of vestibular deficit patients. A maturational process of the vestibular around 6 or 7 years might explain the better performance on the left side for the right-sided children aged 6 to 10 years. Concluding, the right bias in the youngest children is challenging to explain, although there are various studies that have assessed it [10]–[30].

5. Conclusion

Differences between the body left and right sides were clearly observed by posturographic assessments in right-handed and right-footed children. Age seems to be a determinant for these outcomes: some of our results demonstrated better performance on the right side for the youngest and on the left side for the older children. According to the literature [36], footedness must be a part of neuro-psychological evaluation owing to the feet sensitivity in reflecting certain maturational and motor system's functional characteristics. In addition, it seems that some kind of maturation of antigravity extension on the left side occurs around 6 or 7 years old. Further studies on left-handed and left-footed children of the same ages are proposed as a next step.

In conclusion, the human body's posture control remain a very complex system of organs and mechanisms which controls the body's centre of gravity (COG) over its base of support (BOS) (Blazkiewicz [1], Piecha et al. [21], Iwańska and Urbanik [18]).

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