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Original paper

Repeatability of frequency of corrective foot pressure during balance control in children aged between 2 and 7

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The frequency of corrective signal (the centre of corrective (COC) signal), which is the decomposition of COP (centre of pressure) and estimated COM (centre of mass) time series, is one of the indicators reflecting the quality of postural control during stance. Young children, in the period of intensive development, gradually improve the quality of postural control in a daily life. The purpose of this paper was to describe the time series of corrective centre of foot pressure repeatability in young children aged between 2 and 7 during body stability in natural stance position. 272 healthy children aged between 2 and 7 were divided into 6 age groups. Two AccuSway force platforms were used (one foot of the subject was on one platform, the second foot, on the other). The COP trajectories were the basis for the calculation of the frequency stability indices in frontal and sagittal planes for the left leg and right leg separately. The COC signals were collected by the method based on the Kuczyński viscoelastic model. In order to assess the repeatability, the concordance correlation coefficient (CCC) was used between the 1st and the 2nd trials, the 2nd and the 3rd trials, and the 1st and the 3rd trials. The maturation of postural control system goes rather slowly in two youngest groups which showed the poor repeatability in COC frequency between the 2nd and the 3rd years of life. From the 4th to the 7th year of life the inter-session repeatability rapidly increases in three consecutive trials. Poor difference of frequency concordance was found between the left and right lower limbs. It is concluded that the frequency of corrective foot pressure is the reliable indicator of postural control for children aged between 4 and 7, but not for younger ones.

Key words: *postural control, young children, frequency, repeatability*

1. Introduction

Some investigations of body balance state using posturography to assess pediatric deficits are discussed [1]. The description of the repeatability of postural control makes it possible to appreciate the investigations of body stability as a diagnostic tool in pediatric diseases.

The repeatability of postural control in stance position is the subject of research connected with the analysis of the centre of pressure (COP) excursion [2]–[4]. GOLDIE et al. [5] investigated the repeatability of balance during standing on both feet in adults and found that it was weak when estimated on the basis of the COP trajectory, but was much better when forces and torques were analyzed. In children aged between 2 and 7 in the period of intensive motor development, the problem of repeatability is still not well enough recognized. McEVOY and GRIMMER [6] suggested in their study that the standind posture in the children at a primary age (5–13 years), quantified by five whole body or segmental angles, did not change significantly in tests repeated twice within an hour. The analysis of body stability control in children aged between 4 and 9 revealed high repeatability of stance time on one lower limb, but low repeatability of the stance quality [7]. The frequency of corrective signal (centre of corrective (COC) signal), which is the decomposition of COP and estimated COM (centre of mass) time series, is one of the indicators reflecting the quality of postural control during stance [8], [9]. CHERNG et al. [10] claim that 7–10-year old children show a higher frequency of foot pressure than adults and

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in their opinion that is the symptom of ankle strategy development in body stability control. RIACH and HAYES [11] also confirm a decrease in COP frequency with the age of children. It is assumed that children, in the period of intensive development, gradually improve the quality of postural control in a daily life. The question arises: how does the repeatability of frequency indicator change with the age of children?

The purpose of this work was to describe the time series of corrective centre of foot pressure repeatability in young children aged between 2 and 7 during body stability in natural stance.

2. Method

272 healthy children aged between 2 and 7 were divided into 6 age groups which are represented in the table. The Bioethical Commission agreed to the study. The parents gave their informed consent prior to the study.

Each child took a standing position on the force platform, with their feet parallel to each other, at the distance between them approximately equal to the pelvic width. Data were collected for at least 1.5 min. The next three 20-second consecutive trials were cut out. During the collection of the data the child's arms were hanging freely, and no movements were allowed during the trial. Two AccuSway force platforms were used (one foot of the subject was on one platform, the second foot – on the other). The trajectories of left and right leg COPs were recorded at 100-Hz sampling rate.

The COP trajectories were the basis for calculating the frequency stability indices in frontal and sagittal planes for the left and right legs separately. The COC signals were collected by the method based on the Kuczyński viscoelastic model [8], [9]. The exponential smoothing module in Statistica 8.0 software separated the COC time series from the COP signals. As a result, two signals were obtained: smoothed COP which may be identified as the center of mass (COM) excursion and residual signal representing the center of corrective (COC) movement of feet (figure 1). The model describing the COC signal is given in the following form [8]:

Table. Characteristics of age groups of children

Age groups	Range of months	Body mass (kg)	Body height (m)	Body mass index
2-year-olds ($N = 35$)	18–29	13.2 (±1.6)	0.89 (±0.04)	16.76 (±1.24)
3-year-olds ($N = 50$)	30–41	14.8 (±1.8)	0.97 (±0.05)	15.58 (±1.88)
4-year-olds ($N = 35$)	42–53	17.5 (±3.6)	1.05 (±0.05)	15.77 (±1.72)
5-year-olds ($N = 59$)	54–65	20.1 (±3.9)	1.11 (±0.06)	15.91 (±2.55)
6-year-olds ($N = 60$)	66–77	21.9 (±3.7)	1.18 (±0.05)	15.50 (±2.12)
7-year-olds ($N = 33$)	78–89	22.2 (±3.2)	1.20 (±0.06)	16.35 (±2.37)

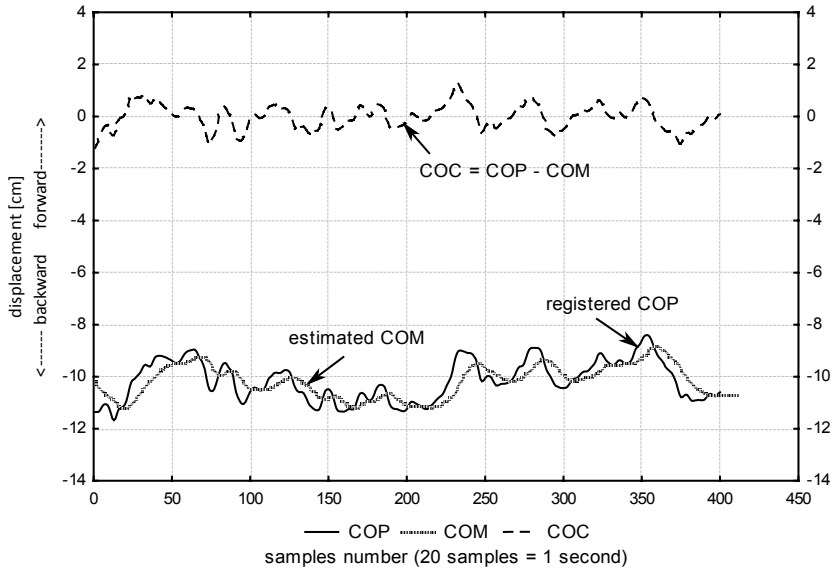

Fig. 1. The way of estimating the COM and COC time series in a 5-year-old child

$$Z_t = p_1 Z_{t-1} + p_2 Z_{t-2} + a_t,$$

where:

Z_t represents the output of the model and reflects the time variability of the actual foot adjustment force at the moment t,

a_t is the white noise,

p_1, p_2 are the parameters which are to be estimated in ARIMA (2, 0, 0) model.

The parameters p_1, p_2 served as the variables to compute the frequency (peak frequency (*PF*)) of the COC signal according to the following formula [9]:

$$PF = \arccos \frac{\frac{(p_2 - 1) \cdot p_1}{4 \cdot p_2}}{2 \cdot \frac{\pi}{\Delta}},$$

where Δ (s) stands for the step of sampling equal to 0.05 s.

The normality of the variability of COC frequency variables was confirmed using the Shapiro–Wilk test. Therefore the parametric tests were used for further evaluations.

In order to assess the repeatability, the concordance correlation coefficient (CCC) was used between the 1st and the 2nd trials, the 2nd and the 3rd trials, and the 1st and the 3rd trials. This coefficient was calculated according to the following formula:

$$\mathrm{CCC} = \frac{2 \cdot r \cdot sd_1 \cdot sd_2}{sd_1^2 + sd_2^2 + (\bar{x}_1 - \bar{x}_2)^2},$$

where:

r is the coefficient of correlation between two trials,

$\bar{x}_1, \bar{x}_2$ and sd_1 and sd_2 are the averages and standard deviations of the two trials.

The comparisons were made separately for age groups, and left and right foot.

The statistically significant difference between CCC of the left and right legs was checked using the parametric test for correlation coefficient difference.

The repeatability was assessed based on the interpretation of CCC (similar to the interpretation of the correlation coefficient): 0–0.2 – very low repeatability, 0.3–0.4 – low repeatability, 0.5 – medium repeatability, 0.6–0.7 – good repeatability, 0.8–1.0 – high repeatability.

3. Results

The concordance of COC frequency was very poor in children aged between 2 and 3 and ranged from 0 to 0.36 in both planes in each comparing option (figures 2 and 3). No significant differences were found between the left foot and right foot in the youngest groups of subjects as well as in the other age groups. In 4-year-old children, CCC of corrective signal rapidly increased and reached the medium and good repeatability from 0.45 to 0.70 in frontal plane and from 0.36 to 0.54 in sagittal plane.

Five-years-old children revealed a decreasing concordance of COC frequencies compared with four-year-olds. Only in comparison with the 1st and the 2nd

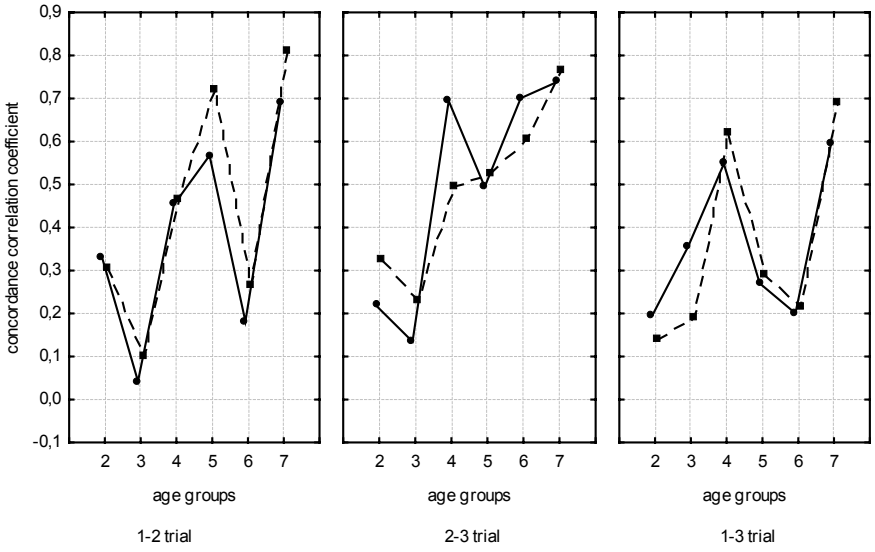

Fig. 2. Concordance correlation coefficients for COC frequencies in frontal plane (solid line – left foot, dashed line – right foot). No statistically significant differences between left foot and right foot

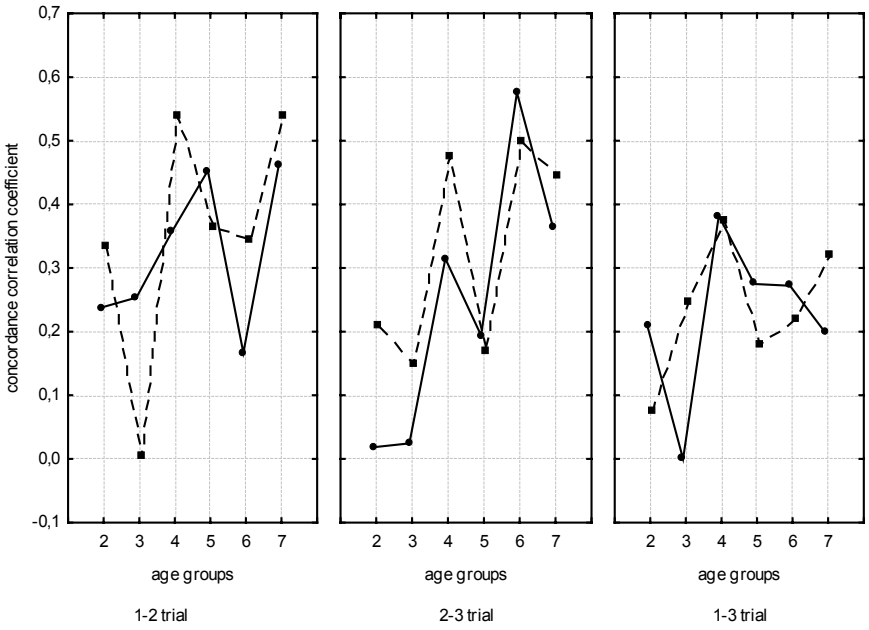

Fig. 3. Concordance correlation coefficients for COC frequency in sagittal plane (solid line – left foot, dashed line – right foot). No statistically significant differences between left foot and right foot

trials in frontal plane the concordance increased in five-year-olds up to the level beyond medium (figure 2). In the next comparison of trials, the CCCs of both feet were consecutively lower, i.e. up to the level of 0.28–0.3 in the third option. In the sagittal plane, the concordance of COC frequencies also became lower in the second and the third comparison of trials than in the first one, where the CCC values ranged from 0.36 to 0.45 for both feet (figure 3).

Six-year-old children revealed much higher concordance of COC frequencies in the second comparison of trials (0.61–0.7 in a frontal plane and 0.5–0.58 in sagittal plane) than in another comparisons where the CCC values reached a low concordance in both feet (figures 2 and 3).

Seven-year-old children displayed generally higher values of CCC in frontal plane (0.6–0.8) than the other age groups in all options of comparison. The concordance of COC frequencies in sagittal plane was lower than in frontal plane and showed the medium level (0.46–0.54) in the first comparison of trials, but in the next one it became worse (0.20–0.32) (figure 3).

4. Discussion

Based on the results we can notice that the maturation of postural control system goes rather slowly in the two youngest groups which is probably the reason for the poor concordance in COC frequency, so 2- and 3-year-old children showed low repeatability of the frequency of corrective foot movements independently of the comparing option. This fact proves that children at this age are able to control body sway in a different way each time. FOUDRIAT et al. [1] also observed in 3-year-olds the ability to ignore misleading sensory inputs to maintain balance during Equitest investigation, but the older ones revealed the transition to adult-like balance responses although even 6-year-olds were not complete for all sensory conditions.

From the 4th to the 7th year of life the inter-session repeatability rapidly increases in the three consecutive trials. STEINDL et al. [12] stated the maturation of proprioceptive function of postural control in 3–4-year-old children, so it seems that the repeatability of COC excursion frequency is connected with the development of postural control. An improvement in postural stability was observed in the children between the ages of 4 and 5 [1], thus the results in this paper confirm the norm in age-related development of postural control.

Only 6-year-old children showed poor concordance in the first and the third comparison of trials in frontal plane with reference to younger or older ones. This suggests that 6-year-olds should be prepared for investigation of body sway by standing for about 20 seconds on the platform just before the registration of data. The other groups of children revealed

similar level of concordance in the first and the second comparison although the values of CCC were slightly higher in the first option. It is presumed that the preparation for registering the data of body sway control for each age group of children is recommended. The distribution of the results in sagittal plane confirms that the second comparison of trials was more reliable than the first and the third ones for almost all age groups except 5-year-olds. COC frequency concordance was better in the first than in the second comparison of trials, so that children at the age should not be specially prepared for the registration of body sway like the other age groups.

The repeatability of COC frequency was noticed to be a little higher in frontal plane than in sagittal one in each age group of children which means that the lateral body sway is more repeatable than the anterior-posterior sway. That is probably why the median spectral frequency in the medial-lateral direction in children and adult groups was not different as CHERNG et al. [10] reported. Each consecutive comparison of trials in frontal plane reveals that the corrective foot pressure frequency in both foot is controlled in the repetitive way. The second comparison of trials reflects the age-related development of children in concordance with COC frequency control which increases with the age of children (figure 2).

5. Summary

The best repeatability of COC frequency of the 2nd and the 3rd trials in 6-year-olds suggests that the age group should be prepared for the trial standing for about 20 seconds on the platform just before the registration of data. Children at the age of 4-, 5- and 7-years reveal medium or higher level of repeatability of COC frequency excursion in the two first trials so they are ready for registering body balance trial just after they strike a correct position on platform.

Poor difference of frequency concordance in both planes between left and right lower limbs in consecutive trials, in most subjects, allows us to certify that it is not necessary to analyze the repeatability of COC frequency separately for each leg.

It is concluded that the frequency of corrective foot pressure is a reliable indicator of postural control in 4–7-year-old children, but not in younger ones.

Acknowledgement

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