KINEMATICS OF WALKING OF SIX-YEAR-OLD HEALTHY CHILDREN

by

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The paper outlines the studies on gait of six-year-old children having a good general health state and the body posture in norm. The research was performed at the Center of Child's Health Promotion and Fitness, whereas, the data analysis was carried out at the Center of Locomotion Research in Gdańsk. The study involved the utilization of a video-computerized system. Registration of gait was performed both in the sagittal and frontal plane.

The gait study considered the following kinematic quantities: length and time of double pace, velocity, walking frequency, the width of feet positioning during gait and the angular values of body parts in joints.

The kinematic analysis of translation motion quantities for the whole body demonstrated characteristic features of a healthy six-year-old child's gait: the length of double pace was 83.6% of body height, the width of feet positioning during gait was 13.2% of the relative lower extremity length and 80% of the hip joint distance, the longitudinal foot axis (toes) abduction from the walking direction was 10°; the time of double pace was 0.92 s and included the support sequence of one extremity (61%) swing sequence (39%) and support sequence of both extremities (12%). During the support sequence for one extremity valgity of the calcaneal bone (the calf-tarsus angle was 8.5°) and a varus deformity of the femoral bone according to the calf in the knee joint (of 5°) were observed. The gait velocity was 1.09 m/s at a frequency of 1.09 Hz.

The gathered data of walking velocity gave way to evolving a gait model for healthy six-year-olds. The obtained model of walking in the function of velocity will be used as a reference pattern for further studies on the gait of children with abnormalities in body posture.

Key words: gait, healthy children, kinematics, model

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Introduction

The development of the locomotor abilities contributes to the time of early childhood which is the age of 2 - 6 years. Not only it is acquiring new motorical abilities as running or gamboling but also consolidating the gait stereotype once initiated in the end of the first year of life.

Striving for perfection, gait of a six-year-old becomes acquired enough for the child to maintain a locomotive independence. It is an outcome of many factors as physical development, maturation of the central nervous system and the most important, experience [Teklin 1996].

The given Polish and world literature in majority presents data regarding pathological gait. It characterizes the walking of children and young people suffering from different myoskeletal and neural illnesses [Bannon et al. 1980, Kalinowska et al. 1998, Sloman et al. 1980, Syczewska et al. 1997]. Seldomly, studies on the gait of healthy children especially in pre-school age are found.

The purpose of this study was to research into the most significant gait features and maintaining a reference material for further gait analysis of children with abnormalities in body posture and children with pathological walking. The walking style characteristic of a healthy child at its peak of early childhood can be a model while aiming at physical activity improvement at that age or a practical prompt for the therapeutic rehabilitation of ill children.

Material and methods

The study of gait was carried out among 33 children aged 5.5 to 6.5 (14 boys and 19 girls). The inclusion criteria for the entry of the study was a good general health state, the body posture in norm and proper configuration of lower extremities. Pediatric and body posture examinations were performed by medical doctors at the Center of Child's Health Promotion and Fitness, whereas, the gait investigation was carried out by the authors of this paper from the Center of Locomotion Research of Jędrzej Śniadecki University School of Physical Education and Medical University School of Physicians in Gdańsk.

Subjects were divided after Winter [1984] onto three groups. They were selected on the bases of different gait velocities: fast (F-I), medium (M-II), slow

(S-III). The standard deviation (SD) of the velocity was the basis for subject categorization. The S-II group was within the range of -1 to +1 SD (Tab.1).

Table 1. Selected morphological and functional features of six-year-olds (categorized to three subgroups) whose velocity was: fast (F-I), medium (M-II), slow (S-III); [means ± SD (ranges)].

FEATURE / GROUP	**F - I** **n = 6**	**M - II** **n = 21**	**S - III** **n = 6**
Body weight [kg]	23.8 ± 2.1 (21.0 - 27.0)	22.5 ± 3.4 (17.0 - 30.0)	21.9 ± 2.3 (18.5 - 25.0)
Body height [cm]	122.7 ± 6.3 (114.0 - 133.0)	118.8 ± 6.1 (106.0 - 128.0)	120.0 ± 4.01 (118.0 - 124.0)
Relative lower extremity length [cm]	64.0 ± 4.66 (57.1 - 71.8)	62.9 ± .15 (55.4 - 79.10)	62.9 ± 2.50 (59.3 - 66.7)
Distance of hip joints while standin [cm]	9.9 ± 0.71 (9.0 - 11.3)	10.7 ± 1.09 (9.0 - 13.0)	10.2 ± 0.56 (9.6 - 11.3)
Width of feet positioning in gait [cm]	7.5 ± 1.5 (6.0 - 9.4)	8.4 ± 1.5 (6.4 -11.2)	8.4 ± 1.7 (6.0 - 10.1)

Body posture evaluation according to Dega's instructions [1983] included viewing it from the front, back and from above, i.e. in the sagittal, frontal and transversal plane. The measured quantities were: length of the lower extremities, foot length and width, width of hip joints and ranges of joint movement in the shoulder and pelvic girdle. In addition, the configuration of the knee, tarsus and arch of the foot were examined. For determining the longitudinal arch of the foot a plantocontourographic and podoscopic method were used. The given imprints were compared with the plantar surface image in the podoscopic mirror and furthermore, evolved with the Wejsflog's method [1955]. The utilization of the podoscope allowed an evaluation on the static / dynamic activity of feet which are put under static symmetric pressure, i.e. while standing.

The gait was registered with a video camera in sagittal and frontal plane. During the recording the children walked in a straight line, with a natural manner, three times in both directions: perpendicular (for sagittal plane) and then along, towards and away from, the camera lens (for frontal plane). They were barefoot and had the characteristic body points, joints and the posterior surface of the longitudinal calf- heel axis marked with contrasting bands. Each subject before recording was instructed about the speed of walking (vigorous walking was recommended), with the forward eyesight direction and with unrestrained motion of the upper extremities while directed downwards. Additionally, before registration a few blind trails in front of the camera were made. In the further analysis of each translation motion quantity in both planes a mean value from all three trails was utilised.

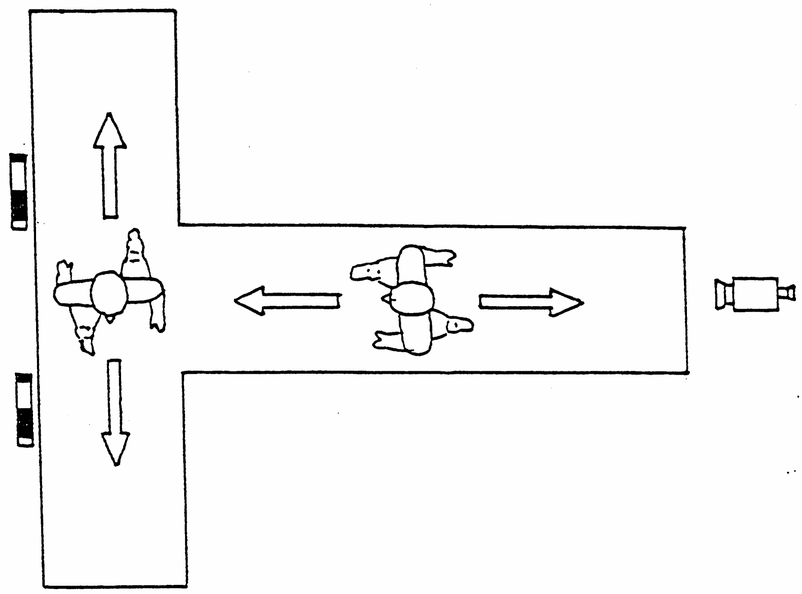

Fig. 1. View of the televising location from above.

The recording was played frame by frame at a 25 Hz frequency. Together with the interpolation the range of error was estimated as $\Delta t = 0.02$ s [Erdmann et al. 1996, 1998, Kuzora 1995] (Fig. 1 - 5). For data processing a multimedia card, a commercial program Video-Cap and a Kuzora's program „Ort" is used.

In the sagittal plane the collected data were: time of double pace (the cycle from placing one heel on the floor to putting it down again), time of support sequence and swing sequence for one extremity and time of support sequence for two extremities. The double pace length, velocity and frequency were calculated.

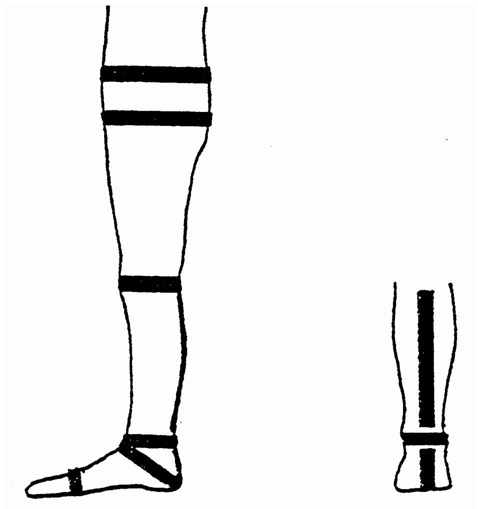

Fig. 2. Examples of marking of characteristic points (especially joints) on the child's body.

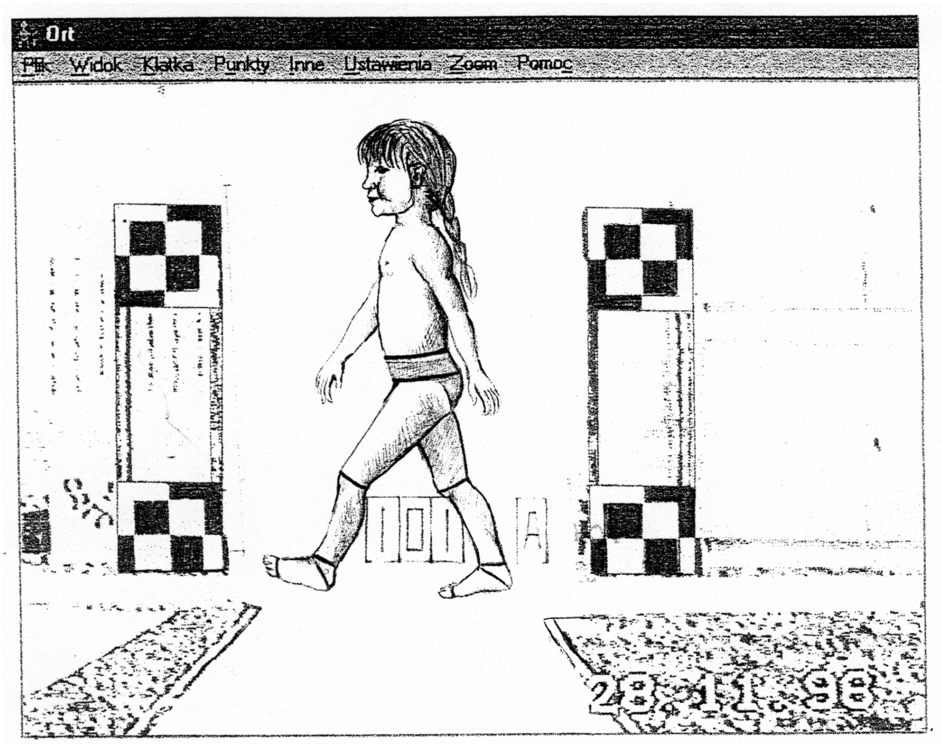

Fig. 3. View of a camera viewfinder (slightly retouched).

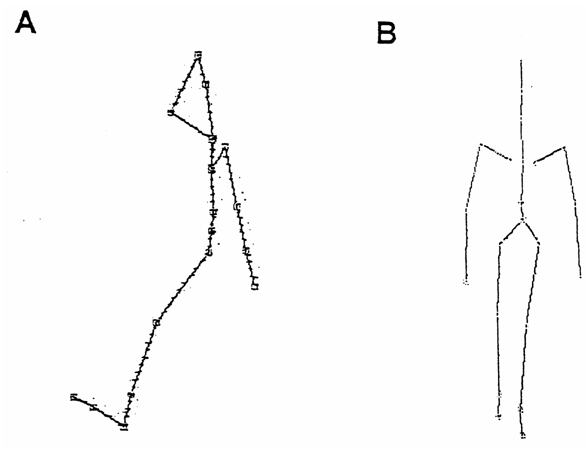

Fig. 4. Segmental models of a child's body in: A - sagittal plane, B - frontal plane.

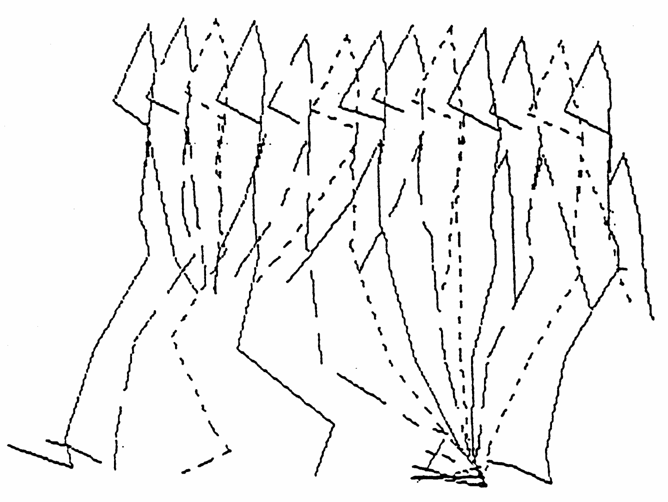

Fig. 5. Cycle of gait cinegram. For the 25 Hz frequency player, here: the scanning was done every second frame.

In the frontal plane the following data were considered: width of feet span (according to the lower extremity length measured from the anterior superior iliac spine to the medial ankle, and according to the with of separation of hip joints). The procedure of obtaining this diameter was as follows: on the first frame the distance of one foot (mid-heel) to the middle walking direction line (line on Fig. 7) was measured and on the other frame the same distance for the

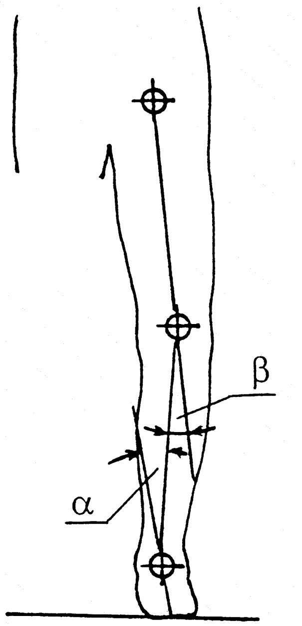

Fig. 6. Angles in the frontal plane: α - the calf - tarsus angle, β - the thigh-shin angle.

other foot was measured. The sum of these two distances gave the width of feet positioning.

For determining data of each limb, measurements were performed during the support sequence of the extremity, when its angles taking into account sagittal plane were nearly zero. The following angular values according to other planes were taken into account: deviation of the calf according to the tarsus, positioning of the shin and thigh in the knee joint (Fig 6), rotation of the femur in the hip joint. The rotation was determined by the changing projection of the foot. While viewing the foot from the front the deviation of its longitudinal axis (measured at its anterior edge - Fig. 7) from the walking direction was measured. The value of this distance according to the foot's mechanical length, i.e. the distance between the projection of the ankle axis on the floor and the anterior foot edge, was the tangent of the rotation angle from which an angle was obtained.

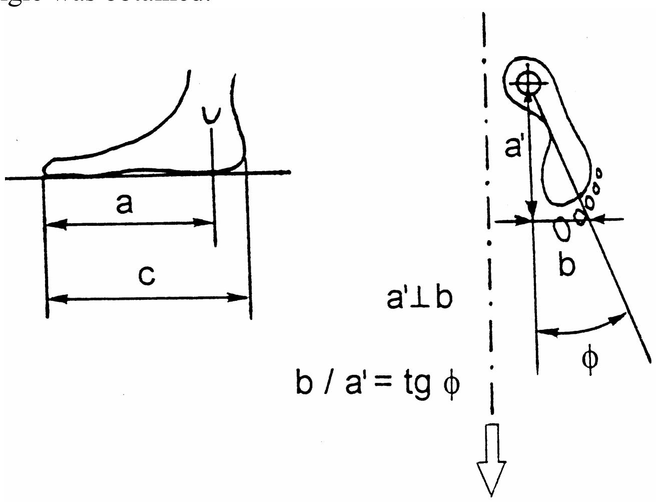

Fig. 7. Obtaining the tan ϕ of the thigh rotation angle in hip joint

Results and discussion

On average (± standard deviation, S. D.) the body height of the 33 subjects was 119.8 ± 5.9 cm and ranged from 106.0 to 133.0 cm, whereas, the body weight was 22.6 ± 3.09 kg and ranged between 17.5 and 30.0 kg. The group mean for height and weight were appropriate for the age standard. Moreover, the proportions of these measures for all subjects were regular and did not go beyond the vast norm ranges (i.e. 5 - 95 centile on the centile chart by the Mother's and Child's Institute).

I. The results of the quantities of translation motion for the sagittal and frontal plane are given in Table 2. In the sagittal plane, the group mean for the length of double pace was s = 1.00 m, (ranging from 0.85 to 1.24 m). This equaled 83.6 % of the mean body height. Furthermore, the time of double pace t = 0.92 s and ranged between 0.84 and 1.00 s. The double pace (cycle) included: the time of support sequence for one extremity (t = 0.56 s; ranges 0.48 - 0.64 s) which formed 61 % of the cycle, the time of swing sequence (t = 0.36 s; ranges 0.28 - 0.40 s) which formed 39 % of the cycle and the time of support sequence for both extremities (t = 0.11 s; ranges 0.08 - 0.13 s) which formed 12 % of the cycle (Fig. 8). The mean frequency of double pace f = 1.09 Hz and had a range of 0.96 - 1.19 Hz. The mean velocity of walking v = 1.09 ± 0.07 m/s and varied from 0.92 to 1.41 m/s.

The calf - tarsus angle α = 8.0° for the right foot (RF) and α = 9.0° for the left foot (LF) with a variation of 4.0° - 15° (RF) - 19° (LF). This value indicated the pronation degree of the calcaneal bone or rather represented its valgity during the sequence of extremity's mid-position and foot laying down on the ground.

Furthermore, the mean thigh-shin angle of the knee joint (in RF and LF) measured in the frontal plane during a single extremity support sequence was β = 5.0° and oscillated between 0° and 8.0° (RF), and 9.0° (LF). The thigh versus shin positioning was varus.

For the frontal plane the differences between the angular values of both extremities were statistically insignificant.

Table 2. Confrontation of the results on translation motion quantities in sagittal and frontal planes and selected morphological and functional features [means ± SD (ranges)].

FEATURES	SI	Own research N = 33 6 year	Stolze et al. N = 12 6 year 8 m.	Bannon i wsp. N = 8 8 year
Body mass	kg	22.6 ± 3.09 (17.0 - 28.0)	25.1 ± 3.5	
Body height	cm	119.8 ± 5.93 (114.0 - 133.0)	126.5 ± 7.4	134.0
Double pace length	m	1.00 ± 0.09 (0.85 - 1.24)	1.11 ± 0.12	0.99
Double pace time	s	0.92 ± 0.06 (0.84 - 1.00)	1.01 ± 0.08	0.84
Time of support sequence for one extremity	s %	0.56 ± 0.04 (0.48 - 0.64) 61.0 ± 1.90 (57.0 - 64 .0)	0.61 ± 0.05	62.0
Time of support sequence for both extremities	s %	0.11 ± 0.02 (0.08 - 0.13) 12.0 ± 1.71 (9.0 - 14.0)	0.10 ± 0.01	12.0
Time of swing sequence for one extremity	s %	0.36 ± 0.02 (0.28 - 0.40) 39.0 ± 2.02 (37.0 - 42.0)	0.41 ± 0.04	38.0
Frequency of double pace	Hz	1.09 ± 0.07 (0.96 - 1.19)	1.18 ± 0.11	1.19
Velocity	m/s	1.09 ± 0.13 (0.92 - 1.41)	1.10 ± 0.16	1.20
Ankle angle in frontal plane R [α] L	deg	8.0± 2.96 (4.0 - 15.0) 9.0 ± 3.49 (4.0 - 19.0)		
Knee angle in frontal plane R [β] L	deg	5.0 ± 1.91 (0.0 - 8.0) 5.0 ± 1.82 (0.0 - 9.0)		
Deviation of foot from walking R direction [ϕ] L	deg	10.2 ± 1.50 (7.7 - 15.3) 9.9 ± 1.33 (7.5 - 12.2)	6.8 ± 4.6	
Leg length	cm	63.12 ± 4.71 (55.4 -79.1)	64.6 ± 5.0	
Width of feet positioning according to hip joints' width	cm	10.5 ± 1.0 (9.04 - 13.00)		
Width of feet positioning according to lower extremity's length	cm	8.3 ± 1.55 (56.6 -11.5)	8.0 ± 2.38	
Relative length of lower extremities to the width of feet positioning	%	13.6 ± 2.80 (8.14 - 19.5)	(12.4)	6.8 (to body height)
Width of hips joints to width of feet positioning	%	80.0 ± 6.93 (55.0- 103.0)		
Length of double pace to body height	%	83.6 ± 7.16 (70.0 - 99.0)		74.1

R - right, L - left.

Moreover, the mean angle between the longitudinal foot axis and the walking direction line was for RF ϕ = 10.2° ranging between 7.7° and 15.3°, whereas for LF ϕ = 9.9° ranging between 7.5° and 12.2°. The angle demonstrates the rate of abduction or adduction of the foot from the walking direction. In addition, it represents the thigh rotation in the hip joint during support sequence of one extremity. It is a sequence during which the supporting extremity is in a mid position, barring the whole body weight and between the dorsal and plantar flexion of its talocrural joint [Sanders 1953]. All subjects were found to adduct their feet.

Table 3. Quantities of translation motion in the functional of velocity for children whose mean velocity was: fast F-I, medium M-II, slow S-III; [means ± SD (ranges)].

FEATURES \ GROUP	**SI**	**F- I** **n = 6**	**M - II** **n = 21**	**S - III** **N = 6**
Double pace length	m	1.14 ± 0.05 (1.07 -1.24)	*0.98 ± 0.06 (0.9 - 1.11)*	0.92 ± 0.03 (0.88 - 0.96)
Double pace time	s	0.87 ± 0.06 (0.84 - 0.88)	0.91± 0.05 (0.84 - 1.0) *	0.99 ± 0.04 (0.92 - 1.04)
Time of support sequence for one extremity	s %	0.52 ± 0.03 (0.48 - 0.56) 60.0 ± 2.30(57.0 - 64.0)	0.55 ± 0.03 (0.48 - 0.60)* 60.7 ± 1.75 (59.0 - 63.0)	± 0.03 (0.56 - 0.64) 61.7 ± 1.5 (60.0 - 64.0)
Time of support sequence for both extremities	s %	0.09 ± 0.02 (0.08 - 0.12) 10.7 ± 2.40 (9.0 - 14.0)	± 0.01 (0.08 - 0.13) *12.5 ± 1.47 (9.0 - 14.0)	± 0.0 (0.12 - 0.12) 12.0 ± 0.57 (11.0 - 13.0)
Time of swing sequence for one extremity	s %	0.35 ± 0.04 (0.32 - 0.36) 40.0 ± 2.30 (36.0 - 41.0)	± 0.03 (0.28 - 0.40) 39.3 ± 1.75 (37.0 - 41.0)	± 0.02 (0.36 - 0.40) 38.0 ± 2.08 (37.0 - 40.0)
Frequency of double pace	Hz	1.55 ± 0.03(1.13-1.19)	*1.09 ± 0.06 (0.96 - 1.19)	1.01 ± 0.04 (0.96 - 1.08)
Velocity	m/s	1.31 ± 0.05 (1.28 - 1.41)	*1.08 ± 0.06 (0.97 - 1.2)*	0.92 ± 0.03 (0.86 - 0.96)
Ankle angle R in frontal plane [α] L	deg	9.5 ± 1.26 (7.0 - 11.0) 10.5 ± 2.89 (8.0 - 13.0)	± 3.41 (2.0 - 10.0) 8.22 ± 3.96 (2.0 - 19.0)	± 1.89 (4.0 - 10.0) 7.8 ± 1.91 (4.0 - 10.0)
Knee angle R in frontal plane [β] L	deg	4.7 ± 0.47 (4.0 - 5.0) 4.7 ± 0.47 (4.0 - 6.0)	4.9 ± 2.15 (0 - 9.0) 4.6 ± 2.11 (0 - 9.0)	± 1.81 (4.0 - 9.3) 5.1 ± 1.48 (3.0 - 7.7)
Deviation of foot from R walking direction [ϕ] L	deg	9.4 ± 1.36 (8.0 - 12.2) 9.5 ± 1.30 (8.3 - 12.2)	10.5± 1.46 (8.3 - 15.3) 10.0 ± 1.35 (7.5 - 12.2)	10.3 ± 1.43 (7.7 - 12.0) 9.9 ± 1.13 (7.7 - 11.3)
Width of feet positioning according to length of lower extremity	%	11.7 ± 2.13 (8.6 - 14.9)	13.5 ± 2.78 (8.1 - 19.5)	13.4 ± 3.02 (8.5 - 16.3)
Width of feet positioning according to width of hip joint	%	74.6 ± 18.5 (55.8 - 96.9)	79.3 ± 14.55 (57.0- 103.8)	84.7 ± 16.3 (64.2 - 99.3)
Length of double pace to body height	%	93.4 ± 5.28 (85.0 - 99.1)	*82.9 ± 5.13(70.3- 89.5)*	76.2 ± 2.80 (72.6 - 80.5)

* significant difference, ($p < 0.05$); R - right, L - left.

Finally, the proportion of the feet positioning width during gait to the width of the separation of hip joints varied between 55.0 and 103.0 % and was in average 80.0 %. However, comparing the width to the extremity's relative length the value was 13.2 % and it ranged between 8.1 and 19.5 %.

The evaluated translation motion quantities for the whole body in both planes were compared to values reported by other authors (Table 2). A comparison of the 6-year-old subjects from the current study made with a group of 7-year-olds from Germany [Stolze et al. 1997] and with a group of 8-year-olds from Canada [Bannon et al. 1980] showed many similarities. On the one hand, little difference was found between Stolze's study results and our own. However, the comparison is incomplete due to the lack of data on certain angular quantities (calf-tarsus and thigh-shin angles). On the other hand, a slight difference of the present study from that of the Canadian's was noticed. It could account for the differences in physical development of the children due to age.

II. The results of the translation motion quantities in a function of walking velocity are given in Table 2. The medium velocity was obtained by 21 subjects (i.e. 63.6% of subjects), whereas the fast and slow walking was obtained by 6 subjects in each subgroup (18.2%).

The mean velocity for the subjects walking with the medium speed (M-II) was 1.08 m/s and was significantly different from the walking velocities of fast (F-II) and slow (S-II) gait. Similarly, statistical differences occurred in the values of the double pace length and the proportion of the length to body height. There were no significant differences between the subgroups for the double pace time, the time of its sequences and the cycle frequency. On the one hand, the F-I subjects walked with a longer double pace length yet accomplished it in a shorter time period (while the time sequence of one or both extremity support was shorter, the swing sequences was larger), and at a higher frequency. The only quantities that demonstrated a significant difference between groups were the percentage values of support sequence for both extremities and the frequency of double pace. On the other hand, the S-III subjects compared to the M-II subjects, made a smaller double pace at a longer time (longer was the time sequence of one or both extremity support, shorter was the swing sequence) and less frequent. The significant differences between the F-I and S-III groups and the M-II group were observed for the time of double pace and the absolute value of time sequence of one extremity support, but not for other quantities.

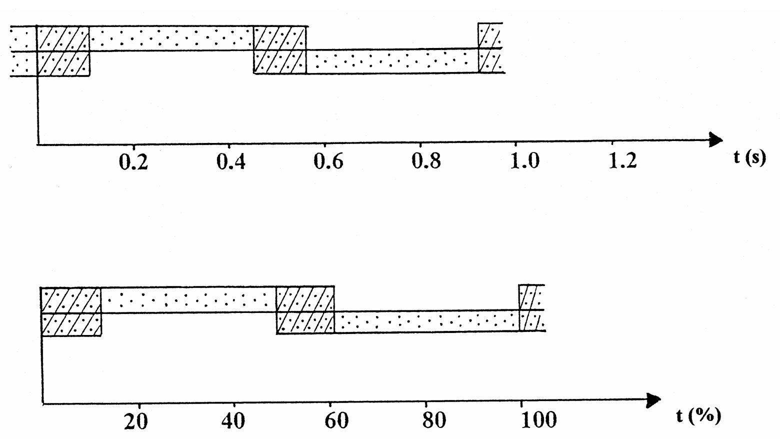

Fig. 8. Mean chronograme values of the six-year-old children's gait (the support sequence of extremities: one - dots, both - stripes).

However, a comparison of the quantities in the frontal plane did not demonstrate similar results. The quantities in the F-I and S-III groups versus the M-II group, i.e. calf-tarsus angle, thigh-shin angle in the knee joint, the angle of the longitudinal foot axis according to the walking direction and the proportion of the width of feet positioning to the with of the separation of hip joints, and to the lower extremity length were similar.

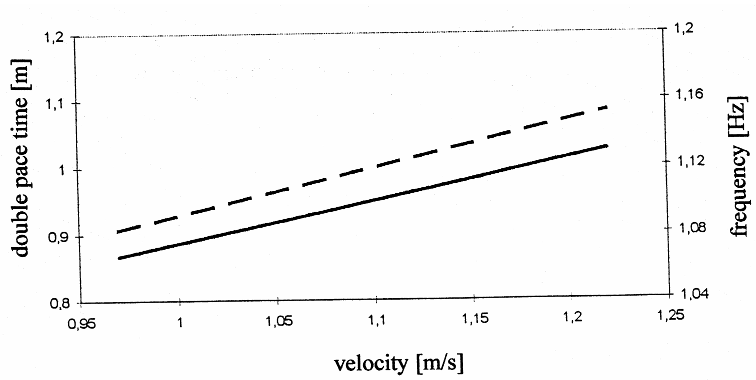

Fig. 9. Regression lines of the relationship between length & frequency of double pace and gait velocity of six-year-olds (dashed line - length of double pace, solid line - frequency of double pace).

The gait analysis demonstrated a trend towards an increase in the length and frequency of double pace while increasing the walking velocity (Fig. 9).

Straight-linear relation of a length and frequency according to the velocity of walking obtained in this paper is to that obtained by Matsuo et al. quoted by Bober [1985].

Further analysis of the variability between the F-I and S-III groups' gait quantities was dropped out due to a low number of subjects.

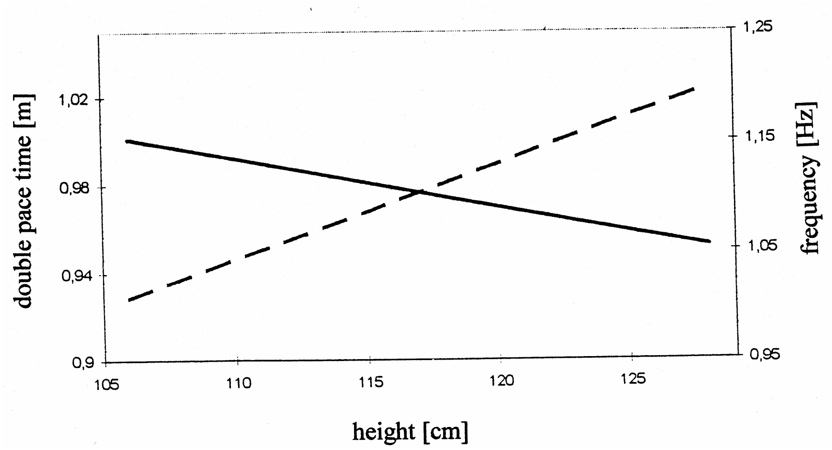

Fig. 10. Regression lines of the relationship between length & frequency of double pace and body height of six-year-olds (dashed line - length of double pace, solid line - frequency of double pace).

The results of the study of the three subgroups, especially the group walking with a medium velocity (M-II), represent the features of gait of a healthy six-year-old children. Group means for the kinematic quantities of translation motion are related with the mean walking velocity, whereas, according to Bober [1985] the kinematic quantities depend additionally from body diameters. Therefore, the gathered values on the gait of children are additionally a function of their lower extremity length and indirectly of their body height. The mean body height of the M-II group was 118.0 cm (Table 1) and despite being the smallest of all three groups did not differ significantly. The regression of the length and the frequency of double pace to body height of six-year-olds is shown in Fig. 10. The straight-linear relation demonstrates that as the body height increases the length of double pace simultaneously increases but the walking frequency decreases.

Conclusions

The kinematic analysis of gait in the function of velocity for subjects walking with medium velocity v = 1.08 ± 0.06 m/s, draws a gait pattern for a six-year-old child. The study demonstrates its characteristic features (in mean values):

1. length of double pace was 0.98 m which equaled 82.9 % of the mean body height,

2. width of feet positioning during walking equaled 80.0 % of width of the hip joint separation and 13.5 % of the relative lower extremity length,

3. abduction of the right and left foot from the walking direction line which derives from thigh rotation in hip joint was 8.2°,

4. time of double pace was 0.91 s and included: time of support sequence for one extremity by 0.55 s (60.7 % of the cycle), time of swing sequence by 0.35 s (39.3 % of the cycle), time of support sequence for both extremities by 0.11 s (12.5 % of the cycle),

5. during the support sequence valgus deformation of the calcaneal bone occurred, whereas, the calf-tarsus angle was 8.0° for the right and 8.2° for the left extremity,

6. during the support sequence of one extremity the femoral bone according to the shin in the knee joint deformed varus, whereas, the angle was 4.9° for the right and 4.6° for the left extremity,

7. frequency of double pace was 1.09 Hz,

8. as the length and frequency of double pace increases the velocity increases,

9. as the body height increases the length of double pace increases but the frequency of double pace decreases,

The results of the study will be as a reference pattern for further studies on the gait of children with several abnormalities in body posture. Investigations on children with body posture_abnormalities, lateral spine curvature and statical deformations in the lower extremities are planned.

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