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Original Article

Model biomechanical characteristics of child's walking during primary school age

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Abstract:
Human walking is a cyclic locomotor movement carried out by pushing. It is walking that can be considered as a criterion for assessing the state of human motorics. *The purpose of the research:* To identify the model time characteristics of walking in healthy children 6-8 years old. *Participants:* 94 healthy boys and 120 healthy girls of 6-8 years old. *Methods:* the analysis of scientific and methodological references and documentary materials, videometry by the "BioVideo" software. *Results:* The duration of the double support phase in the left supporting leg in healthy boys 6 years old is on average 0.12 s (SD = 0.01 s), in girls – 0.14 s (SD = 0.01 c), in healthy boys and girls 7 years old the duration of this phase is the same and is 0.14 s (SD = 0.01 s), as well as in boys and girls 8 years old and is 0.16 s (SD = 0.02 s in boys and SD = 0.01 s in girls). A difference in the duration of the double support phase in the left supporting leg between boys and girls in each of the age categories 7-8 years was not statistically significant ($p > 0.05$) in contrast to boys and girls 6 years, in whom the indicators of the duration of this phase were statistically significantly different ($p < 0.05$). In the final phase of the double step of walking, there was a statistically significant increase in its duration in girls 7 years, compared with boys of this age by 0.04 s ($p < 0.05$), its duration is in girls 7 years, and in boys and girls 8 years on average 0.24 s (SD = 0.03 s in girls 7 years and boys 8 years and SD = 0.02 s in girls 8 years). According to the time indicators of the walking phases of healthy children 6-8 years old, model characteristics have been developed. The lower and upper limits of the confidence bounds for the arithmetic mean of the general population by the value of the arithmetic mean of the sample with a 95% confidence level were chosen as model characteristics. *Conclusions:* The structure of the walking cycle of healthy children 6-8 years old was studied, the significance of which was confirmed by objective time indicators. It was reaffirmed that the biomechanical structure of the locomotor act is almost completely formed at the age of 7-8 years.
Key words: junior schoolchildren, walking, biomechanical indicators, time structure, model characteristics.

Introduction

A characteristic feature of human walking is the presence of constant contact of the supporting leg (period of single support) or both legs (period of double support) (Bernstein et al., 1940; Grygus et al., 2019; Kashuba et al., 2018; **Mykhaylova et al., 2014**). In turn, the periods of single and double support are divided into phases: back step, front step and phase of double support (Bernstein et al., 1940). It is walking that can be considered as a criterion for assessing the state of human motorics (Hodges & Smeets, 2015; Kashuba & Goncharova, 2018; Krupenya & Khmelnitska, 2018; Nesterchuk et al., 2019). Human walking is cyclical and this means that by analyzing one cycle, we obtain information that characterizes the whole locomotion as a whole (Laputin & Khmelnitska, 1995; Needham, Stebbins & Chockalingam, 2016; Da Gama et al., 2019).

The study of the biomechanics of human movement provides extensive material for understanding the physiological and nervous processes that determine the functioning of the locomotion control system. At the same time, the data accumulated over more than a century, concerning the phase composition of walking, the role and purpose of each of the phases in the double step cycle, the mechanism of implementation of basic motor actions, do not differ from each other. At the same time, information on the formation of the biomechanics of walking in junior schoolchildren is limited.

The purpose of the research was to identify the model time characteristics of walking in healthy children 6-8 years old.

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Material & methods

Participants: The research involved 94 healthy boys of 6-8 years old (among them 30 boys in each age of 6 and 7 years old and 34 boys of 8 years old) and 120 healthy girls of 6-8 years old (among them 40 girls in each age of 6-8 years old). All parents of every child gave written permission to participate in this research according to the recommendations of the Ethics Committee, in accordance with the ethical standards of the Helsinki Declaration.

Procedure/Measure: A walking in the frontal plane performed by 214 healthy children was recorded using a standard (PAL/SECAM) digital camcorder at 25 frames per second. In the research, we used an automated processing system based on the video-computer complex – personal computer (PC) with the "BioVideo" software developed by Irene Khmelnitska in order to perform the biomechanical analysis on the basis of registration (video recording) of child's motion action by a digital camera (Kashuba & Khmelnitska, 2007). The use of this measurement system has made it possible to investigate the walking of junior children at a whole new level (Kashuba & Khmelnitska, 2014). As a model of the child's musculoskeletal system, a 14-segment branched bio-kinematic chain was used. The coordinates of its links, by geometrical characteristics, correspond to the coordinates of the position in the space of the human body's bio-links, and the reference points – to the coordinates of the centers of the major joints (by Bernstein, 1947). The obtained qualitative and quantitative information was the basis for the development of model time characteristics of the walking of healthy children in primary school age.

Data collection and analysis: We used the data generalization of scientific and methodological literature and practice experience, biomechanical video-computer analysis, methods of mathematical statistics. The following methods of mathematical statistics were used: descriptive statistics and the 95 % confidence intervals for means as a range of model biomechanical characteristics of child's walking. Since the samples of time characteristics of child's walking corresponded to the law of normal distribution, as confirmed by the Shapiro-Wilkie test, we used t- Student's criterion for independent samples to determine the statistical significance of differences between indicators of boys vs girls. The following parameters were determined: arithmetic mean – $\bar{x}$, standard deviation – SD & standard error – m. Confidence bounds were calculated as ($\bar{x}$-mt, $\bar{x}$+mt). As the population standard deviation was unknown then the Student's t distribution was used as the critical value. This value was dependent on the confidence level (95 %) for the test and degrees of freedom. The degrees of freedom were found by subtracting one from the number of observations, n-1. The critical value was found from the t-distribution table. The calculations were performed using the Statistica 10.0 (StatSoft, Inc).

Results

A biokinematic scheme of walking of healthy girl of 8 years old obtained by "BioVideo" software is presented in Figure 1. The study of walking time characteristics included the determination of the duration of both the double step of walking in general and its phases in particular (phases of double support, back and front step), as well as the assessment the rhythmic structure of walking of healthy children 6-8 years old.

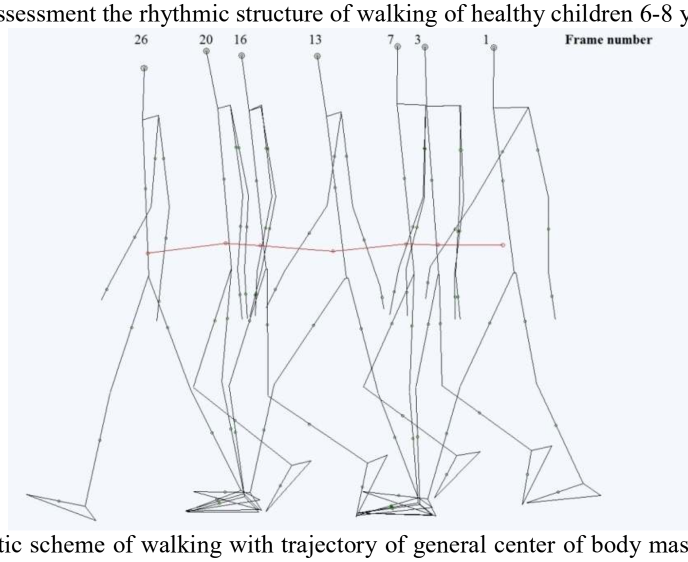

Figure 1. Biokinematic scheme of walking with trajectory of general center of body masses of healthy girl of 8 years old: phase of double support at the right pushing leg (frames 1–3); phase of the back step at the left supporting leg (frames 3–7); phase of the front step at the left pushing leg (frames 7–13); phase of double support at the left pushing leg (frames 13–16); phase of the back step at the right supporting leg (frames 16–20); phase of the front step with the right pushing leg (frames 20–26)

It was found that the duration of the phase of double support at the left supporting leg in healthy boys aged 6 years old is on average 0.12 s (SD = 0.01 s), in girls – 0.14 s (SD = 0.01 s), at the same time in healthy boys and girls of 7 years old the indicators of duration of this phase are identical and are 0,14 s (SD = 0,01 s), as the same duration of this phase at boys and girls of 8 years and are 0,16 s (SD = 0.02 s in boys and SD = 0.01 s in girls) (Table 1).

There was no statistically significant difference in the duration of the double support phase in the left supporting leg between boys and girls in each age category (7-8 years) (p> 0.05) in contrast to boys and girls aged 6 years, in whom the indicators of the duration of this phase differ statistically significantly (p <0.05), which was confirmed by Student's test for independent samples.

Table 1. Time characteristics of walking phases in healthy children aged 6–8 years (n=214)

Phase	Age, years	Phase duration, s				The difference between boys vs girls, p
		boys, n=94		girls, n=120		
		$\bar{x}$	SD	$\bar{x}$	SD	
Double support phase in the left supporting leg	6	0.12	0.01	0.14	0.01	<0.05
	7	0.14	0.01	0.14	0.01	>0.05
	8	0.16	0.02	0.16	0.01	>0.05
Phase of the back step at the left supporting leg	6	0.16	0.01	0.16	0.01	>0.05
	7	0.16	0.02	0.18	0.02	<0.05
	8	0.18	0.02	0.20	0.02	<0.05
Phase of the front step at the left pushing leg	6	0.20	0.02	0.22	0.02	<0.05
	7	0.20	0.02	0.24	0.02	<0.05
	8	0.24	0.02	0.28	0.03	<0.05
Phase of double support at the right pushing leg	6	0.12	0.01	0.10	0.01	<0.05
	7	0.12	0.01	0.14	0.01	<0.05
	8	0.14	0.02	0.16	0.02	<0.05
Phase of the back step at the right supporting leg	6	0.20	0.03	0.20	0.02	>0.05
	7	0.18	0.02	0.16	0.02	<0.05
	8	0.16	0.02	0.16	0.01	>0.05
Phase of the front step with the right pushing leg	6	0.20	0.02	0.20	0.03	>0.05
	7	0.20	0.03	0.24	0.03	<0.05
	8	0.24	0.03	0.24	0.02	>0.05

At the same time, we did not find statistically significant differences in the time structure of the phase of the back step in the left supporting leg between boys and girls aged 6 years (p> 0.05), the duration of which was 0.16 s (SD = 0.01 s), however between the indicators of the duration of this phase in boys and girls of 7-8 years old there was a statistically significant difference (p <0.05) – 0.16 s (SD = 0.02 s) in boys 7 years old, in girls of the same age and boys aged 8 years – 0.18 s (SD = 0.02 s), girls of 8 years old – 0.20 s (SD = 0.02 s).

The duration of the phase of the front step at the left supporting leg in boys and girls of every ages (6-8 years) was statistically significantly different (p <0.05) – in healthy boys 6-7 years old it was equal to 0.20 (SD = 0.02 s), boys 8 years old – 0.24 s (SD = 0.02 s), girls 7 years old – 0.24 s (SD = 0.02 s) and girls 8 years old respectively 0.28 s (SD = 0.03 s). In the phase of the front step of the supporting leg, the longitudinal axis of the forward leg is in front of the vertical lowered from the GCM (general center of masses) of the body (Kashuba & Kholodov, 2020). The force of gravity was directed downward, strictly perpendicular to the support surface, and the response force had an angular direction, respectively, the longitudinal axis of the support leg. If the response force was decomposed into components – vertical and horizontal, the horizontal component was directed backwards, which, of course, somewhat slows down the headway of the body (Kashuba et al., 2006).

Considering the time structure of the phase of double support in the right supporting leg, it should be noted that its duration was statistically significantly greater in boys than in girls 6 years old, and statistically significantly shorter in boys than in girls 7-8 years old (p < 0.05). At the same time, in healthy 7-year-old boys the phase of the back step with the right supporting leg lasted on average by 0.02 s compared to girls of this age (p <0.05). There was no statistically significant difference between healthy boys and girls at the age of 6 and 8 years (p>0.05).

The phase of the back step is the most important, because at its end due to the contraction of the muscles of the lower extremities there was a push, which gave additional momentum needed for forward movement (Laputin & Kashuba, 1999). During the period of the back step of the supporting leg the rolling of the foot ended, the support with the whole sole passed to the phalanges of the feet. The support area decreased sharply. The action of gravity was directed perpendicularly downwards, and the response forces were directed upwards, along the axis of the supporting leg. As the free leg moved forward, which occurred synchronously with the front step of the supporting leg, the GCM of the body moved forward (Laputin & Kashuba, 2009). As a result, there was a shoulder of gravity. When the moment of gravity became greater than the moment of response force, the balance of the body was disordered, and it under the action of gravity fallen on the forward free leg. The horizontal component of the equivalent response force promoted the headway motion, increasing the speed of movement of the body (Laputin, 1995; Kashuba, Kholodov & Bakanichev, 2019).

In the final phase of the double step of walking, there was a statistically significant increase in its duration in girls 7 years, compared with boys of this age by 0.04 s ($p < 0.05$). Its duration was in girls 7 years, and also in boys and girls 8 years old on average 0.24 s (SD = 0.03 s in girls 7 years old and boys 8 years old and SD = 0.02 s in girls 8 years old).
The linear chronograms of walking in children 6-8 years old are presented in Figure 2.

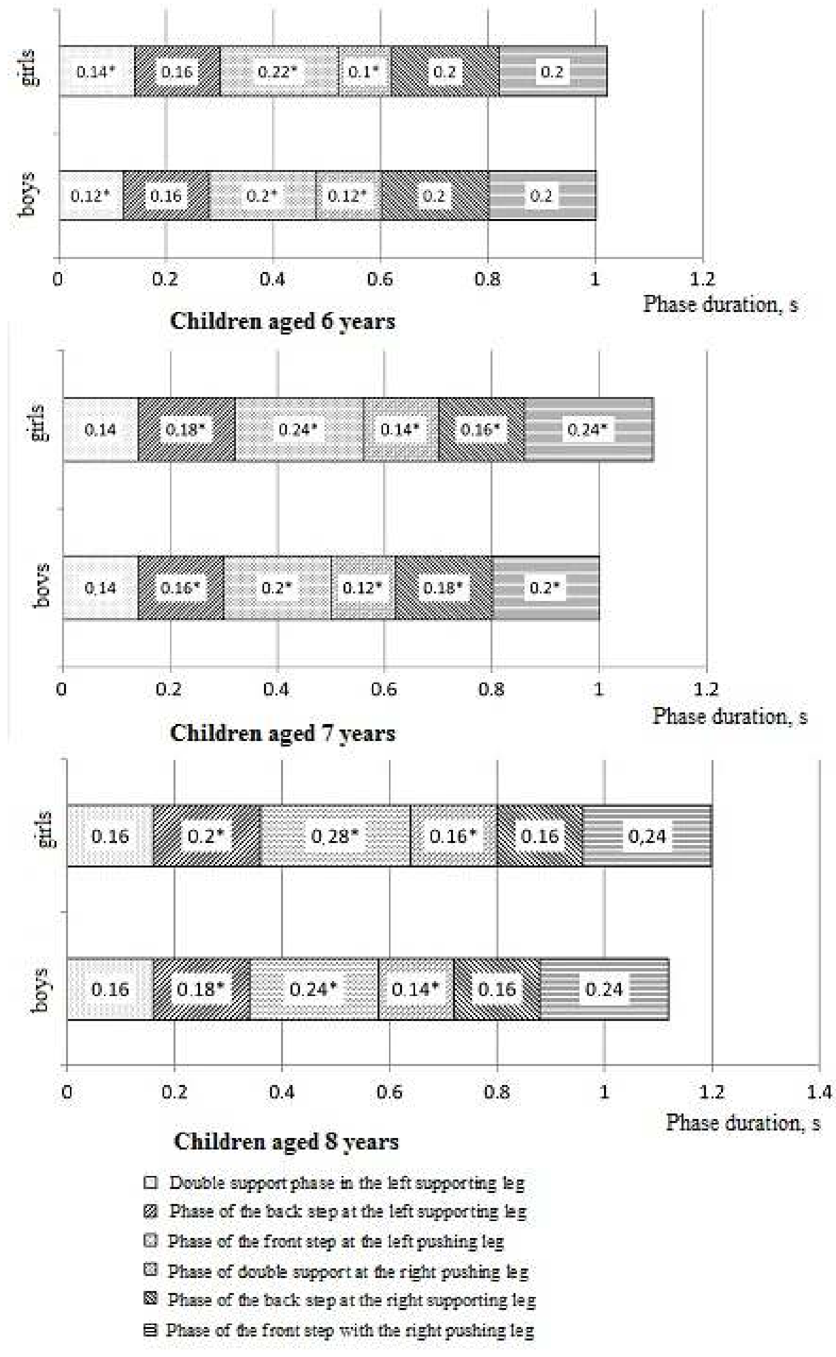

Figure 2. The linear chronograms of walking in children 6-8 years old (* – the difference between boys vs girls are statistically significant at level $p<0.05$)

According to the time indicators of the walking phases of healthy children 6-8 years old, model characteristics have been developed. Since the samples of duration of each walking phase were normally distributed, the lower and upper limits of the confidence bounds for the arithmetic mean of the general population by the value of the arithmetic mean of the sample with a 95% confidence level were chosen as model characteristics (Table 2).

Table 2. The model characteristics of walking phase duration (at the 95 % confidence level) of healthy children aged 6–8 years (n=214)

Phase	Age, years	Model characteristic of phase duration, s			
		Boys (n=94)		Girls (n=120)	
		Lower bound	Upper bound	Lower bound	Upper bound
Double support phase in the left supporting leg	6	0.118	0.122	0.138	0.142
	7	0.138	0.142	0.138	0.142
	8	0.156	0.164	0.158	0.162
Phase of the back step at the left supporting leg	6	0.158	0.162	0.158	0.162
	7	0.156	0.164	0.176	0.184
	8	0.176	0.184	0.196	0.204
Phase of the front step at the left pushing leg	6	0.196	0.204	0.216	0.224
	7	0.196	0.204	0.236	0.244
	8	0.236	0.244	0.274	0.286
Phase of double support at the right pushing leg	6	0.118	0.122	0.098	0.102
	7	0.118	0.122	0.138	0.142
	8	0.136	0.144	0.156	0.164
Phase of the back step at the right supporting leg	6	0.194	0.206	0.196	0.204
	7	0.176	0.184	0.156	0.164
	8	0.156	0.164	0.158	0.162
Phase of the front step with the right pushing leg	6	0.196	0.204	0.194	0.206
	7	0.194	0.206	0.234	0.246
	8	0.234	0.246	0.236	0.244

Discussion

The main dynamic effect of walking – lifting and headway of the general center of mass of the body – is created by summing the force effects of the extensor muscles of both legs (Vitenzon, 1998; Kashuba & Savlyuk, 2017; Giannotti, 2018). Although the crucial role in walking belongs to the movements and work of the leg muscles, certain tasks of these locomotions are performed by the muscles of the upper body. Thus, the lower half of the torso when walking makes a complex movement, which can be projected on three mutually perpendicular planes (Bernstein et al., 1940; Laputin & Kashuba, 2009). As noted by many researchers (Yang et al., 2017; Kashuba et al., 2018; Zia et al., 2018; Samy et al., 2020; Khmelnitska et al., 2021), it is walking that can be considered as a criterion for assessing the state of human motorics.

The study of issues related to the organization of the child's movement is one of the most important tasks of the theory and methods of physical education and differential biomechanics. This study examined various aspects of the biomechanics of walking in children 6-8 years old. The results of our studies of the walking kinematics of jumior schoolchildren confirm the data of Bernstein (1947), Laputin (1995) and others, who indicated that the final formation of the "adult" biomechanical structure of walking took place at the age of 7-8 years. We support the opinions of experts: Vitenson (1998), Kashuba, Goncharova & Nosova (2018); Lisenchuk et al. (2020) who noted that since the load value on the lower extremities during locomotion depends largely on the spatial location of all departments of the human support-motional apparatus (SMA) located above, it is necessary to direct exercise to develop the skill of correct statodynamic posture, which ensures the normal functioning of the musculoskeletal system of the lower extremities and the entire SMA.

Modeling of walking phases of practically healthy children 6-8 years old was based on the following principles: the principle of information sufficiency – in the complete absence of information about the object, it is impossible to build its model. There is a certain level of a priori information about the object, only when it can be built an adequate model. In the presence of complete information about the object, the construction of its model does not make sense. The principle of feasibility – the created model should ensure the achievement of the research goal with a probability significantly different from zero. The principle of multiplicity of models – the created model should reflect first of all those properties of real object (system) which interest the researcher. For a complete study of the object, it is needed a large number of models that reflect the studied object from different angles and with varying degrees of detail. The principle of aggregation – in most studies, the system should be presented as a set of subsystems to describe which the standard schemes are suitable. The principle of parameterization – the model is built in the form of a known system, the parameters of which are unknown.

Conclusions

The study of the biomechanics of human movement provides extensive material for understanding the physiological and nervous processes that determine the functioning of the locomotion control system. As a result of the study, the structure of the walking cycle of healthy children 6-8 years old was studied, the significance of which was confirmed by objective time indicators. It was confirmed the opinion of a number of experts, who pointed out that the biomechanical structure of the locomotor act was formed almost completely at the age of 7-8 years.

Modeling of walking phases of practically healthy children 6-8 years old was based on a number of axioms: 1. The model does not exist in itself, but acts in tandem with some material object, which it represents (replaces) in the process of its study or design. 2. The model is secondary for natural material objects. 3. The model is always simpler than the object. It reflects only some of its properties, and does not represent the object "in all its glory." A number of models are built for one object, reflecting its behavior or properties from different angles or with different degrees of detail. With an infinite improvement in the quality of the model, it approaches the object itself. 4. The model should be similar to the object it replaces. The model in a sense is a copy, analogous to the object. If in the studied situations the model behaves in the same way as the modeled object, or this discrepancy is small and suits the researcher, then they say that the model is adequate to the original. Adequacy is the reproduction of a model with the necessary completeness and accuracy of all the properties of the object, essential for the purposes of this study. 5. Building a model is not an end in itself. It is built so that you can experiment not with the object itself, but with a more convenient for this purpose, its representative, called the model.

Conflicts of interest

The authors have no conflicts of interest.

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