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BIOMECHANICAL INVESTIGATION OF THE HORIZONTAL AND STAIRS WALKING

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Abstract: The basic, temporal, kinetic and dynamic parameters of the horizontal and stairs walking of the normal subjects were investigated. It was established that the stairs walking was slower and less stable than the horizontal walking. At the same time, the basic phases of the locomotor cycle (stance and swing) were observed for all types of walking, and those phases had the similar biomechanical contents in different locomotions. The peculiarities of change of different biomechanical parameters (podograms, angular displacements and their first and second time derivatives, ground reaction force components) were described and analysed. It was shown that the stairs walking had larger parameters variations and hence, this type of walking was less perfect locomotor act than the horizontal walking.

Key words: walking, stairs, biomechanical parameters

Introduction

Horizontal and stairs walking are the most prevalent natural human locomotor acts. Investigation of walking is of considerable interest not only for the movements' physiology but also for the development of the new rehabilitation methods for the patients with the locomotor pathology, in particular, for the muscle electrostimulation method.

In contradistinction to the previous investigations on this point [1-5] the present study allows to obtain the new results and to determine the old biomechanical data more precisely by using the modern computer techniques.

Methods of investigation

The group of 10 normal subjects, age 20-40, was studied. Their heights lay in the limits 172-190 cm (the mean value = 180 cm), and their masses lay in the limits 64.3-103.6 kg (the mean value = 84.2 kg).

At first all subjects walked along a straight horizontal track 14 m long, and then they walked along the stairs. The stairs had 7 steps with the metal contact surface, 15 cm height each, and the stairhead. The force plate was fixed on one step to measure three components of the ground reaction force. The comparative investigations of the horizontal and stairs walking were carried out for the same subjects during common experiment, without inter-link angles gauges rearrangement and any changes in apparatus calibration.

The biomechanical parameters were recorded in 6 trials of horizontal walking and in 8 trials of upstairs and downstairs walking. The recorded biomechanical parameters were as follows: basic walking parameters (cadence, stride length, average velocity), temporal walking parameters (cycle duration, single and double support phases durations, heel-contact, foot-contact and toe-contact intervals, τ-interval [the period between the heel-off of one limb and the heel-strike of the other limb – I.B. Lisitza, A.V. Sarantzev, 1991]), kinematic walking parameters (angle displacements in the ankle joint (AJ), in the knee joint (KJ), in the hip joint (HJ), the corresponding angular velocities and angular accelerations), dynamic walking parameters (the vertical R_Z, longitudinal R_X and transverse R_Y components of the ground reaction force). All those parameters were recorded in the both lower limbs. Hence, the degree of symmetry of biomechanical parameters of horizontal and stairs walking could be revealed.

All the measured parameters were computer-processed at the frequency 200 Hz by means of 12-digit analogic-digital converter (ADC) with an error of 2 digits.

As a result of the investigations, the mean values (M), the standard deviations (SD) and the variation coefficients (VC) of the biomechanical parameters were calculated. Those values were represented in the form of tables and plots.

Results

Basic and temporal walking parameters

Table 1 shows the following parameters of the normal subjects horizontal walking: free cadence = 99 steps/minute, double stride length = 1.42 m, average velocity = 1.17 m/s or 4.23 km/hour. The parameters of the upstairs walking are: free cadence = 78 steps/minute, double stride length = 0.74 m, average velocity = 0.48 m/s or 1.74 km/hour. The parameters of the downstairs walking are: free cadence = 86 steps/minute, double step length = 0.70 m, average velocity = 0.50 m/s or 1.81 km/hour.

Thus, the upstairs walking is the slower process than the free horizontal walking. But the variations of the basic walking parameters corresponding to different locomotion types are rather similar to each other.

Table 2 shows the temporal walking parameters.

On the whole, the temporal parameters of the horizontal walking correspond to those presented in the publication [5].

Table 1. The basic parameters of the horizontal and stairs walking.

		Horizontal track	Stairs			
			Up		Down	
Double stride duration (s)	M	**1.18**	**1.56**	**132%**	**1.41**	**119%**
	SD	0.06	0.18		0.14	
	VC	5%	12%		10%	
Double stride length (m)	M	**1.44**	**0.74**	**51%**	**0.70**	**49%**
	SD	0.10	0.03		0.03	
	VC	7%	4%		4%	
Average velocity (m/s)	M	**1.22**	**0.48**	**39%**	**0.50**	**41%**
	SD	0.10	0.05		0.05	
	VC	8%	10%		10%	
Average velocity (m/h)	M	**4.41**	**1.74%**	**39%**	**1.81**	**41%**
	SD	0.36	0.20		0.17	
	VC	8%	11%		9%	
Cadence (steps/min)	M	**101.8**	**77.8**	**76%**	**86.0**	**84%**
	SD	5.66	8.92		8.46	
	VC	6%	11%		10%	

Note: the mean values in the horizontal walking are considered to be equal to 100 %, the values in the upstairs and downstairs walking are expressed as a percentage with respect to those of the horizontal walking.

Table 2. The temporal parameters of the horizontal and stairs walking.

Parameters		Horizontal track		Stairs							
				Up				Down			
		Left	Right	Left		Right		Left		Right	
Heel-contact interval	M	6.4	6.5	3.0	47%	2.1	32%	5.6	88%	6.4	98%
	SD	1.8	2.0	3.3		2.3		2.6		2.6	
	VC	28%	31%	110%		110%		46%		41%	
Foot-contact interval	M	37.4	36.2	50.9	136%	51.4	142%	42.1	113%	40.7	112%
	SD	7.2	6.8	6.0		5.1		5.3		5.8	
	VC	19%	19%	12%		10%		13%		14%	
Toe-contact interval	M	19.0	20.5	10.5	55%	12.3	60%	13.4	71%	14.9	73%
	SD	6.8	6.6	3.7		3.1		3.2		3.2	
	VC	36%	32%	35%		25%		24%		21%	
Swing phase	M	37.1	36.8	35.5	96%	34.2	93%	38.9	105%	38.0	103%
	SD	1.8	2.0	3.7		2.5		4.2		3.3	
	VC	5%	5%	10%		7%		11%		9%	
Double support phase	M	13.0	13.2	14.5	112%	14.9	113%	11.0	85%	13.2	100%
	SD	2.1	1.9	3.7		3.2		5.3		6.8	
	VC	16%	14%	26%		21%		48%		52%	
τ-interval	M	6.1	7.3	-3.5	-57%	-2.7	-37%	2.4	39%	1.8	25%
	SD	7.9	7.6	5.0		4.2		6.5		7.0	
	VC	130%	104%	143%		156%		271%		389%	
Rhythm coefficient		0.99		0.96				0.98			

Note: the mean values in the horizontal walking are considered to be equal to 100 %, the values in the upstairs and downstairs walking are expressed as a percentage with respect to those of the horizontal walking.

The relative durations (per cent of the cycle) are: the swing phase = 37.1 % and 36.8 % (two values correspond to the left and right limbs respectively), the double support phase = 13.0 % and 13.0 %, heel-contact interval = 6.4 % and 6.5 %, foot-contact interval =37.4 % and 36.2 %, toe-contact interval =19.0 and 20.6 %, τ-interval = 6.1 % and 7.3 %. The τ-interval has the largest variation (117 %); the intervals of the stance phase have the medium variations (21 %-36 %); the duration of the swing phase has the least variation (5-7 %).

The following changes of the temporal walking parameters can be noted for the upstairs walking: the heel-contact interval decreases almost doubly (3.0-2.1 %); the foot-contact interval increases sharp (50.9-51.4 %); the toe-contact interval decreases almost doubly (10.6-12.3 %); the duration of the swing phase slightly decreases (35.6-34.42 %); the duration of the double support phase changes also slightly (14.5-14.9 %); the sign of the τ-interval changes and becomes negative (-3.5, -2.7 %), it means that the contact of one foot upon the stairs step takes place earlier than the toe-contact of another foot.

The downstairs walking exhibits less expressed changes of the podogram. Note only some changes of the stance phase: the foot-contact interval slightly increases; the toe-contact interval slightly decreases; the duration of the swing phase slightly increases; the τ-interval decreases strongly, but its sign remains positive. The variations of all temporal walking parameters in the downstairs walking somewhat increase in comparison with the upstairs walking, and especially in comparison with the horizontal walking.

Thus, the temporal parameters of walking show that the stairs walking, when compared with the horizontal walking, is characterised not only by the slower cadence, but also by lesser stability. The lesser stability of the stairs walking is indicated by

a) the increase of the foot-contact interval;
b) the decrease of the heel-contact and toe-contact intervals;

c) the decrease of the positive τ-interval in the downstairs walking, and the change of its sign in the upstairs walking.

Besides, the stairs walking leads to the increase of variations of some temporal parameters (the durations of the swing and stance phases, τ-interval); it means that this type of walking is less skilled than the horizontal walking.

Kinematic walking parameters

Figure 1 and Table 2 show the angular displacements in the main joints of the lower limbs and the extreme values of the inter-link angles for the horizontal and up- and downstairs walking of the normal subjects.

The pattern of the angular displacements in the horizontal walking is well-known. In general, it is characterised by the flexion's and extensions, their number diminish in the proximal direction. Two plantarflexions are observed in the AJ at the beginning and at the end of the stance phase, and two dorsiflexions are observed in this joint at the mid-stance and during the swing phase. Two half-waves of the angular displacements are observed in the KJ during the stance and swing phases, the first being the joint bending and the second being the basic swing phase flexion. Only one oscillation exists in the HJ, it consists of the stance extension and swing flexion with the short connecting intervals between them.

Although the kinematic pattern of the upstairs walking changes, it keeps some features of the usual locomotion.

Table 3. The extreme values of the angular displacements in the joints for the normal horizontal and stairs walking (degrees).

	Leg	Horizontal track				Stairs							
						Up				Down			
		% T	M	SD	VC	% T	M	SD	VC	% T	M	SD	VC
AJA	Left	8.0	**-8.2**	3.7	45%	25.0	**12.6**	4.1	33%	0.0	**-18.0**	4.8	27%
		49.0	**11.3**	4.3	38%	25.0	**12.6**	4.4	35%	52.0	**22.8**	4.8	21%
		66.0	**-9.2**	6.0	65%	68.0	**-6.0**	4.0	67%	100.0	**-18.0**	9.3	52%
		83.0	**1.0**	3.1	310%	92.0	**15.0**	4.4	29%	100.0	**-18.0**	11.0	61%
	Right	8.0	**-7.1**	4.8	68%	25.0	**12.5**	5.0	40%	0.0	**-20.9**	6.5	31%
		49.0	**10.2**	3.9	38%	25.0	**12.5**	5.6	45%	52.0	**24.9**	5.7	23%
		65.0	**-8.4**	5.8	69%	67.0	**-7.8**	4.4	56%	100.0	**-20.9**	11.4	55%
		82.0	**3.1**	4.9	158%	90.0	**16.2**	5.1	31%	100.0	**-20.9**	12.3	-59%
KJA	Left	17.0	**16.3**	8.1	50%	0.0	**59.9**	5.4	9%	17.0	**22.2**	6.3	28%
		42.0	**3.3**	3.5	106%	46.0	**13.3**	5.0	38%	27.0	**20.1**	6.8	34%
		73.0	**64.6**	4.9	8%	80.0	**75.3**	10.1	13%	66.0	**73.4**	4.8	7%
		100.0	**1.3**	4.3	331%	100.0	**59.9**	16.4	27%	100.0	**11.9**	8.1	68%
	Right	16.0	**13.8**	7.1	51%	0.0	**58.0**	4.8	8%	17.0	**23.8**	7.6	32%
		42.0	**1.4**	4.4	314%	50.0	**12.4**	4.1	33%	29.0	**21.4**	9.3	43%
		73.0	**61.4**	4.0	7%	80.0	**73.8**	11.1	15%	66.0	**73.3**	6.1	8%
		100.0	**-1.0**	5.2	520%	100.0	**58.0**	14.9	26%	100.0	**11.0**	9.1	83%
HJA	Left	0.0	**25.2**	4.0	16%	0.0	**51.0**	5.0	10%	0.0	**14.1**	4.1	29%
		52.0	**-9.6**	3.2	33%	57.0	**10.3**	3.4	33%	33.0	**8.4**	3.8	45%
		88.0	**26.9**	4.8	18%	94.0	**52.1**	13.1	25%	76.0	**27.7**	8.2	30%
	Right	0.0	**25.8**	4.9	19%	0.0	**53.2**	6.4	12%	10.0	**13.8**	4.2	30%
		54.0	**-10.6**	4.5	42%	58.0	**8.4**	3.9	46%	37.0	**8.2**	3.8	46%
		89.0	**27.8**	5.1	18%	95.0	**53.7**	14.3	27%	77.0	**28.5**	7.3	26%

Note: AJA – ankle joint angle, KJA – knee joint angle, HJA – hip joint angle.

Для рис. 1.

The first plantarflexion in the AJ vanishes; the dorsiflexion of 12-13° is observed during the most part of the stance phase. The small plantarflexion of 6-8° takes place only at the end of this phase; then it is replaced again by the considerable swing dorsiflexion.

The KJ movements begin with the considerable flexion up to 60°, this flexion corresponds to the foot placement on the upper step of stairs. Then the limb straightens up to 13° and keeps this position during the 20 % of the cycle. The transference of the leg to the next step leads to the quick flexion up to 80°, then the extension up to 60° is observed at the very end of the swing phase.

The pattern of the HJ movements for the upstairs walking is like that in the horizontal walking. The extension phase is expressed distinctly, this phase lasts almost until the end of the stance phase and then it is replaced by the flexion phase. The difference is that the initial flexion angle reaches 50° because of leg transference to the next step of stairs. Also, the extension in the HJ is not complete, and it turns into the quick flexion at the end of the stance phase.

Thus, the upstairs walking has some peculiarities of the horizontal walking of the bent in the subject knees; these peculiarities are registered in some pathological locomotions [6].

The locomotion pattern of the downstairs walking is quite different from that of the horizontal walking.

The AJ movements are characterised by the expressed plantarflexion (up to 20°) at the beginning and at the end of the cycle; the distinct dorsiflexion up to 20° is observed at the mid-stance.

In the KJ the limb is tucked up to 30° during the first third of the stance phase, and then the sharp flexion up to 75° and extension up to 10° are observed. It should be noted that the flexion at this joint takes place mainly during the stance phase, but the extension is observed mainly during the swing phase.

The movements in the HJ during the stance phase practically vanish; the small flexion angle up to 10° is observed. Small flexion and extension take place in this joint during the swing phase.

Thus, there is a following pattern of the downstairs walking: the equilibrated (first) foot, being slightly bent in the KJ and HJ, is placed on the lower step; then the quick flexion in the KJ of the second leg is observed, further the plantarflexion in the AJ and the extensions in the KJ and HJ of the second leg take place while this leg lowers to the next step of stairs.

The above-cited data show that for the considered locomotions the significance of the movements in the different joints changes in comparison with the horizontal walking. The flexions and extensions in the HJ and KJ are of special importance for in the upstairs walking, and these movements in the KJ and AJ are of special importance in the downstairs walking.

The consideration of the angular displacements in the lower limb joints should be supplemented by the analysis of the corresponding derivatives (angular velocities and accelerations).

Table 1 and Figures 2-4 show that the largest velocities and accelerations are observed during the horizontal walking because the higher cadence of this locomotion is connected with the resonance phenomenon [7], the stride length being defined by the anthropometric parameters of the subjects.

In the stairs walking the stride length is limited by the step height, and the cadence is lower than that in the horizontal walking.

Для рис. 2.

Для рис. 3.

Для рис. 4.

Table 4. The extreme values of the angular velocities (rad/s) and the angular accelerations (rad/s^2) at the joints for the normal horizontal and stairs walking.

		Angular velocities						Angular accelerations					
		Horizontal track		Up		Down		Horizontal track		Up		Down	
	Leg	% T	M	% T	M	% T	M	% T	M	% T	M	% T	M
AJA	Left	4.0	-2.7	0.0	0.0	0.0	0.0	1.0	-96.2	-	-	-	-
		15.0	1.4	5.0	0.5	4.0	3.5	7.0	69.3	4.0	5.9	4.0	10.5
		-	-	27.0	-0.7	22.0	0.2	55.0	-41.1	56.0	-16.9	7.0	-36.2
		-	-	46.0	0.2	42.0	1.1	64.0	66.2	66.0	27.9	64.0	19.5
		60.0	-3.4	61.0	-1.8	60.0	-2.1	100.0	-64.4	83.0	-12.1	75.0	-10.7
		71.0	1.4	77.0	1.9	69.0	-0.7	-	-	-	-	-	-
		88.0	-0.6	97.0	-0.3	81.0	-1.8	-	-	-	-	-	-
	Right	4.0	-1.9	0.0	0.0	0.0	0.0	1.0	-54.3	-	-	-	-
		11.0	1.5	5.0	0.6	5.0	4.0	7.0	69.0	4.0	8.4	4.0	23.3
		-	-	27.0	-0.7	24.0	0.1	54.0	-37.6	57.0	-17.1	8.0	-34.6
		-	-	47.0	0.1	41.0	1.2	64.0	71.8	66.0	33.1	63.0	20.1
		59.0	-3.1	61.0	-1.9	60.0	-1.9	100.0	-32.4	84.0	-17.1	71.0	-11.8
		69.0	1.6	78.0	2.2	67.0	-0.7	-	-	-	-	-	-
		89.0	-0.8	96.0	-0.6	80.0	-2.0	-	-	-	-	-	-
KJA	Left	8.0	2.2	1.0	-0.1	9.0	1.4	1.0	49.8	0.0	30.0	0.0	26.1
		27.0	-1.2	25.0	-2.3	21.-	-0.4	12.0	-30.5	8.0	-18.1	14.0	-20.1
		61.0	5.8	72.0	4.9	56.0	3.1	56.0	40.0	64.0	30.3	34.0	13.8
		89.0	-6.2	95.0	-2.8	82.0	-3.9	67.0	-52.4	83.0	-38.2	66.0	-36.0
		-	-	-	-	-	-	96.0	82.4	99.0	64.4	99.0	32.1
		-	-	-	-	-	-	99.0	38.6	100.0	30.0	100.0	26.1
	Right	9.0	2.2	1.0	-0.1	9.0	1.7	1.0	60.0	0.0	26.6	0.0	22.7
		26.0	-1.1	26.0	-2.1	22.0	-0.4	13.0	-34.2	8.0	-15.3	14.0	-23.0
		61.0	5.5	72.0	4.9	57.0	3.2	56.0	34.1	63.0	33.3	32.0	14.0
		90.0	-6.0	94.0	-2.7	81.0	-3.8	70.0	-56.7	84.0	-38.4	64.0	-34.7
		-	-	-	-	-	-	96.0	78.3	99.0	59.8	99.0	28.7
		-	-	-	-	-	-	99.0	54.2	100.0	26.6	100.0	22.7
HJA	Left	4.0	-0.3	-	-	3.0	-0.4	1.0	-0.8	1.0	-15.1	1.0	-14.2
		8.0	0.0	0.0	0.0	9.0	0.2	6.0	8.5	5.0	-2.5	6.0	12.8
		27.0	-1.7	26.0	-1.5	18.0	-0.5	12.0	-22.5	8.0	-9.8	13.0	-11.6
		66.0	2.4	76.0	2.2	61.0	1.5	33.0	4.2	40.0	6.3	29.0	4.9
		93.0	-0.5	97.0	-0.4	92.0	-1.1	57.0	27.4	61.0	16.0	55.0	12.9
		99.0	0.0	100.0	0.0	100.0	-0.1	87.0	-16.2	93.0	-14.2	75.0	-10.5
		-	-	-	-	-	-	96.0	13.9	99.0	12.1	99.0	23.5
	Right	4.0	-0.2	-	-	3.0	-0.4	1.0	-4.9	1.0	-17.5	1.0	-15.6
		8.0	0.1	0.0	0.0	9.0	0.6	6.0	9.0	5.0	-0.8	6.0	18.2
		25.0	-1.9	25.0	-1.6	18.0	-0.5	11.0	-29.1	9.0	-8.2	13.0	-16.5
		68.0	2.6	74.0	2.4	62.0	1.6	30.0	4.9	40.0	5.8	32.0	4.5
		93.0	-0.6	97.0	-0.2	92.0	-1.2	57.0	26.6	63.0	18.0	57.0	13.7
		99.0	0.0	100.0	0.0	100.0	-0.1	88.0	-20.0	91.0	-14.2	78.0	-10.9
		-	-	-	-	-	-	96.0	12.9	99.0	7.5	99.0	25.9

Note: AJA – ankle joint angle, KJA – knee joint angle, HJA – hip joint angle.

The usual walking is characterised by the high velocities and accelerations of the foot plantarflexion at the beginning of the stride and of the flexions and extensions at the KJ during the swing phase. But the velocities in the HJ are lower. The attention should be paid to the fact that the velocity values of flexion and extension in the KJ during the swing phase are approximately the same. It may point to the oscillation character of the movements with the small contribution of the muscle forces (Fig. 2).

The largest angular velocities and accelerations during the upstairs walking take place in the KJ and HJ at the end of the stance phase and during the swing phase; the extension velocities are two-three times as less as the flexion velocities. The angular accelerations reach their maximum values at the end of the cycle. Note also that all movements in both proximal joints are characterised by the significant synchronism and by approximately equal values of the first two time derivatives of the inter-link angles. The movements in AJ have the lower velocities; especially it concerns the plantarflexion at the end of the stance phase.

The difference in the velocities of the extension and flexion movements during the upstairs walking is determined, probably, by the muscles working conditions: the slower extension movements in KJ and HJ overcome the body weight, while the faster flexion movements in the same joints overcome only the lower limb weight (Fig. 3).

During the downstairs walking the angular velocities and accelerations reach their maximum values at the first plantarflexion in the AJ and during the KJ movements. The flexion in the KJ is slower than the extension. This fact may be explained as follows: the flexion in the KJ takes place under the load and the oscillation properties of the lower limb reveal themselves mainly during the extension. The lowest velocity parameters are characteristic of the movements in the HJ (Fig. 4).

Thus, the analysis of the first two time derivatives of the inter-link angles may be conducive to the elucidation of some movements' mechanisms of different locomotions.

Dynamic walking parameters

Figure 5 shows the vertical (R_Z), longitudinal (R_X) and transverse (R_Y) components of the ground reaction force for the horizontal and stairs walking. The extreme values of these components are presented in Table 5. Figure 5(a) shows that the R_Z-curve for the horizontal walking has two-peak shape with distinctly expressed heel-strike and push-off and symmetrical disposition of minimum. The heel-strike maximum corresponds to 17-18 % of cycle, the push-off maximum corresponds to 51 % of cycle, and minimum corresponds to 33-34 % of cycle. The extreme values are approximately equal in both legs. The extreme values at heel-strike and at push-off are approximately equal.

R_X component is characterised by two extreme values with different signs. The negative one corresponds to 14-15 % of cycle; the positive one corresponds to 56 % of cycle; R_X component vanishes at 32-33 % of cycle. The relative temporal and amplitude symmetry of R_X component values in both legs is observed.

R_Y component has two less distinct extreme values with the same temporal parameters as the extreme values of R_Z.

Note that the extreme values of R_Z component have the lowest variations; the variations are equal to 8 % at heel-strike and toe-off and 13-14 % at the minimum of the curve. The variations of the extreme values of R_X component reach 16-20 %; the extreme values of R_Y component have the largest variations of 31-35 %.

On the whole, the ground reaction force components in the upstairs walking are the same. Nonetheless, there are some differences. The extreme values of R_Z component are characterised by the shift to the right. The heel-strike maximum corresponds to 18-19 % of cycle, the push-off maximum corresponds to 56 % of cycle, and minimum corresponds to 35-37 % of cycle. The extreme values are slightly lower in comparison with the horizontal walking, but the variations of the extreme values are approximately the same (for both legs).

Для рис. 5.

Table 5. The extreme values of the ground reaction force components in the horizontal and stairs walking (% of the body weight).

Compo-nents	Leg	Horizontal track				Stairs							
						Up				Down			
		% T	**M**	SD	VC	% T	**M**	SD	VC	% T	**M**	SD	VC
R_x	Left	14.0	**-18.1**	3.6	20%	16.0	**-10.7**	2.0	19%	14.0	**-10.5**	3.7	35%
		56.0	**22.3**	4.4	20%	61.0	**5.1**	2.4	47%	58.0	**12.0**	4.2	35%
	Right	15.0	**-18.7**	2.9	16%	15.0	**-8.6**	1.7	20%	14.0	**-11.1**	4.0	36%
		56.0	**20.1**	4.1	20%	61.0	**5.1**	2.2	43%	58.0	**15.8**	3.3	21%
R_y	Left	18.0	**-7.5**	1.8	24%	19.0	**-6.6**	1.5	23%	13.0	**-7.8**	3.3	42%
		51.0	**-6.5**	1.6	25%	55.0	**-5.3**	1.5	28%	53.0	**-4.0**	1.5	38%
	Right	17.0	**-7.4**	2.3	31%	18.0	**-2.3**	1.6	70%	12.0	**-4.6**	2.5	54%
		51.0	**-6.6**	1.5	23%	56.0	**-4.0**	1.6	40%	54.0	**-7.6**	1.9	25%
R_z	Left	18.0	**109.8**	11.1	10%	19.0	**105.5**	7.2	7%	13.0	**123.7**	27.5	22%
		33.0	**72.3**	9.8	14%	37.0	**69.1**	8.1	12%	36.0	**74.9**	10.5	14%
		51.0	**111.7**	9.3	8%	55.0	**106.0**	8.0	8%	53.0	**96.6**	9.0	9%
	Right	17.0	**111.1**	9.1	8%	18.0	**109.1**	8.4	8%	12.0	**117.2**	26.5	23%
		34.0	**72.4**	9.7	13%	35.0	**75.8**	7.4	10%	38.0	**68.7**	9.4	14%
		51.0	**110.9**	8.7	8%	56.0	**108.5**	8.3	8%	54.0	**92.4**	11.9	13%

Note: R_x is the longitudinal component of the ground reaction force, R_y is the transverse component of the ground reaction force, and R_z is the vertical component of the ground reaction force.

The changes of R_X component are more significant. The extreme values are considerably smaller and they are not equal: the extreme value corresponding to the heel-strike is almost twice as much as that corresponding to the toe-off. The time coordinates of these values are shifted to the right.

The shape of R_Y component curve remains the same, but the extreme values of this component slightly decrease.

Thus, the importance of R_X component decreases sharp in the upstairs walking, especially at the toe-off.

The changes of R_Z occur in the downstairs walking. The extreme value corresponding to the heel-strike increases sharp, the extreme value corresponding to the toe-off becomes smaller than the body weight. Front and rear parts of the curve become steeper. The extreme values of R_X and R_Y components significantly decrease in comparison with those in the horizontal walking, but exceed those in the upstairs walking. The variations of all components values increase. The above-cited data show that the change of the locomotor problem, i.e. the necessity of the large vertical displacements of the centre of gravity, leads to the significant changes of all the ground reaction force components; these components are adapted to the peculiarities of the definite biomechanical situation.

Discussion

On the whole, the obtained results correspond to those presented in the certain publications. But these results introduce new information about a number of important walking parameters. Some conclusions could be made of the biomechanical mechanisms of the investigated locomotion types.

Really, notwithstanding that investigated motor acts are original at first sight, two basic locomotion phases are distinctly seen in their structure: the stance one and the swing one. These phases have different biomechanical contents. The stability of the human body is provided and the driving forces are created during the stance phase. The problem of the lower limb movement either forward (in horizontal walking) or in vertical direction (up in upstairs walking and down in downstairs walking) is solved during the swing phase.

Hence, there is a unified scheme of different locomotor acts: the extensions in the lower limb joints provide the force component of locomotion, and the flexions provide the limb transportation and its correction. This scheme becomes especially visible during the stairs walking, when the force function prevails in the ascent and the correction function prevails in the descent.

The high degree of extensions and flexions synchronism shows that the synergetic temporal unity of the force sources forms the basis of these movements. The significant symmetry of the most kinematic and dynamic parameters of both lower limbs in different types of walking is also the argument in favour of this assumption.

At the same time, some differences between these locomotions should be noted.

The oscillation properties of the lower limb, which are connected with the resonance phenomena, are rather used during the horizontal walking than during the stairs walking. The stability of the human body during the first locomotion turns out to be higher than during the second one.

The variations of almost all investigated kinematic and dynamic parameters are considerably smaller in the horizontal walking in comparison with the stairs walking.

It follows from the numerous experimental investigations that the usual gait is more economical energetically than the other types of locomotion.

Conclusions

1. The upstairs and downstairs walking are the slower processes than the horizontal walking; this fact is connected with lesser usage of the oscillation properties of the lower limbs and with the stride length limitation.
2. The stairs walking is less stable than the horizontal walking; this fact is shown by the increase of the foot-contact interval, by the decrease of the heel-contact and toe-contact intervals and by the decrease or sign inversion of the τ-interval.
3. The basic phases of the locomotor cycle – stance and swing phases – take place in all investigated types of walking. The stability of the human body is provided and the driving forces are created during the stance phase. The problem of the lower limb movement is solved during the swing phase. The stance phase movements, which take place under the load, are slower than the swing phase movements.
4. The components of the ground reaction force change in the stairs walking: R_X component decreases sharp in the upstairs walking, especially at toe-off; in the downstairs walking R_Z component increases sharp at heel-strike and decreases at toe-off, R_X component also somewhat decreases. The originality and the lower velocity of these motor acts cause the noted changes.
5. The stairs walking is more variable and hence, less perfect locomotion than the horizontal walking.

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БИОМЕХАНИЧЕСКОЕ ИССЛЕДОВАНИЕ ХОДЬБЫ ПО ГОРИЗОНТАЛЬНОЙ ПОВЕРХНОСТИ И ПО ЛЕСТНИЦЕ

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Целью работы является исследование биомеханической структуры распространенных естественных двигательных актов человека. Объектом исследования являлась группа здоровых испытуемых (10 человек) при ходьбе в произвольном темпе по горизонтальной поверхности и по лестнице вверх и вниз.

Регистрировали следующие параметры: основные (темп, длину шага, среднюю скорость), временные (длительности цикла, опорной, переносной, двухопорной фаз, интервалов опоры на пятку, всю стопу, носок, τ - интервал), кинематические (угловые перемещения и их первые две производные при движениях в голеностопном, коленном и тазобедренном суставах), динамические (вертикальную, продольную и поперечную составляющие главного вектора опорных реакций).

В результате исследований было установлено:

1) по сравнению с ходьбой человека по горизонтальной поверхности передвижение по лестнице вверх и вниз является более медленным процессом, что связано с меньшим использованием колебательных свойств нижних конечностей и ограничением длины шага;

2) ходьба по лестнице характеризуется меньшей устойчивостью по сравнению с горизонтальной ходьбой, о чем свидетельствует увеличение интервала опоры на всю стопу, сокращение интервалов опоры на пятку и носок, уменьшением длительности или инверсия знака τ - интервала (время от отрыва пятки одной ноги до начала опоры другой ноги);

3) при всех исследованных видах ходьбы сохраняются основные фазы локомоторного цикла: опорная и переносная; в первой из них обеспечивается устойчивость тела и создание сил для его перемещения в пространстве, во второй - осуществляется перенос нижней конечности и его коррекция; движения в опорной фазе, происходящие под нагрузкой, совершаются более медленно, чем движения в переносной фазе;

4) при ходьбе по лестнице происходит изменение составляющих опорной реакции: при подъеме вверх резко уменьшается продольная составляющая, особенно в фазе заднего толчка; при ходьбе вниз резко увеличивается вертикальная составляющая в фазе переднего толчка и снижается в фазе заднего толчка, также несколько

уменьшаются значения продольной составляющей; отмеченные изменения обусловлены своеобразием этих двигательных актов и меньшей скоростью их выполнения;

5) ходьба по лестнице является более вариативным и, следовательно, менее совершенным двигательным актом по сравнению с горизонтальной ходьбой.

Библ. 6.

Ключевые слова: ходьба, лестница, биомеханические параметры

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