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DIFFERENCES IN MORPHOLOGICAL AND BIODYNAMIC CHARACTERISTICS OF MAXIMUM SPEED AND ACCELERATION BETWEEN TWO GROUPS OF FEMALE SPRINTERS

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Abstract. The purpose of the study was to identify those morphological characteristics and biomotor parameters that differentiate between trained female sprinters in terms of 100-m sprint results. Morphological characteristics were established with a set of 21 variables measured with the International Biological Programme (IBP) procedure. Biodynamic parameters of sprint running were identified on the basis of the start acceleration test and the maximum speed test. The criterion for start acceleration was a 30-m run from the sprint start and the criterion for maximum speed was a 30-m run from a flying start. In these two tests measurements were carried out using the Opto–Track system. Statistically significant differences between the two groups of female sprinters were established by the t-test for independent sample. The results of the study showed that the athletes did not differ in terms of morphological characteristics, with the exception of leg length ($p<0.05$). The differences between the athletes were statistically significant in the start acceleration speed and the maximum speed ($p<0.01$). In both tests, the most important generator that differentiated between the superior and the inferior sprinters was the stride length ($p<0.01$). The contact phase time was on the edge of statistical significance only in the case of start acceleration. Superior sprinters develop higher starting speed ($p<0.05$), due to shorter average contact time, longer stride ($p<0.05$) and the same frequency compared to the inferior group.

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Key words: Morphological characteristics - Biodynamic parameters - Start acceleration - Maximum speed - Female sprinters

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Introduction

Sprint running is a complex cyclic movement defined by stride frequency and stride length. Both parameters are interdependent and each is conditional on the central movement regulation processes, biomotor abilities, energetic processes and morphological characteristics [2,4,9,17,21,22]. Sprint running as a movement stereotype consists of repetitions of strides in a time unit. The length of stride depends mainly on body height and/or leg length as well as the force developed by extensor muscles of the hip, knee and ankle joints in the contact phase. On the other hand, execution of contact phase is one of the most important generators of the sprinting speed efficiency [14,21]. The contact phase has to be as short as possible with an optimal ratio between the braking phase and the propulsion phase. Stride frequency depends on the functioning of the central nervous system and is to a large extent genetically predetermined [23]. The ratio between stride frequency and stride length is defined individually, and it is automatised. The higher the frequency, the shorter the stride length, and vice versa. Sprinting speed is in fact an optimal ratio between length and frequency of athlete's strides. Some studies pointed to direct correlation between the frequency and length of stride and the length of the lower extremities, while at the same time these studies did not confirm morphological measures to be an important success factor in sprint [23,24]. There were many studies regarding this topic focusing only on male sprinters [21]. Regarding to that, the first objective of this study was to find out which morphological characteristics statistically significantly differentiate between the trained female sprinters of different performance levels. On the other hand, the second objective of the study was to identify differences between two groups of female sprinters in terms of biodynamic parameters in the start acceleration test, and the third one was to discover differences between biodynamic parameters in the maximum speed test.

Materials and Methods

Subject sample: The research included 17 women sprinters of the senior and junior national teams of Slovenia. They were divided into two groups by the quick cluster statistical method, in view of the criterion result of their 100-m sprint. In the first, superior group (group A) the average age of athletes was 19.7±4.31 years and the average 100-m sprint result 12.14±0.32 s. In the second, inferior group (group B) the average age was 18.8±1.57 years and the average 100-m sprint result 12.96±0.17 s.

Experimental design: The subjects executed test on the athletic track in laboratory conditions. The measurements were carried out in the sports hall of the Athletic Centre of Slovenia in Šiška, Ljubljana. The subjects accelerated maximally for 30 meters from sprint start and 30 m from flying start. In the second test subjects were asked to maximally accelerate from the standing start over the first 30 m. The maximal running velocity was then achieved over the second 30 meter's distance during the second test. The athletes performed the start acceleration test and the absolute speed test twice in a row. The athletes had a break of at least 10 min between the tests and gained full recovery before the next repetition.

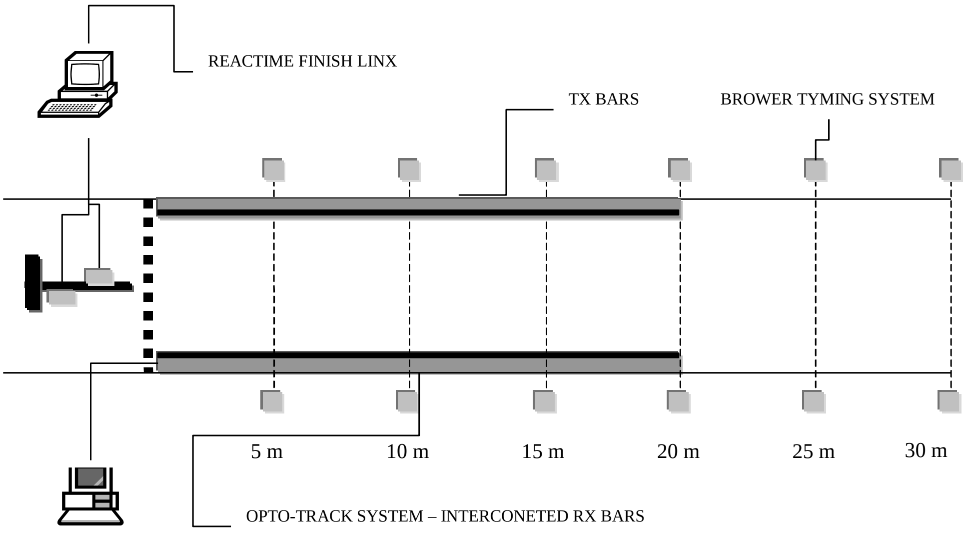

Fig. 1
Diagram of the sprint starts over 30 m

Track sprinting test: During the 30 m (Fig. 1) from the sprint start and flying start biodynamic parameters were measured with Opto-Track system, manufactured by the Italian company Microgate. The basis of the measuring system are the interconnected rods (100 cm x 4 cm x 3 cm) fitted with optical sensors and a computer program for data storing and processing (Fig. 1). Each rod is fitted with 32 sensors – photocells, arranged 4 cm one from another and 0.2 cm above the ground. The length of the interconnected rods was 20 m. The rods were distributed along the width of the sprint athletic track (1.22 m). The measuring chain (RX bars and TX bars) enabled the measurement of the following sprint parameters: contact time (CT), flight time (FT), stride length (SL), stride frequency (SF). In addition to the Opto–Track measuring system, the infrared photocell timing system (BROWER) was also used in the start acceleration test (30-m sprint from a sprint start) and in the absolute speed test (30-m sprint from a flying start) to measure time (Fig. 1). At the start, the electronic starting blocks REACTIME FINISH LINX (Fig. 1) were used to register premotor time (RT). Premotor time is defined as the time interval lasting from the starting signal to the onset of the movement. The measurements of reaction time were carried out by an expert "TIMING" team.

Anthropometric measurements: Morphological characteristics of women sprinters were established by means of a set of 21 measures and the International Biological Programme (IBP) procedure was applied. Measurements were carried out by a professional medical team.

Muscle mass, fat free mass and bone mass were estimated trough anthropometry using equation reported by Mateigka [19].

Statistics: T-test for independent samples was used to test the significance of differences between two sub-groups.

Results

The difference between group A and group B in 100 m sprint result is shown in Table 1.

Table 1
Differences in 100 m sprint result between two sub-groups of female sprinters

		Group A (n=10)		Group B (n=7)		T-Test	
Variable	Unit	M	SD	M	SD	T	SIG
100-m sprint result	s	12.4	0.32	12.96	1.17	-6.09	0.00**

**$p<0.01$

Table 2
Differences in morphological parameters between two sub-groups of female sprinters

		Group A (n=10)		Group B (n=7)		T-Test	
Variable	Unit	M	SD	M	SD	T	SIG
Body height	cm	169.2	5.19	168.5	2.13	0.32	0.72
Body mass	kg	58.9	4.55	57.6	4.47	0.63	0.53
Body mass index		20.5	4.43	20.3	3.12	0.69	0.77
Leg length	cm	98.6	2.86	95.2	2.15	2.57	0.02*
Circumference of upper arm	cm	25. 2	1.27	25.8	1.65	- 0.96	0.35
Circumference of forearm	cm	23.3	0.76	23.2	1.14	0.01	0.99
Circumference of thigh	cm	55.9	2.06	55.8	2.90	0.04	0.96
Circumference of calves	cm	36.1	1.95	36.4	1.45	- 0.43	0.67
Shoulder width	cm	37.7	1.32	36.3	1.67	1.31	0.21
Pelvis width	cm	26.9	1.22	26.7	1.40	0.35	0.72
Elbow diameter	cm	6.1	0.39	6.2	0.20	-0.45	0.65
Wrist diameter	cm	4.9	0.25	5.1	0.11	-0.51	0.61
Knee diameter	cm	8.6	0.30	8.7	0.29	-0.70	0.49
Ankle diameter	cm	6.8	0.28	6.8	0.12	0.00	0.87
Back skin fold	mm	8.2	1.39	8.7	1.70	-0.71	0.49
Abdominal skin fold	mm	12.1	4.77	11.2	3.17	0.45	0.66
Thigh skin fold	mm	14.5	3.31	19.4	7.12	-1.93	0.07
Share of fat mass	%	17.0	2.60	18.3	2.91	-0.94	0.36
Muscle mass	kg	29.2	2.70	28.8	1.86	0.32	0.75
Share of muscle mass	%	50.0	2.51	49.4	2.22	-0.56	0.58
Bone mass	kg	13.4	0.89	13.5	0.29	-0.16	0.87
Share of bone mass	%	22.8	1.42	23.5	1.47	-0.95	0.36

*$p<0.05$

As regards the quality of competitive 100-m sprint, the results in Table 2 show no significant differences ($p<0.05$) between the sampled female sprinters in morphological parameters. The only exceptions are the leg length and the thigh skin fold, which is on the verge of statistical significance. In general, the superior female sprinters have 1.3% less fat mass and 0.6% more muscle mass (according to Matiegka) compared to the inferior group.

Table 3
Differences in biodynamic parameters between two sub-groups of female sprinters

		Group A (n=10)		Group B (n=7)		T-Test	
Variable	Unit	M	SD	M	SD	T	SIG
30 m from sprint start	**$m \cdot s^{-1}$**	**6.45**	**0.14**	**6.17**	**0.08**	**4.60**	**0.00****
First starting block - line	cm	50.7	5.43	49.7	3.35	1.74	0.10
First starting block – line/leg length	**-**	**0.26**	**0.03**	**0.25**	**0.02**	**0.74**	**0.47**
Distance between blocks	cm	26.0	3.46	23.4	2.07	0.42	0.67
Reaction time	s	0.150	0.02	0.146	0.03	0.39	0.70
0-5 metre sprint	$m \cdot s^{-1}$	3.51	0.12	3.39	0.10	2.17	0.04*
5-10 metre sprint	$m \cdot s^{-1}$	6.79	0.17	6.54	0.15	3.07	0.00**
10-15 metre sprint	$m \cdot s^{-1}$	7.56	0.38	7.01	0.10	3.65	0.00**
15-20 metre sprint	$m \cdot s^{-1}$	7.73	0.37	7.56	0.23	1.07	0.30
20-25 metre sprint	$m \cdot s^{-1}$	8.38	0.18	7.82	0.32	4.54	0.00**
25-30 metre sprint	$m \cdot s^{-1}$	8.55	0.40	8.24	0.20	1.84	0.08
Average stride length	cm	148.7	7.32	140.8	5.07	2.54	0.02*
Average stride length/leg length	**-**	**1.51**	**0.05**	**1.48**	**0.04**	**1.47**	**0.16**
Average stride frequency	Hz	4.11	0.12	4.12	0.06	-0.25	0.80
Average stride frequency/leg length	**-**	**0.04**	**0.00**	**0.04**	**0.00**	**-1.51**	**0.15**
Average contact time	ms	149	5.22	153	4.09	-1.85	0.08
Average flight time	ms	95	7.3	89	6.0	1.61	0.13
Length of stride 1	cm	102.2	4.46	94.4	4.99	3.29	0.00**
Length of stride 1/leg length	**-**	**1.04**	**0.05**	**0.99**	**0.05**	**1.80**	**0.09**
Length of stride 2	cm	114.1	9.33	107.0	4.54	1.84	0.08
Length of stride 2/leg length		**1.17**	**0.06**	**1.12**	**0.05**	**2.01**	**0.06**
Length of stride 3	cm	125.0	5.19	119.6	6.72	1.82	0.08
Length of stride 3/leg length		**1.27**	**0.05**	**1.25**	**0.06**	**0.51**	**0.62**
Length of stride 4	cm	140.5	9.63	132.0	6.37	2.02	0.06
Length of stride 4/leg length		**1.43**	**0.07**	**1.38**	**0.05**	**1.55**	**0.15**
Length of stride 5	cm	147.3	7.21	145.0	7.61	0.62	0.54
Length of stride 5/ leg length		**1.49**	**0.06**	**1.52**	**0.07**	**-0.83**	**0.42**
Contact time of stride 1	ms	200	12.55	194	9.59	1.14	0.27
Contact time of stride 2	ms	183	10.50	184	13.04	-0.26	0.79
Contact time of stride 3	ms	154	9.78	160	6.79	-1.50	0.16
Contact time of stride 4	ms	146	13.35	155	5.85	-1.67	0.12

*$p<0.05$; **$p<0.01$

The results in Table 3 show differences in biodynamic parameters of a 30-m sprint from the sprint start in terms of quality of the sprinters. As regards the position of the starting blocks with respect to the starting line, no statistically significant differences were found, even when we normalised the distances to leg length. In superior female sprinters the first starting block was placed 50.7±5.4 cm from the starting line, while in inferior sprinters the distance was 49.7±3.3 cm. The distance between the blocks in groups A and B was 26.0±3.4 cm and 23.4±2.0 cm, respectively.

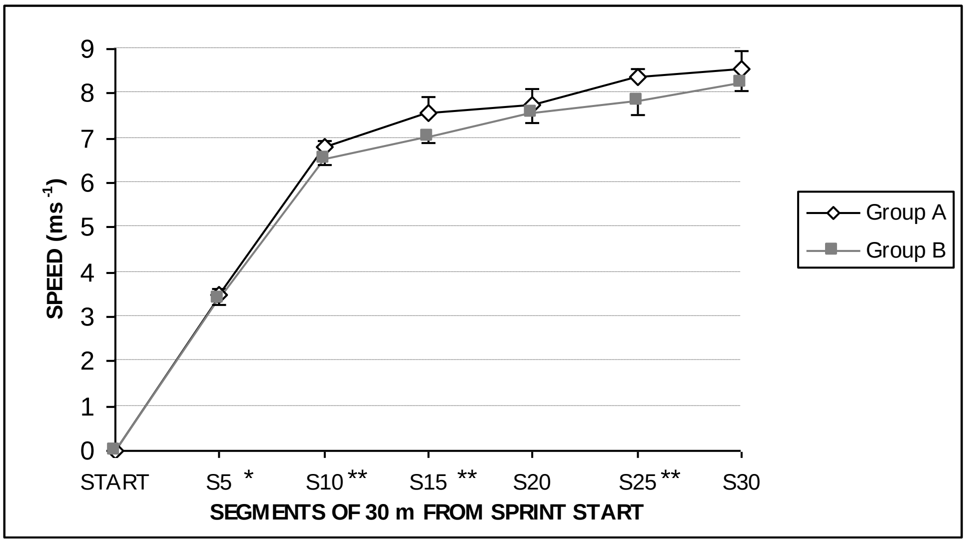

Fig. 2
Differences in average section velocity during start acceleration over 30 m from the sprint start between two sub-groups of female sprinters

The results show that the inferior group of female sprinters had shorter reaction time (146±0.03 ms) on average compared to the superior group (150±0.02 ms), which is rather surprising. On the other hand, there were significant differences between the athletes in transition of starting action to start acceleration. The average speed of group A in this segment was 3.51±0.12 $m \cdot s^{-1}$, while that of group B was 3.39±0.10 $m \cdot s^{-1}$. The groups differed in terms of speed realisation in other segments as well, except in 15-20 m start acceleration (Fig. 2). The pick-up acceleration from 25 to 30 m was on the verge of statistical significance differentiating between superior and inferior female sprinters.

In the start acceleration some biodynamic parameters of sprinting stride such as length, frequency, contact time and flight time changed very dynamically. The groups A and B statistically significantly differed in terms of absolute average length of stride and were on the verge of statistical significance in terms of contact time duration. Progression of stride length along with appropriate stride frequency is typical of start acceleration. In a 30-m sprint from a sprint start, group A developed significantly higher speed, owing to greater absolute average leg length, while in terms of stride frequency, there were no differences whatsoever between the groups. The average stride length of group A was 148.7±7.32 cm and group B 140.8±5.07 cm. On the other hand, there were no differences in average relative stride length (Table 3) or relative frequency over the start acceleration between two sub-groups.

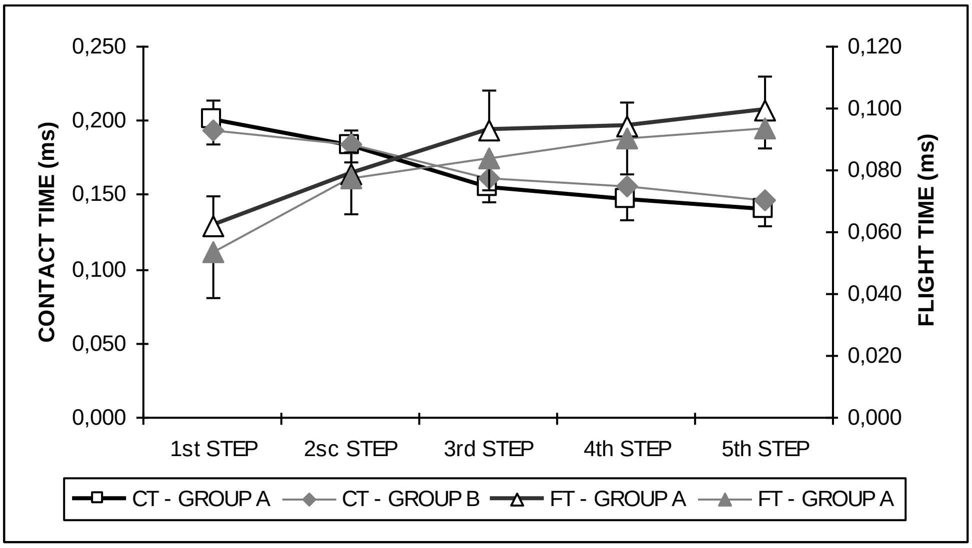

Fig. 3
Differences in biodynamic parameters of first strides during the start acceleration during the 30 m

More accurate view in the stride length-frequency relationship pointed on greater absolute differences during first five strides (Fig. 3). On the other hand, when we used relative values, the differences in stride length became minor and on the verge of significance (Table 3).

In group A the contact phase in the first four strides shortened on average by 54 milliseconds and in group B by 39 milliseconds. The contact time in the first stride (group A) accounted for 76% of total stride time. In the fourth stride the contact time accounted for only 60% of total stride time. In group B the share of contact time in the first stride was 78% and in the fourth stride 63%.

Table 4
Differences in biodynamic variables of maximum speed between two sub-groups of female sprinters

		Group A (n=10)		Group (n=7)		T-Test	
Variable	Unit	M	SD	M	SD	T	SIG
30 m with flying start	**$m \cdot s^{-1}$**	**8.84**	**0.34**	**8.28**	**0.19**	**3.91**	**0.00****
Average contact time	ms	110	11.9	113	5.55	-0.56	0.58
Average flight time	ms	121	9.41	116	4.49	1.09	0.29
Average stride length	cm	205.9	12.4	192.4	5.92	2.66	0.00**
Average stride length/leg length	**-**	**2.09**	**0.09**	**2.02**	**0.05**	**1.86**	**0.08**
Stride frequency	Hz	4.35	0.28	4.36	0.15	-0.14	0.89
Average stride frequency/leg length	**-**	**0.04**	**0.00**	**0.04**	**0.00**	**-1.47**	**0.16**

**$p > 0.01$

Table 4 shows that the female sprinters differed in maximum speed ($p < 0.01$). The maximum speed of the superior group was 8.8±0.3 $m \cdot s^{-1}$ and that of the inferior group 8.3±0.2 $m \cdot s^{-1}$. On the other hand, there were no differences in contact time and the duration of contact phase is slightly longer than that of elite athletes. On the other hand, the differences in stride length were significant and they became minor, when we used relative values. The contact times for elite sprinters range from 90 ms to 100 ms [20], whereas in group A the contact time range in average from 98 ms to 121.9 ms, which accounted for 47.6% of total time of sprinting stride (contact phase + flight phase). In group B the contact times range in average from 107.4 ms to 118.5 ms, which accounted for 49.3% of total time of sprinting stride.

Discussion

The findings of this study probably indicate that the major difference among the two groups of female sprinters is their ability to produce longer stride length over the first five strides during the acceleration phase of sprinting and also during the maximum speed of running, although we should have in mind that the differences in relative stride length were only at the verge of significance during both phases of sprint.

In most of the studies the authors could also not establish any correlation between the reaction time and the final result in a 100-m run [1,5,8,10,18,19,23]. In our study the superior group A was faster then inferior group B over the first segment of run (Table 3), whereas the premotor reaction time was longer in the superior then inferior group (Table 3), although the difference was not significant. Apparently, there exists a specific, genetically conditioned ability enabling a rapid transmission of afferent and efferent nerve impulses. Obviously, the starting action is conditioned by very specific motor abilities, with reaction time being only one of them. In the superior group the reaction time accounted for 11.7% of total start acceleration time in the first 5 m, while in the inferior group the respective figure was 10.9%. The share of reaction time in aggregate results of 30-m from the sprint start was 3.3% in group A and 3.1% in group B. These percentages are not negligible; quite on the contrary, many times these hundredths of seconds determine the positioning of athletes on crossing the finish line.

According to some studies [13,26] realisation of the first three strides after the starting action is extremely important. This has been also confirmed by our study. The quality of transition the starting action to start acceleration is seen in the first five meters of the 30 m run. The superior female sprinters had longer first four strides and at the same time shorter contact phases – both at the verge of statistical significance (Fig. 3). The superior group of sprinters could probably developed greater horizontal force, especially during the first two strides, when the projection of the centre of gravity is located ahead the foot’s point of contact with the ground [20]. It is not until the third and fourth strides that the projection of the centre of gravity shifts behind of the foot’s point of contact with the ground [20]. Owing to the changing biomechanical conditions and the increasing speed during the acceleration phase, the ratio between contact and flight phases changes in both sub-groups of sprinters. The contact phases becoming shorter and the flight phases longer (Fig. 3), and the differences between two sub-groups became minor. The curve shift, which indicates changed ratio between contact and flight phases, origin later in the inferior group of female sprinters (Fig. 3).

According to some studies [3,9,11,12,23,25], maximum speed results from an optimal ratio between stride frequency and stride length. The most important generator of differences in maximum speed among two sub-groups is the stride length ($p<0.01$). This is rather surprising. Namely, some of the previous studies showed that frequency specifically influenced the speed of sprint running in men and women [9,23]. Stride length is a complex parameter that depends on many factors among which morphological characteristics (leg length), muscle structure, reflex mechanisms and transmission of force to the ground in the contact phase are of particular importance. We should emphasise that, there were only minor differences in other morphological characteristics then leg length. We have expected substantially greater differences between the groups in terms of muscle mass percentage. Of course, the share of muscle mass is not the only relevant factor for development of longer strides; there are also other factors such as efficiency of biochemical energetic processes in the working muscles and intramuscular co-ordination of agonists and antagonists [7].

The groups differ significantly in terms of leg length and consequently also stride length. According to some studies [9,23] female sprinters' stride length depends more on leg length than on fast force of the hip and knee extensor muscles and plantar flexor muscles of foot. However, the female sprinters of both sub-samples were practically equal in terms of body height, body mass index, diameter of shoulders, hips, knee and ankle as well as circumferences of the lower and upper extremities. High homogeneity of the sample of female sprinters in the morphological area is a consequence of their biological development and selection, as optimal morphological characteristics are a prerequisite for realising the sprinting potential.

However, the superior group realised their maximum speed with longer strides, even when we compared relative values of the stride length. According to that also the other mechanism, such as muscle structure, reflex mechanisms and transmission of force to the ground in the contact phase, are of particular importance. Mero [22] established a significant correlation between the ratio of fibres of type II in the muscle vastus lateralis and the average resultant of propulsion force in the contact phase. The greatest ground reaction force in the contact phase occurs 10 ms to 40 ms after the foot touches the ground. In order to be able to withstand such a powerful force, the extensor muscles of legs have to be adequately preactivated, while at the same time the stretch reflex system has to be activated to ensure the necessary stiffness of muscles [7]. In view of the EMG values, the most important role is played by the muscle rectus femoris [21].

Also the contact phase is undoubtedly the key kinematic factor, although there were no significant differences among two sub-groups, defining economical sprint running from the point of view of the ratio between the braking phase and the propulsion phase [16]. This ratio should be 40% : 60% [6,16]. The shorter the braking phase, the lower the reduction of horizontal speed of the centre of gravity.

In the sampled female sprinters the contact phase in group A was 110±11.9 ms and in group B 113±5.5 ms. There were no significant differences between the two groups in terms of this parameter. The duration of contact phase is slightly longer than that of elite athletes, since the contact times of the latter range from 90 ms to 100 ms [20]. In group A the contact phase accounted for 47.6% of total time of sprinting stride (contact phase + flight phase) and in group B 49.3%. Superior female sprinters obviously have shorter contact times and longer flight times, while in inferior female sprinters it is the other way around. Stride frequency correlated with duration of contact phases; however, there were no differences between the groups in terms of start acceleration and maximum speed. Stride frequency is above all a parameter bearing a specific genesis and is more difficult to change than stride length. It has a strong genetic code which is rooted in the central nervous system. Changing of the movement stereotype of maximum speed with special tools and methods (method for developing supramaximal) speed is a very risky pursuit, especially in young female and male athletes.

Conclusion

Start acceleration and maximum speed are two extremely important phases, defining the result in sprint running. It was precisely these two capabilities that were the subject of this study, and they were studied in terms of biodynamic parameters of trained female sprinters. There are relatively few experimental studies of this kind drawing from a sample of female athletes.

Speed is a biomotor ability manifesting itself in various ways. One of them is the sprinting speed which is a very conservative ability and is very difficult to change. Namely, it has a very strong genetic background and may only be improved, if one is familiar with its mechanisms and sensitive phases. Forming of an optimal movement stereotype is a long-term process, therefore, a proper methodology is very important. Results in sprint running depend on many factors and their optimal correlation. Some factors are well known; the others have not yet been explained. In this study we tried to identify those morphological characteristics and biomotor abilities that differentiate between trained young female sprinters in a 100-m run. In this very homogeneous morphological area, it was not possible to establish any significant differences, except in leg length. Together with stride length, this parameter statistically significantly differentiates between superior and inferior female sprinters in terms of realisation of sprinting speed. As regards start acceleration and maximum speed, there were significant differences between the sub-samples. Different efficiency in both types of speed is primarily the consequence of stride length and to some extent also contact phase duration. Hypothetically, we expected to get a higher number of parameters differentiating between the female sprinters. This did not happen, probably owing to the specificity of the sample of young athletes with relatively few years of training with special means and methods.

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