RELATIONS OF THE VARIABLES OF POWER AND MORPHOLOGICAL CHARACTERISTICS TO THE KINEMATIC INDICATORS OF MAXIMAL SPEED RUNNING

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Abstract:

The aim of the present research was to investigate the relations of 7 variables of power and 12 variables of morphological characteristics with the kinematic indicators (stride frequency, stride length, foot-ground contact duration, flight duration) of maximal running speed. The research was conducted on a sample of 133 physical education male students, 19 to 24 years (age 21.7 ± 1.08; body height 180.8 ± 6.98; body weight 76.6 ± 7.62), freshmen at the Faculty of Kinesiology, University of Zagreb. By means of the component model of factor analysis under the GK criterion and non-orthogonal rotation under the promax criterion the following factors were obtained: three morphological factors (skeleton dimensionality, in which the longitudinal component prevailed, body voluminosity and subcutaneous fatty tissue) and two factors of power (power of a jumping type and ballistic power). Canonical analysis of the morphological factors and power factors with kinematic parameters resulted in two pairs of canonical factors with statistically significant canonical correlations ($Rc1=0.76$; $p<0.01$, and $Rc2=0.57$; $p<0.01$). On the basis of the first pair structure of canonical factors it was concluded that the Faculty of Kinesiology students who had pronounced dimensionality of skeleton, a smaller amount of subcutaneous fatty tissue and better developed relative power, performed longer strides in maximal speed running. The structure of the second canonical factor pair indicated that the students with the greater skeleton dimensionality had a smaller frequency of strides and their foot-ground contact lasted longer. It was also determined that stride length and stride frequency were negatively correlated in maximal speed running which was the result of positive correlation between skeleton dimensionality and stride length, on the one hand, and of negative correlation between skeleton dimensionality and stride frequency on the other. The findings may contribute to a better understanding of the factors responsible for sprint performance in the population of athletes who are not top-level sprinters, i.e. they may be useful to PE teachers, coaches who work with novices in athletics and physical conditioning coaches who work in sports other than athletics, to get a more thorough insight into the sprinting efficiency mechanisms.

Key words: *canonical analysis, morphological characteristics, power, kinematics, stride length, stride frequency, sprinting, PE students*

Introduction

Quite a lot of previous research has focused on the investigation of biomechanical factors responsible for performance in sprint or maximal speed running (for a review see Mero, Komi, & Gregor, 1992; Čoh, Dolenec, & Jošt, 2003; Korhonen, Mero, & Suominen, 2003; Babić, 2005; Wang, 2006; Pain & Hibbs, 2007). It was found, among other findings, that the maximum speed of running is determined by the following kinematic parameters: stride frequency, stride length, ground-foot contact duration, non-contact phase duration (or airborne phase duration) (Bellotti, 1991; Brüggemann & Glad, 1988; Müller & Hommel, 1997; Harland & Steele, 1997; Ferro, Riviera, Pagola, Ferreruela, Martin, & Rocandio, 2001). Maximum sprinting speed is actually a result of the optimal relationship between stride frequency and stride length. Several authors indicated stride frequency as being more important for maximum speed of running performance than stride length (Ballreich, 1976; Luhtanen & Komi, 1978; Mero, Luhtanen, Viitasalo, & Komi, 1981). On the other hand, both parameters - stride length and stride frequency, are influenced by numerous factors, such as muscular structure (Costill, Daniels, Evans, Fink, Krahenbuhl, & Saltin, 1976; Mero, Luhtanen, Viitasalo, & Komi, 1981; Mero, Kuitunen, Harland, Kyröläinen, & Komi, 2006), running technique (Mero, Luhtanen, & Komi, 1986), speed strength and elasticity of muscular-tendon locomotor complex (Mero et al., 1981). Based on the analysis of stride frequency and stride length parameters and on their comparison it is feasible to conclude that changes in stride length and stride frequency, found in the best, fastest world sprinters, enable great acceleration and speed maintenance over the course of a running event.

As far as stride length is concerned, it is possible to differentiate between two parameters. The first one is the distance between two foot-ground contacts, and the second is the distance the runner's centre of gravity travels within one stride (effective stride length). Movement velocity of the runner's centre of gravity varies within a sprinting stride. So, in the phase of the rear leg support (take-off), the velocity of the gravity centre increases, whereas it decreases in the phase of the front leg support. In top quality sprinters the horizontal velocity of the gravity centre decreases up to 2 to 3%, whereas in less quality sprinters it decreases even up to 5 to 6%. Stride length depends on the take-off velocity, take-off angle and the height of the centre of gravity at the moment of take-off, whereas stride frequency depends on the time needed for a stride performance and it is limited by stride length.

In several previous research studies (e.g. Donati, 1995; Gambetta, 1997) it was determined that runners achieve their maximal running speed by means of an individual-specific ratio between stride length and stride frequency. World-class male sprinters manage to run over a 100m-course at a speed of 12 m/s, whereas female sprinters achieve a speed of 11 m/s. The number of strides performed by the 100 m male sprint finalists in Seoul ranged from 43.6 to 46.6, whereas their stride frequency ranged from 4.76 to 4.39 strides per second. The number of strides performed by the 100 m female sprint finalists in Seoul ranged from 42.6 to 50.8, whereas their stride frequency ranged from 3.88 do 4.69 strides per second. It is obvious that when enhancing the speed of running, one must enhance either the stride length, or the stride frequency, or both. However, one must have in mind that Hunter, Marshall and McNair (2004) determined a relatively high negative correlation between stride length and stride frequency ($r=-0.70$, $P<0.01$), meaning that in the athletes who performed a larger number of strides they noticed the tendency of a smaller stride length, and vice versa.

The issue treated in the present research is an investigation of the phenomenon of sprinting conducted on a sample of variably trained physical education teacher students who were not top-level athletes-sprinters. The research was conducted on the sample of the Faculty of Kinesiology students who had been positively selected for their study, meaning generally for sport, but had not been oriented towards athletics nor had been trained specifically for it. Sport achievements in this case were neither an integral indicator of the effects of learning athletics technique of sprinting, nor the indicators of athletics training effects simply because previous training stimuli were not sufficient to induce considerable effects. Situations of this kind are the same as those with which physical education teachers, coaches who work with novices in athletics and physical conditioning coaches, who work in sports other than athletics, have to face in their actual practice. Therefore, the main issue of the research was to determine the relationships among the kinematic parameters (stride length, stride frequency, airborne duration, and ground-foot contact duration) in subjects who ran with maximal speed (sprinted) and the relations of these kinematic parameters to morphological characteristics and the variables of power in order to disclose the mechanisms that determine the sprinting performance of athletes who were not top-level sprinters.

Methods

Sample of subjects

The population were the students of the Faculty of Kinesiology, University of Zagreb, Croatia, who were positively selected for their study as regarding their motor and physiological abilities (capacities) and motor knowledge (skills). The research was conducted on the convenience sample embracing 133 male freshmen, aged 19 to 24 years (age 21.7±1.08 yrs; body height 180.8±6.98 cm; body weight 76.6±7.62 kg), who regularly attended their first-year classes at the Faculty of Kinesiology, University of Zagreb. The obtained results can be generalized to a population of similar anthropological features.

Sample of variables

In this research three groups of variables were measured: a) power, b) morphological characteristics, and c) kinematic characteristics of sprint.

a) The power of the subjects was assessed by means of five tests assessing power of a jumping type and two tests assessing power of a ballistic (throwing) type. All the applied tests were of good metric characteristics and had been successfully utilized in previous research (e.g. Markovic, Dizdar, Jukic, & Cardinale, 2004; Artega, Dorado, Chavarren, & Calbert, 2000). The following tests were utilized to assess power of a jumping type:

- *standing long jump* (SLJ)
- *standing triple jump* (STJ). A subject stands on the start line and performs a triple jump so as to perform the first take-off by two legs and the consecutive take-offs first by the take-off leg and then by the lead leg. The landing is on both legs.
- *drop-broad jump* (DBJ). A subject stands on his take-off leg on the edge of a box (height: 50 cm). He pushes himself off with his take-

off leg and lands on the same leg; after landing, he quickly performs another take-off with the same leg and finishes by landing on both feet on the mat. The landing from the box and the consecutive take-off must be performed in the zone of 70 cm which is 150 cm away from the box. The distance between the projection of the box edge on the floor and the landing foot mark on the mat is measured.

- *squat jump* (SJ). The capacitive contact mat Ergojump, Psion XP, MA.GI.CA., Rome, Italy was used.
- *countermovement jump* (CMJ). The capacitive contact mat Ergojump, Psion XP, MA.GI.CA., Rome, Italy was used.

In all the jumping tests the final score, expressed in centimetres, is an arithmetic mean of the results achieved in three performances.

For the ballistic power assessment the following tests were used:

- *medicine ball throwing backwards from supine position* (MBTSL). A subject is on his back with his head in the vicinity of the start line. With his arms extended he throws a 3 kg medicine ball as far as possible in the measuring scale direction.
- *medicine ball sitting put from the chest* (BSPC). A subject sits on the chair leaning with his shoulder-blades and head against the wall; his feet are on the floor slightly apart. From his chest he puts a 3 kg medicine ball as far as possible in the direction of the measuring scale simultaneously keeping his contact with the wall. The distance between the chair's front legs and the ball's landing spot is measured.

In all throwing tests the final score, expressed in centimetres, is an arithmetic mean of the results achieved in three performances.

b) Morphological characteristics were measured using International Biological Program (IBP) protocols (Mišigoj-Duraković et al., 1995). With respect to the hypothetical model of the morphological dimensions, the following morphological variables were measured, describing primarily the following:

- longitudinal dimensionality of skeleton: *body height* (BH), *leg length* (LL), *foot length* (FL);
- transversal dimensionality of skeleton: *knee diameter* (KD), *ankle diameter* (AD) and *elbow diameter* (ED);
- voluminosity and body mass: *body weight* (BW), *upper arm circumference* (UAC), *forearm circumference* (FC), *thigh circumference* (TC), *calf circumference* (CC);
- subcutaneous fatty tissue: *back skinfold* (BS), *abdominal skinfold* (AS), *thigh skinfold* (TS) and *lower leg skinfold* (LLS).

Trained measurers performed the measurements of all the morphological and power variables in the Sports Diagnostic Centre of the Faculty of Kinesiology, University of Zagreb.

c) Kinematic measurements of maximal speed running were conducted by means of a contact 20-m-long mat (ERGO TESTER – Bosco; Italy), with a measuring electronic system and respective computer software. After a 20 m run-up, a subject was supposed to run over the mat with maximal speed. The test was performed two times, with a pause of 15-20 minutes between the two trials. The following variables were registered (Čoh et al., 2001):

- f*oot-ground contact average duration* (TLCAD),
- *average airborne or flight phase duration* (TLFAD),
- *average stride frequency* (TLASF) and
- *average stride length* (TLASL).

Kinematic parameters were measured by a team of trained measurers with the Institute for Sport of the Faculty of Sport, University of Ljubljana, Slovenia.

Data analysis

For all variables the basic descriptive parameters were computed: arithmetic mean (Mean), minimal result (Min), maximal result (Max), and standard deviation (SD). Normality of distribution of the variables was tested by means of Kolmogorov-Smirnov test at the error level of 0.05.

Latent structure of morphological characteristics and of power indicators was determined with the component model of factor analysis under the Guttman-Kaiser (GK) criterion and with a non-orthogonal rotation of the initial coordinate system under the promax criterion.

Relations of power and morphological variables to kinematic parameters (stride frequency, stride length, foot-ground contact duration and airborne phase duration) of maximal running speed were determined using canonical analysis.

Results

The descriptive parameters obtained are presented in Table 1.

In order to reduce the group of manifest morphological variables to a smaller number of latent dimensions, the method of principal components was utilized. By the application of GK criterion three principal components were obtained which explained about 72% of the common variance of the manifest variables (Table 2).

Table 1. Descriptive indicators: arithmetic mean (Mean), minimal (Min) and maximal (Max) result, standard deviation (SD), and maximal deviation of the relative cumulative empirical frequency from the relative theoretical frequency (max D) of the variables of power, morphological characteristics and kinematic parameters

Morphological variables	Mean	Min	Max	SD	max D
BH (cm)	180.77	166.60	201.90	6.98	0.06
BW (kg)	76.56	57.00	98.80	7.62	0.07
LL (cm)	102.54	93.00	118.80	4.98	0.06
FL (cm)	26.76	23.20	30.80	1.39	0.08
ED (cm)	7.10	6.20	8.10	0.35	0.13
KD (cm)	9.39	8.40	10.50	0.44	0.12
AD (cm)	7.47	6.20	8.70	0.42	0.10
BS (cm)	10.34	5.00	25.17	3.40	0.12
AS (cm)	10.77	2.17	30.33	6.02	0.16
TS (mm)	14.43	4.33	28.00	5.24	0.09
LLS (mm)	8.07	2.00	25.17	3.84	0.13
UAC (mm)	33.24	27.50	39.00	2.14	0.11
FC (mm)	27.43	24.00	30.00	1.27	0.13
TC (mm)	57.80	43.50	70.50	3.74	0.09
CC (mm)	37.66	32.50	62.00	2.91	0.16
Power variables					
SLJ (cm)	254.10	221.67	291.67	15.44	0.11
STJ (cm)	718.56	603.33	844.67	46.99	0.06
DBJ (cm)	458.43	368.33	518.33	27.66	0.06
MBTS (cm)	483.09	326.67	633.33	52.93	0.05
SPC (cm)	561.95	403.33	706.67	64.22	0.06
SJ (cm)	33.08	24.03	43.57	4.54	0.09
CMJ (cm)	35.71	24.73	50.70	5.06	0.07
Kinematic parameters					
TLASF (k/s)	4.22	3.57	4.90	0.25	0.05
TLASL (m)	2.01	1.71	2.39	0.12	0.07
TLCAD (ms)	117.82	94.63	141.67	9.63	0.05
TLFAD (ms)	120.08	97.50	143.00	10.14	0.05

Abbreviations: BH – body height; BW – body weight; LL – leg length; FL – foot length; ED – elbow diameter; KD – knee diameter; AD – ankle diameter; BS – back skinfold; AS – abdominal skinfold; TS – thigh skinfold; LLS – lower leg skinfold; UAC – upper arm circumference; FC – forearm circumference; TC – thigh circumference; CC – calf circumference; SLJ – standing long jump; STJ – triple jump; DBJ – drop-broad jump; MBTS - medicine ball throwing backwards from supine position; SPC – (medicine ball) sitting put from the chest ; SJ – squat jump; CMJ – countermovement jump; TLASF – average stride frequency; TLASL – average stride length; TLCAD – average foot-ground contact duration; TLFAD – average flight duration

Table 2. Eigenvalues of the correlation matrix of morphological variables

GK	λ	λ%	cumλ	cum%
1	6.20	41.32	6.20	41.32
2	3.50	23.30	9.69	64.62
3	1.16	7.71	10.85	72.33

Abbreviations: eigenvalues (λ), percentage of the explained variance (λ%), cumulative values of eigenvalues (cumλ), cumulative percentage of the explained variance (cum%)

Using non-orthogonal rotation under the promax criterion the initial coordinate system was transformed to obtain a simple factor structure. Table 3 displays the relationships among the manifest variables and the rotated factors.

The relationships among the manifest variables of morphological characteristics and the rotated factors (Table 3) indicate that the variables of longitudinal dimensionality have the largest parallel and orthogonal projections on the first factor: *body height* (BH), *leg length* (LL) and *foot length* (FL), whereas the variables of transverse body dimensionality *knee diameter* (KD), *ankle diameter*

Table 3. Parallel (A) and orthogonal (F) projections of manifest variables on the promax factors and communalities of the manifest variables (h^2)

	A			F			
	1	2	3	1	2	3	h^2
BH	**1.02**	-0.16	0.03	**0.95**	0.33	-0.08	0.91
LL	**1.01**	-0.24	0.03	**0.90**	0.24	-0.12	0.85
FL	**0.75**	0.12	-0.05	**0.81**	0.44	-0.03	0.66
ED	**0.41**	**0.49**	-0.19	**0.64**	**0.59**	0.00	0.55
KD	**0.36**	**0.57**	0.03	**0.63**	**0.76**	0.27	0.67
AD	**0.47**	**0.53**	0.10	**0.72**	**0.70**	0.12	0.70
BS	-0.31	0.26	**0.68**	-0.22	0.41	**0.81**	0.72
AS	-0.04	-0.13	**0.93**	-0.15	0.26	**0.88**	0.79
TS	0.06	-0.09	**0.89**	-0.03	0.32	**0.85**	0.73
LLS	0.14	-0.05	**0.80**	0.08	0.36	**0.77**	0.60
BW	**0.47**	**0.56**	0.23	**0.72**	**0.88**	0.45	0.93
UAC	-0.26	**0.93**	-0.04	0.18	**0.79**	0.38	0.68
FC	-0.09	**1.01**	-0.19	0.38	**0.89**	0.27	0.81
TC	-0.06	**0.66**	0.36	0.23	**0.79**	0.66	0.79
CC	0.09	**0.48**	0.30	0.31	**0.66**	0.51	0.54

Abbreviations: BH – body height; BW – body weight; LL – leg length; FL – foot length; ED – elbow diameter; KD – knee diameter; AD – ankle diameter; BS – back skinfold; AS – abdominal skinfold; TS – thigh skinfold; LLS – lower leg skinfold; UAC – upper arm circumference; FC – forearm circumference; TC – thigh circumference; CC – calf circumference.

(AD) and *elbow diameter* (ED) have moderate projections.

Also, the latent structure of power variables was determined. Using the method of principal components under the GK criterion two significant latent dimensions were extracted which explained 68.62% of the total variance of the manifest variables (Table 4).

Table 4. Eigenvalues of the correlation matrix of power variables

GK	λ	λ%	cum λ	cum%
1	3.63	51.91	3.63	51.91
2	1.17	16.70	4.80	68.62

Abbreviations: eigenvalues (λ), percentage of the explained variance (λ%), cumulative values of eigenvalues (cumλ), cumulative percentage of the explained variance (cum%).

Table 5. Parallel (A) and orthogonal (F) projections of manifest variables on the promax factors and communalities of the manifest variables (h^2)

	A		F		
	1	2	1	2	h^2
SLJ	**0.72**	0.19	**0.80**	0.48	0.66
STJ	**0.70**	0.24	**0.79**	0.52	0.67
DBJ	**0.62**	0.08	**0.65**	0.33	0.42
MBTS	-0.07	**0.88**	0.29	**0.85**	0.72
STC	0.05	**0.83**	0.38	**0.85**	0.72
SJ	**0.93**	-0.16	**0.86**	0.21	0.76
CMJ	**0.96**	-0.15	**0.90**	0.24	0.83

Abbreviations: SLJ – standing long jump; STJ – triple jump; DBJ – drop-broad jump; MBTS - medicine ball throwing backwards from supine position; STC – (medicine ball) sitting put from the chest ; SJ – squat jump; CMJ – countermovement jump; TLASF – average stride frequency; TLASL – average stride length; TLCAD – average foot-ground contact duration; TLFAD – average flight duration

By means of the non-orthogonal rotation under the promax criterion the final solution was obtained (Table 5).

High parallel and orthogonal projections on the first factor were obtained for the following variables: *countermovement jump* (CMJ), *squat jump* (SJ), representing vertical jumping ability, and *standing long jump* (SLJ), *standing triple jump* (STJ) and *drop-broad jump* (DBJ), representing horizontal jumping ability. Due to the characteristics of the mentioned tests it was feasible to conclude that we were dealing with the factor of *power of a jumping type*, whereas the second factor was best determined by the following variables: *medicine ball throwing backwards from supine position* (MBTS) and *medicine ball sitting put from the chest* (STC). Therefore, the second factor was named *power of a ballistic type.*

Table 6 displays correlations among the power and morphological factors. Nearly zero correlations were obtained for the following factors:
- *skeleton dimensionality* (F_DS) and *subcutaneous fatty tissue* (F_SFT),
- *skeleton dimensionality* (F_DS) and *power of a jumping type* (F_POW_J)
- *subcutaneous fatty tissue* (F_SFT) and *power of a ballistic type* (F_POW_B), and
- *body voluminosity* (F_BV) and *power of a jumping type* (F_POW_J),

whereas the correlations among the other factors were moderately high.

Tabe 6. Matrix of correlations among the morphological and power factors

	F_DS	F_SFT	F_BV	F_POW_J	F_POW_B
F_DS	1				
F_SFT	-0.04	1			
F_BV	0.46	0.44	1		
F_POW_J	0.08	-0.36	-0.04	1	
F_POW_B	0.48	-0.04	0.46	0.40	1

Abbreviations: F_DS – skeleton dimensionality; F_SFT – subcutaneous fatty tissue; F_BV - body voluminosity; F_POW_J – power of a jumping type; F_POW_B – power of a ballistic type

Table 7 displays correlations among the kinematic parameters. It is obvious that *stride frequency* (TLASF) has negative and relatively high correlations with the rest of the kinematic parameters (*average stride length* - TLASL, *average foot-ground contact duration* – TLCAD, and *average flight duration* - TLFAD).

Table 7. Matrix of correlations among the kinematic parameters

	TLASF	TLASL	TLCAD	TLFAD
TLASF	1			
TLASL	-0.73	1		
TLCAD	-0.69	0.30	1	
TLFAD	-0.74	0.75	0.03	1

Abbreviations: TLASF – average stride frequency; TLASL – average stride length; TLCAD – average foot-ground contact duration; TLFAD - average flight duration

In order to reveal and thoroughly explain the mechanisms regulating sprint performance, it was necessary to determine the crucial relationships between power and morphological factors and kinematic parameters (stride frequency, stride length, foot-ground contact duration) of maximal speed running. Canonical analysis was used.

Table 8. Canonical correlations, canonical correlation determination coefficients and χ^2-test results testing statistical significance of the obtained canonical correlations

Canonicl R	Canonicl R^2	Chi-sqr.	df	p
0.76	**0.58**	**163.68**	**20.00**	**0.00**
0.57	**0.32**	**54.87**	**12.00**	**0.00**
0.20	0.04	5.55	6.00	0.48
0.05	0.00	0.32	2.00	0.85

According to the canonical analysis results, out of the four possible pairs of linear composites (canonical factors), two were singled out by the statistical significance of their canonical correlation. Both canonical correlations are relatively high (0.76 and 0.57).

Table 9. Structure of canonical factors

Kinematic parameters	CF1	CF2
TLASF	-0.49	**-0.75**
TLASL	**0.91**	0.16
TLCAD	0.29	**0.91**
TLFAD	0.42	0.19
Morphological factors and power factors	**CF1**	**CF2**
F_DS	**0.69**	**0.71**
F_SFT	**-0.40**	0.34
F_BV	0.03	-0.12
F_POW_J	**0.70**	-0.49
F_POW_B	**0.54**	0.00

Abbreviations: F_DS – skeleton dimensionality; F_SFT – subcutaneous fatty tissue; F_BV - body voluminosity; F_POW_J – power of a jumping type; F_POW_B – power of a ballistic type; TLASF – average stride frequency; TLASL – average stride length; TLCAD – average foot-ground contact duration; TLFAD - average flight duration

The first canonical factor among kinematic parameters is determined mostly by *stride length* (TLASL), whereas the first canonical factor among morphological factors and power factors (Table 9) is determined by the positive correlation between the factors of *power* (F_POW_J, F_POW_B) and *skeleton dimensionality* (F_DS), on the one hand, and by the negative correlation between the factors of *subcutaneous fatty tissue* (F_SFT) on the other.

The analysis of the second pair of canonical factors among morphological factors and power factors revealed a very high positive correlation of the factors *skeleton dimensionality* (F_DS), whereas the structure of the second canonical factor among kinematic parameters was bipolar (Table 9). It was best determined by *stride frequency* (TLASF) on the negative pole and by *foot-ground contact duration* (TLCAD) on the positive pole.

Discussion and conclusion

The analysis of descriptive parameters (Table 1) confirmed the assumption of the results' distribution normality in most variables, with the accepted error of 0.05. The exceptions were the following morphological variables: *elbow diameter* (ED), *abdominal skinfold* (AS), *lower leg skinfold* (LLS), *forearm circumference* (FC) and *calf circumference* (CC). It is well known that morphological characteristics have their own, specific growth rate and that in a population there are individuals with pronounced body diameters, voluminosity and skinfolds. In previous studies similar results were obtained for these variables (Kurelić, Momirović, Stojanović, Šturm, Radojević, & Viskić-Štalec, 1975; Stojanović, Solarić, Momirović, & Vukosavljević, 1975; Šnajder, 1982). The average body height of the observed subjects was 180.77 ± 6.98 cm, and their average body mass was 76.57 ± 7.62 kg (Table 1). These morphological characteristics did not differentiate between them and top-level athletes (Gajer, Thepaut-Mathieu, & Lehenaff, 1999). However, the authors assumed that certain differences in the measures of body voluminosity and subcutaneous fatty tissue would have occurred between the observed sample and top-level athletes only if the rest of the morphological parameters applied in the research had been available for the sample of top-level athletes.

According to Brüggeman, Koszevski and Müller (1997), the world-class top-level sprinters have an average stride length of 2.30 m, and a frequency of 4.78 strides/second in the phase of maximal speed of running. In the same article it was published that the world's fastest sprinters (e.g. Ben Johnson, Carl Lewis and Leroy Burell) achieved an average stride length of 2.45 m and an average frequency of 4.75 stride/second in the phase of maximal speed of their fastest runs at the World Championships and the Olympic Games. On the other hand, the Faculty of Kinesiology students have an average stride length of 2.01 m and an average frequency of 4.22 stride/second, that is, the observed subjects achieved far smaller stride length and frequency than the world-class sprinters. Sprint performance may also be analysed through the kinematic parameters of foot-ground contact duration and flight duration. Values of these parameters in top-level Slovenian sprinters in the phase of maximal speed running are on average 89.76 ms and 126.25 ms for contact duration and flight duration, respectively (Čoh, Milanović, & Kampmiller, 2001). In the analysed sample of students these values were on average 117.82 ms and 120.08 ms for contact duration and flight duration, respectively. Despite the fact that not all Slovenian sprinters are world-class athletes, their foot-ground contact phase duration is considerably shorter (about 28%) than the contact duration of the analysed students.

The initial coordinate system was transformed using a non-orthogonal rotation under the *promax* criterion to obtain a simple factor structure. Table 3 shows the relationships among the manifest variables and the rotated factors. The largest parallel and orthogonal projections on the first factor were obtained for the variables of longitudinal body dimensionality: *body height* (BH), *leg length* (LL) and *foot length* (FL), and moderate projections were obtained for the variables of transverse body dimensionality: *knee diameter* (KD), *ankle diameter* (AD) and *elbow diameter* (ED). It is obvious that bone growth in length (longitudinal dimensionality) and in width (transverse dimensionality) are to a great extent determined by the same mechanism. With regard to such a structure of the first factor it is feasible to regard it as a general factor of *skeleton dimensionality* in which the longitudinal dimensionality prevails. The obtained results confirmed the authors' initial assumption that there were four morphological dimensions, which assumption was based on certain previous research (Marković, 2004). However, these results are no exception at all. Namely, in numerous previous research studies the three-factor latent structure was obtained (Kurelić et al., 1975; Stojanović et al., 1975).

The second factor is mostly determined by the following variables: *forearm circumference* (FC), *upper arm circumference* (UAC), *thigh circumference* (TC) and *calf circumference* (CC). Therefore, this factor can be regarded as the factor of *circular dimensionality* or *body voluminosity.* Besides, it is also obvious that the variables of transverse dimensionality: *knee diameter* (KD), *ankle diameter* (AD) and *elbow diameter* (ED), have moderate projections on this factor as well. The variables of transverse skeleton dimensionality shared equally its variance on the first and the third factor. The finding was expected since bone growth in length (longitudinal component) is to a great extent followed by the body growth in width (transverse component), which also became obvious in the positive correlation with the circular body dimensionality.

The third factor is mostly determined by high projections of the skinfold variables: *back skinfold* (BS), *abdominal skinfold* (AS), *thigh skinfold* (TS) and *lower leg skinfold* (LLS). Taking into account that the other variables had not defined this factor significantly, it may be regarded as the factor of *subcutaneous fatty tissue*, which was also found in previous research studies on the latent structure of morphological variables. The variable *body weight* (BW) shared equally its variance between the first and the second factor, whereas its share in the third factor was somewhat smaller. The finding is expected since body weight is determined by all the three obtained factors.

Two latent dimensions of power were obtained (Tables 4 and 5). Three basic determinants differentiated between the two factors:

- body mass – the first factor displays relative power, whereas the second displays absolute power
- motor activity - the first factor represents power of a jumping type, and the second power of a ballistic type
- muscular group - the first factor represents power of the lower extremities and the second power of the upper extremities.

From Table 6, representing the correlations among power and morphological factors, it is obvious that nearly zero correlations were obtained for the following factors:

- *skeleton dimensionality* (F_DS) and *subcutaneous fatty tissue* (F_SFT),
- *skeleton dimensionality* (F_DS) and *power of a jumping type* (F_POW_J)
- *subcutaneous fatty tissue* (F_SFT) and *power of a ballistic type* (F_POW_B), and
- *body voluminosity* (F_BV) and *power of a jumping type* (F_POW_J),

whereas the correlations between the other factors are of a moderate value. Similar relations were obtained among the morphological factors in previous research (Marković, 2004). Moderate positive relations are understandable between *power of a jumping type* (F_POW_J) and *power of a ballistic type* (F_POW_B), because, despite the listed determinants that differentiate between them (body mass, motor activity, muscle groups engaged), in both factors the greatest possible force should be produced in the shortest time possible.

The results in Table 7 make the following conclusion feasible: the observed Faculty of Kinesiology students who achieved higher *stride frequency* (TLASF) had on average smaller *stride length* (TLASL), shorter *flight duration* (TLFAD) and *foot-ground contact duration* (TLCAD). On the other hand, those students who achieved longer *stride length* had on average longer *flight duration* and *foot-ground contact duration* and lower *stride frequency.* It should be accentuated here that the obtained negative correlation (r=–0.73) between stride frequency and stride length is very similar to the correlation (r=–0.70) obtained in the research by Hunter, Marshall and McNair (2004).

The obtained results of canonical analysis (Tables 8 and 9) indicate that the Faculty of Kinesiology students who are taller, have less subcutaneous fatty tissue and are more powerful (have better developed power, especially of a jumping type), perform longer strides when running with maximal speed. The finding is in accordance with previous research results (Gajer, Thepaut-Mathieu, & Lehenaff, 1999).

It is generally known that taller athletes perform a fewer number of strides (lower frequency) while running and that their foot-ground contact lasts longer – these facts have been corroborated by the present research as well. So, in the population of the observed students the negative corrrelation was determined between stride frequency and stride length in maximal speed running due to the positive correlation between skeleton dimensionality and stride length, on the one hand, and the negative correlation between skeleton dimensionality and stride frequency on the other (Figure 1).

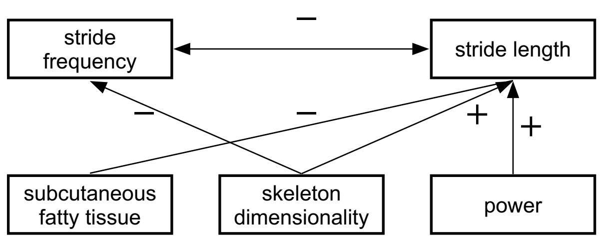

Figure 1. Relationships among subcutaneous fatty tissue, skeleton dimensionality, power, stride length, and stride frequency.

To conclude, the research was conducted with the aim to determine the relations of morphological characteristics and the variables of power to kinematic parameters (stride frequency, stride length, foot-ground contact duration, flight duration) of maximal speed running. Component model of factor analysis under the GK criterion and non-orthogonal rotation under the promax criterion were used for data analysis. Three morphological factors (skeleton dimensionality, in which the longitudinal component prevailed, body voluminosity and subcutaneous fatty tissue) and two factors of power (power of a jumping type and ballistic power) were obtained. Relations among the obtained morphological and power factors to the kinematic parameters were determined by means of canonical analysis. Out of the four possible pairs of canonical factors, two were singled out by their statistically significant correlations. On the basis of the structure of the first pair of canonical factors it was concluded that the Faculty of Kinesiology students who had pronounced dimensionality of skeleton, a smaller amount of subcutaneous fatty tissue and better developed relative power (of a jumping type) performed longer strides in maximal speed running. The structure of the second canonical factor pair indicated that the students with the larger skeleton dimensionality performed less frequent strides and their foot-ground contact lasted longer. Therefore, it is feasible to conclude that in maximal speed running stride frequency and stride length are negatively correlated due to the positive correlation between skeleton dimensionality and stride length on the one hand, and the negative correlation between skeleton dimensionality and stride frequency, on the other. It was also concluded that stride length was positively influenced by power, whereas it was negatively influenced by subcutaneous fatty tissue.

As far as the authors know, this research is the first one that demonstrated integrally the mechanism of mutual relationships between subcutaneous fatty tissue, skeleton dimensionality, explosive power and kinematic parameters, that is, stride length and stride frequency in maximal speed running or sprinting (Figure 1). Therefore, the obtained results contribute to a better understanding of the factors responsible for sprint or maximal speed running performance in a population of subjects who are not top-level athletes-sprinters. Consequently, it may help physical education teachers, coaches of novices in athletics and physical conditioning coaches to get a more thorough insigth into the sprinting efficiency mechanisms.

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RELACIJE VARIJABLI EKSPLOZIVNE SNAGE I MORFOLOŠKIH OBILJEŽJA S KINEMATIČKIM POKAZATELJIMA PRI TRČANJU MAKSIMALNOM BRZINOM

Sažetak

Uvod i problem istraživanja

Veći broj dosadašnjih istraživanja bavio se proučavanjem biomehaničkih faktora koji određuju uspješnost u sprinterskom trčanju (za pregled vidi Mero i sur., 1992; Čoh i sur., 2003; Korhonen i sur., 2003; Babić, 2005; Wang, 2006). Utvrđeno je, između ostaloga, da maksimalnu brzinu trčanja određuju sljedeći kinematički parametri: frekvencija i duljina koraka, trajanje kontakta stopala s podlogom i trajanje nekontaktne faze (faza leta) (Bellotti, 1991; Brueggemann i Glad, 1988; Müller i Hommel, 1997; Harland i Steele, 1997; Ferro i sur., 2001). Maksimalna sprinterska brzina zapravo je rezultat optimalnog odnosa između duljine i frekvencije koraka. Osnovni problem ovog istraživanja je utvrditi međusobne odnose između kinematičkih parametara (duljina koraka, frekvencija koraka, trajanje leta i trajanje kontakta) pri trčanju maksimalnom brzinom te njihove relacije s morfološkim obilježjima i varijablama eksplozivne snage kako bi se što potpunije odredili mehanizmi koji određuju uspješnost u sprinterskom trčanju na entitetima koji nisu vrhunski sprinteri.

Metode istraživanja

Istraživanje je provedeno na uzorku od 133 studenta muškog spola, u dobi od 19. do 24. godine (dob 21,7 ± 1,08 godina; visina 180,8 ± 6,98 cm; masa 76,6 ± 7,62 kg), koji redovito pohađaju nastavu na prvoj godini studija Kineziološkog fakulteta Sveučilišta u Zagrebu. U ovom istraživanju izmjerene su tri skupine varijabli koje opisuju: eksplozivnu snagu, morfološka obilježja i kinematička obilježja sprinta. Za sve su varijable izračunati osnovni deskriptivni parametri: aritmetička sredina (Mean), minimalni rezultat (Min), maksimalni rezultat (Max), standardna devijacija (SD). Normalnost distribucije varijabli testirana je Kolmogorov-Smirnovljevim testom na razini pogreške zaključivanja od 0,05. Latentna struktura morfoloških obilježja i indikatora eksplozivne snage utvrđena je *komponentnim modelom faktorske analize* uz pomoć Guttman-Kaiserova kriterija i neortogonalne rotacije inicijalnoga koordinatnog sustava s *promax* kriterijem. Relacije između varijabli eksplozivne snage i morfoloških obilježja s kinematičkim parametrima (frekvencija koraka, duljina koraka, trajanje kontakta i trajanje leta) pri trčanju maksimalnom brzinom utvrđene su *kanoničkom analizom*.

Rezultati i rasprava

Analizom deskriptivnih parametara (tablica 1) potvrđena je pretpostavka o normalnosti distribucije rezultata u većini varijabli uz pogrešku zaključivanja od 0,05. Izuzetak čine morfološke varijable *dijametar lakta* (ED), *kožni nabor na trbuhu* (AS), *kožni nabor na potkoljenici* (LLS), *opseg podlaktice* (FC) i *opseg potkoljenice* (CC). Kako bi se skup manifestnih morfoloških varijabli sveo na manji broj latentnih dimenzija, primijenjena je metoda glavnih komponenata. Primjenom GK kriterija dobivene su tri glavne komponente koje objašnjavaju oko 72% zajedničke varijance manifestnih varijabli (tablica 2). Neortogonalnom rotacijom prema promax kriteriju (tablica 3) dobiveni su faktori *dimenzionalnost skeleta,* u kojem dominira longitudinalna komponenta, *cirkularna dimenzionalnost* ili *voluminoznost tijela* i *potkožno masno tkivo*. Isto tako, utvrđena je i latentna struktura varijabli eksplozivne snage. Dobivena su dva faktora: *eksplozivna snaga tipa skoka* i *eksplozivna snaga tipa bacanja*.

Prema rezultatima iz tablice 7 (koja prikazuje korelacije između kinematičkih parametara) vidljivo je da *frekvencija koraka* (TLASF) ima negativne i relativno visoke korelacije sa svim ostalim kinematičkim parametrima (TLASL, TLCAD i TLFAD), što upućuje na zaključak da studenti Kineziološkog fakulteta koji postižu veću *frekvenciju koraka* (TLASF), imaju u prosjeku kraću *duljinu koraka* (TLASL), kraće *trajanje leta* (TLFAD) i *kontakta* (TLCAD), odnosno, oni koji postižu veću duljinu koraka, imaju u prosjeku duže trajanje leta i kontakta te nižu frekvenciju koraka. Valja istaknuti da je dobivena negativna korelacija (r=-0.73) između frekvencije i duljine koraka vrlo slična korelaciji (r=-0.70) dobivenoj u istraživanju koje su proveli Hunter, Marshall i McNair (2004).

Kako bi se otkrili i potpunije objasnili mehanizmi koji određuju sprintersku uspješnost, potrebno je utvrditi sve bitne odnose između faktora eksplozivne snage i morfoloških faktora te kinematičkih parametara (duljina koraka, frekvencija koraka, trajanje kontakta i trajanje leta) pri trčanju maksimalnom brzinom. U tu svrhu korištena je kanonička analiza. Prema rezultatima kanoničke analize, od četiri moguća para linearnih kompozita (kanoničkih faktora), izdvojila su se dva čija je kanonička korelacija statistički značajna. Obje kanoničke korelacije su relativno visoke (0.76 i 0.57).

Prvi kanonički faktor u prostoru kinematičkih parametara u najvećoj mjeri određuje *duljina koraka* (TLASL), dok je prvi kanonički faktor u prostoru morfoloških faktora i faktora eksplozivne snage (tablica 9) određen pozitivnom korelacijom faktora *eksplozivne snage* (F_POW_J, F_POW_B) i *dimenzionalnosti skeleta* (F_DS) te negativnom korelacijom faktora *potkožno masno tkivo* (F_SFT). Dobiveni rezultati ukazuju na to da studenti Kineziološkog fakulteta veće tjelesne visine, manje količine potkožnog masnog tkiva i bolje razvijene eksplozivne snage (prije svega tipa skoka) postižu duži korak pri trčanja maksimalnom brzinom, što je u skladu s rezultatima dosadašnjih istraživanja (Gajer i sur., 1999).

Analiza strukture drugoga kanoničkog faktora u prostoru morfoloških faktora i faktora eksplozivne snage pokazuje vrlo visoku pozitivnu korelaciju faktora *dimenzionalnosti skeleta* (F_DS), dok je struktura drugog kanoničkog faktora u prostoru kinematičkih parametara bipolarna (tablica 9). Na negativnom polu najbolje ga određuju *frekvencija koraka* (TLASF), a na pozitivnom polu *trajanje kontakta* (TLCAD). Opće je poznato da sportaši veće tjelesne visine trče s manjom frekvencijom koraka te im je i vrijeme kontakta s podlogom nešto duže, što je također potvrđeno i ovim istraživanjem. Dakle, u populaciji studenata Kineziološkog fakulteta, utvrđena je negativna korelacija između frekvencije i duljina koraka pri maksimalnoj brzini trčanja, što je posljedica pozitivne povezanosti dimenzionalnosti skeleta s duljinom koraka te njene negativne povezanosti s frekvencijom koraka (slika 1).

Zaključak

Dobiveni rezultati pokazuju da studenti Kineziološkog fakulteta koji imaju veću dimenzionalnost skeleta, manju količinu potkožnog masnog tkiva i bolje razvijenu relativnu eksplozivnu snagu (eksplozivnu snagu tipa skoka) postižu duži korak pri trčanju maksimalnom brzinom, dok studenti veće dimenzionalnosti skeleta trče manjom frekvencijom koraka te im je vrijeme kontakta s podlogom nešto duže. Stoga se može zaključiti da su duljina i frekvencija koraka pri trčanju maksimalnom brzinom u negativnoj korelaciji, što je posljedica pozitivne povezanosti dimenzionalnosti skeleta s duljinom i negativne povezanosti s frekvencijom koraka, te da na duljinu koraka pozitivno utječe eksplozivna snaga, a negativno potkožno masno tkivo. Dobiveni rezultati ovog istraživanja prilog su boljem razumijevanju čimbenika koji determiniraju uspješnost u sprinterskom trčanju u populaciji entiteta koji nisu vrhunski sprinteri te time omogućuje nastavnicima, trenerima početnika ili pak kondicijskim trenerima u drugim sportovima potpuniji uvid u mehanizme koji određuju sprintersku efikasnost.