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Review article

INFLUENCE OF MORPHOLOGICAL CHARACTERISTICS ON RUNNING PERFORMANCE OF ENDURANCE ATHLETES

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Abstract. *Running is a popular form of physical activity and can be carried out through several different distances. Morphological characteristics, such as skin fold thickness, limb girth and length, body weight and body fat percentage have an impact on endurance running. The objective of this systematic review study is to collect and analyze studies about the influence of morphological characteristics on running performance of endurance athletes. Based on an analysis of electronic databases and the inclusion criteria set, 20 studies were included in the analysis. The length of the extremities and the sum of the skin folds thickness have the highest statistical significance as the predictor. The results of the analyzed studies indicate that slim limbs, longer legs, lower total skin fold thickness and lower body fat percentage are some of the characteristics that can be good predictors for competitive success and a model to be tended during the preparation period of male and female endurance runners.*

Key words: *anthropometry, body composition, endurance, running.*

INTRODUCTION

Running is a popular form of physical activity and can be carried out through several different distances (Marti, Abelin, & Minder, 1988; Nettleton, & Hardey, 2006). Many physiological, anthropometric and training characteristics are related to racing performance, depending on the length and duration of the activity (Anderson, 1996; Morgan, Martin, & Krahenbuhl, 1989; Saunders, Pyne, Telford, & Hawley, 2004). The achieved result in medium- and long-distance running depends on several variables such as physiological characteristics (Saunders et al., 2004), genetics and demographic characteristics (Onywera,

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2009), physiological parameters (Pate, & O'Neill, 2007; Williams, & Neptune, 1983), age (Lepers, & Cattagni, 2012), gender (Pate, & O'Neill, 2007), training (Karp, 2007; Davis et al., 2001), previous experience (Herbst, 2011), anthropometric characteristics (Hagan, Smith, & Gettman, 1981; Rüst, Knechtle, Knechtle, Wirth, & Rosemann, 2012) and body composition (Arrese, & Ostariz, 2006).

Morphological characteristics, such as skin fold thickness, limb girth and length, body weight and body fat percentage have an impact on running (Knechtle, Stiefel, Rosemann, Rust, & Zingg, 2015). The assessment of body composition gives an insight into fat and lean mass in the human body. It is necessary to respect minimum values for normal functioning of the body. For example, the percentage of essential fat in women is 8-12% of total body fat mass, while in men it ranges from 3-5% of total body fat mass recommended by the National Academy of Sports Medicine (NASM) (Muth, 2009). Determination of body composition or percentage of body fat is a key factor in the assessment of body health (Fahey, Insel, & Roth, 2001; Gilliat-Wimberly, Manore, Woolf, Swan, & Carroll, 2001), but it is also useful in monitoring potential effects of the training process and health status of young athletes (Hergenroeder, & Klish, 1990; Claessens, Hlatky, Lefevre, & Holdhaus, 1994). For example, runners with a proportionally smaller amount of body mass concentrated in the extremities, particularly in the legs, would perform less work moving their body segments during running if all the other factors are unchanged. Therefore, leg mass and distribution of leg mass might be important characteristics of distance runners' performance (Myers, & Steudel, 1985). On the other hand, in previous research, it has been shown that in addition to the body composition values, runners are influenced by several anthropometric parameters such as body height (Bale, Bradbury, & Colley, 1986; Maldonado, Mujika, & Padilla, 2002), arm circumference (Tanaka, & Matsuura, 1982), total skin fold thickness (Bale et al., 1986; Arrese, & Ostariz, 2006) and different lower limb skin fold and circumferences (Legaz, & Eston, 2005). Arrese and Ostariz (2006) found a high positive correlation between the skin fold thickness of lower extremities and the speed of running in disciplines from sprinting to middle- and long-distance running. Considering anthropometric characteristics, taller runners seemed to run slower than shorter ones (Zillmann et al., 2013).

These morphological data can be good predictors for selection, training process planning and improving running results. A small number of studies were concerned with the effects of some other components, such as the amount of skeletal muscle mass, total body water and bone mass. Based on the above mentioned, the aim of this review study was to collect and analyze studies on the influence of morphological characteristics on running performance of endurance athletes.

METHODS

Search strategy

In order to access relevant studies, the following electronic databases were searched: Google Scholar, Kobson and PubMeb. The research was limited to using the following keywords related to the problem of this review paper: anthropometry, body composition, endurance running and track and field running. Within the electronic databases, advanced research was used as well as the option for searching keywords only in titles, abstracts or abstract keywords.

Selection of the research and qualification criteria

The final analysis included all the studies published in the last 12 years, namely between 2005 and 2017, whose samples belong to the group of endurance runners who have been part of some training process for at least a year and which applied parameters for determining body components and parameters for determining morphological characteristics.

Data analysis

Table 1 provides an overview of close analyses of the 20 studies which satisfied the set criteria. Following the conventions for systematic reviews, the table presents the following parameters: information on the sample of participants (the number of participants, gender and age), morphological characteristics, study design, results and conclusion.

Table 1 Summary of the characteristics of all studies meeting the inclusion criteria

Ref.	Sample (gender. number and age)	Morphological characteristics	Study design	Results (M ± S.D)	Conclusion
Legaz & Eston (2005)	M:24 F:13	∑6SF: 44.2±10.8; 42.1±9.2; 42.2±10.2; 41.7±10.2 (initional, after 1., 2., 3. year)	∑6SF and the best running performance were recorded at the beginning and after one, two, and three years of training in short, middle and long distance runners.	$IAAF_{trough\ years}$ ↑ $\sum 6SF_{trough\ years}$ ↓ ($p<.05$)	The lower limb skinfolds may be particularly useful predictors of running performance.
Vučetić et al. (2005)	M:18 Y:18.8±2.4; 25.4±4.3 (MD; LD)	%BF: 7.1; 5.3	Morphological characteristics and the difference between the athletes of various running events.	LD runners Sig.↑ lower circum. of the thigh and lower leg	The upper arm skinfold is Sig.↑ in middle-distance runners.
Arrese & Ostariz (2006)	M:83 F:37 Y: 21.83±3.34; 30.94±4.26 (MD; LD)	∑SF: 37.75±4.88; 33.19±5.54 (MD; LD_{male}) 54.30±12.38; 44.41±7.70 (MD; LD_{fimale})	Correlation between ∑6SF and competitive running performance in middle and long distance male and female elite runners.	Positive corr. btw front thigh, medial calf SF, 1,5km run ($p<.05$) Positive corr. btw front thigh, medial calf SF 10 km run ($p<.05$)	SF thicknesses in the lower limb are positively associated with running time over several distances.

Ref.	Sample (gender. number and age)	Morphological characteristics	Study design	Results (M ± S.D)	Conclusion
Hoffman (2008)	M:310 F:82 Y:18-60+	BMI: 23.2; 20.6 (M;F)	Physical characteristics and competitive running performance in ultra-marathon runners.	Average running speed and BMI were negatively correlated for both men ($p < 0.01$) and women ($p = 0.02$)	Lower BMI values were associated with faster running times.
Knechtle et al. (2008)	M:19 Y: 46.2±9.6	BMI: 22.5±1.9 %BF: 13.1±3.3	Association of anthropometric parameters to race performance in ultra-endurance runners.	Positive correlation of upper arm circumference with the total running time ($p<0.05$)	Circumfer. of the upper arm was the only factor associated with performance in well-experienced ultra marathon runners.
Vučetić et al. (2008)	M:23 Y:18.6±2.4; 27.2±4.7 (MD; LD)	BMI: 21.2±1.7; 21.5±1.4 %BF: 6.9±2.7; 6.0±1.6	Morphological characteristics and the difference between the athletes of various running events.	Greater upper arm skin fold and lower upper arm circumference in MD ($p<.01$) and lower limb and calf circumferences in LD ($p<.05$).	Morph. character. that affect running success are different in middle- and long-distance runners.
Kong & Heer (2008)	M:5 Y:22.0±1.8	BMI:20.1±1.8 %BF: 5.3±1.6 Calf cc: 34.5 ± 2.3 cm	Anthropometric, gait and lower extremity strength characteristics of six elite Kenyan distance runners were analyzed to understand their success.	Low BMI, %BF and small calf circumference.	Their slim limbs may positively contribute to performance by having a low moment of inertia and requiring less muscular effort in leg

Ref.	Sample (gender. number and age)	Morphological characteristics	Study design	Results (M ± S.D)	Conclusion
Knechtle et al. (2009)	M:15 Y:46.7±5.8	BMI:23.1±1.84 %BF: 14.4±3.5	The influence of anthropometric and training parameters on race performance in ultra-endurance runners.	Sig. in height, tight and suprailiac & calf SF($p<.05$) and leg length, upper arm cc ($p=.00$) with total race time.	Anthrop. and training volume does not seem to have a major effect on race performance in a 24-h run.
Knechtle et al. (2009)	M:17 Y: 41.2±6.6	BMI: 22.4±1.2 %BF: 12.9±1.5	Association of anthropometric parameters with race performance in ultra marathon runners.	Positive association between total running time and body mass ($p < .05$) and upper arm circumfer. ($p < .05$)	Body mass and upper arm circum. were negatively associated with race performance in well experienced ultra marathon runners
Knechtle & Roseman n (2009)	M:25 Y:44.5±7.0	BMI: 22.9±1.8 %BF: 13.1±3.2	Association of skin-fold thicknesses with total race time in mountain ultra-marathoners.	Sig.↑ association calf SF with total race time ($p < 0.05$).	The calf skin-fold showed a small to moderate association with total race time.
Hoffman at al. (2010)	M:75 F:34 Y:16-67	BMI: 24.8±2.7; 21.2±2.1 %BF: 17±5; 21±6	Association of body composition characteristics with performance among participants in a 161-km trail ultra marathon.	Sig.↑ corr. ($p=.0025$) between percent body fat and finish time for men. %BF↓ in finishers vs non-finishers for men ($p=.03$), women ($p=.04$).	The faster men have lower percent body fat values than the slower men, and finishers have lower percent body fat values than non-finishers.

Ref.	Sample (gender. number and age)	Morphological characteristics	Study design	Results (M ± S.D)	Conclusion
Knechtle et al. (2011)	F:42 Y: 38.5±1.4	BMI: 21.2±0.3 %BF: 27.2±0.8	Anthropometric and training variables related to half-marathon running performance.	BW; BMI; %BF and SF thickness Sig.↑ correlate w/race time.	Anthrop. and training relate to halfmarathon race time, and skin thicknesses associated with running speed during training.
Barandun et al. (2012)	M:126 Y: 42.8±10.8	BMI: 23.4±2.2 %BF: 16.3±5.6	Association of anthropometric and training characteristics with race times in marathon runners.	Pectoral (p<.0001) Mid axilla (p<.0001) Abdomin. (p<.0001) Medial calf (p<.0001) ∑7SF (p<.0001)	Low body fat and running speed during training are two key factors for a fast marathon race time in recreational male marathoner runners.
Mooses et al. (2013a)	M:45 Y: 23.0 ± 4.4; 25.5 ± 8.3 (competit.; recreation)	BMI: 21.19 ± 1.05; 22.20 ± 2.05 %BF: 7.29 ± 1.62; 10.31 ± 4.49	Comparation in body composition parameters that are related to the individual running economy measured on track.	%BF, %BFcalf and IAAF sig. ↑ in compet. (p<.05)	Running economy at the first threshold was not significantly related to any of the measured body composition values or leg mass ratios either in the competitive or in the recreational runners group.
Mooses et al. (2013b)	M:40 Y: 21.1±3.4; 25.4±3.8 (MD; LD)	BMI: 21.6±1.5; 21.1±1.2 %BF: 8.1±2.0; 7.6±1.9	Association of anthropometric, body composition and physiological parameters in middle- and long-distance runners.	MD ↑ lower leg length (p<0.05)	Relevance of specific anthrop. parameters predict middle, but not long distance run perform

Ref.	Sample (gender. number and age)	Morphological characteristics	Study design	Results (M ± S.D)	Conclusion
Zillmann et al. (2013)	M:173 Y: 40.2±10.1; 42.8±10.8 (half-; marathon)	BMI: 23.3±2.2; 23.7±2.7 %BF: 17.5±4.6; 16.3±3.6	Comparison of training and anthropometric characteristics between recreational male half-marathoners and marathoners	HM runners positive corr. of BMI,%BF with race time. M runners positive corr. of %BF with race time (p<.0001).	Both groups of athletes profit from low body fat and a high running speed during training for fast race times.
Dellagrana et al. (2014)	M:147 Y:18.0±0.9	%BF: 11.63±2.87	Association of physiological, anthropometric, strength, and muscle power characteristics with running performance in young middle-distance runners.	SMM (p=.005) BH (p<.05)	Anthropometric measures showed significant influence in performance prediction.
Yang at al. (2015)	F:96 Y: 23.09±2.74; 22.45±2.80; 19.09±2.83 (international, national, average)	%BF: 15.85±4.03; 17.06±4.35; 18.88±4.15.	Association of anthropometric, characteristics with personal bests of international, national and average levels long-distance female runners.	Positive corr. btw forearm girth and PBs, and subscapula, abdomen, Iliac crest and triceps SF and PB for total athletes.	The international and national runners have low tights circumferences, height, longer limbs and skin folds compare to average one.
Gómez-Molina (2017)	M:78 Y: 31.5±7.2 34.2 ± 6.8	BMI: 22.4±2.0 23.7±2.1 SF: 51.5±17.5 56.9±24.0	Establishing and validating various predictive equations in Male half-marathon Runners who participated in two different phases	Positive corr. of BM, BMI, ∑SF w/the race result (p<.05)	The proposed equations and their validation showed a high prediction of half-marathon performance in long distance male runners.
Šolaja at al. (2017)	M:5 F:4 Y: 22.87±3.39	BMI: 21.74±1.46; 20.05±0.8 %BF: 6.94±0.99; 13.98±2.39 (M; F)	Assuming correlation of various athletics disciplines with anthropometric factors and the training process.	Positive correlation of BH (p<.05), BM (p=.00), ∑SF, BMI and %BF (p=.01) w/running discipline	It is possible to increase the loss of body fat and indirectly improve the athletic performance in athletics.

RESULTS

Study selection

Database searches returned 145 studies. After eliminating all duplicated papers and analyzing titles and abstracts, 25 studies entered the next stage of analysis. Only the studies which included relevant outcomes were considered. The final number of the studies in the analysis was 20.

Study characteristics

The first research in this group was published in 2005 (Legaz & Eston, 2005; Vučetić, Babić, Šentija & Nekić, 2005), and the last one in 2017 (Gómez-Molina, Ogueta-Alday, Camara, Stickley, Rodríguez- Marroyo, & García-López, 2017; Šolaja, Milankov, Pejaković, & Stokić, 2017). The number of participants in the analyzed studies ranged from six, the lowest number of participants in the research of Kong & De Heer (2008) to 392, and the highest number of participants in the study of Hoffman (2008).

Gender-wise, male groups were presented the most, with six studies including both, males and females, while in the research of Yang, Wang, Bao, & Hu (2015) the participants were only females. The youngest participant was16 years old (Hoffman, Lebus, Ganong, Casazza, & Van Loan, 2010), whereas the oldest ones were 60 years and older (Hoffman, 2008).

For the estimation of longitudinal and transversal dimensionality, standardized anthropometric measuring instruments were used, while the anthropometric method was mostly used for estimating body composition content (the sum of skin folds for calculating % BF by Siri (1961); Heath, & Carter (1967); Jackson, & Pollock (1985); Ball, Swan, & Desimone (2004); Legaz, & Est (2005); Lucia et al., (2006)), bioelectric impedance (BIA) (Yang et al., 2015; Hoffman et al., 2010) and dual-energy X-ray absorptiometry (DEXA) (Mooses et al., 2013a; 2013b).

DISCUSSION

Based on the analyzed studies, it is evident that the body height of middle- and long-distance runners ranges from 1.73 ± 0.05 to 1.83 ± 4.17 m in males, and from 1.60 ± 0.09 to 1.69 ± 5.36 m in females. These anthropometric measurements are in correlation with other research where, for example, middle- and long-distance male and female runners of the Serbian national team were 1.83±4.17 m and 1.69±5.36 m tall respectively (Šolaja et al., 2017), whereas Croatian middle- and long-distance runners were 1.80±5.4 m and 1.82±5.2 m tall respectively (Vučetić, Matković, & Šentija, 2008). Kenyan distance runners well recognized for their success in distance running were 1.77±0.06 m tall (Kong, & Heer, 2008). Ultra-marathoners' height in the analyzed research ranged between 175 ± 6 to 179±6 m (Hoffman, 2008; Knechtle, Knechtle, Schulze, & Kohler, 2008; Knechtle, Wirth, Knechtle, Zimmermann, & Kohler, 2009). In the research of Ramírez-Vélez, Argothy-Bucheli, Sánchez-Puccini, Meneses-Echávez, & López-Albán (2015) Colombia's top long-distance runners were 1.71 m tall on average, which is below average in the analyzed studies. In the research of Yang et al. (2015) international and national top level long-distance female runners were 1.61 m tall, amateurs were 1.65±5.08 m tall, 1.66±0.009 m in the research of Knechtle, Knechtle, Barandun, and

Rosemann (2011), while ultra-marathoners ranged between 161 ± 7 m to 1.66 ± 8 m (Hoffman, 2008). Based on the previous studies, with gradual decrease in running distance from marathon to 400 m, the average body height of runners gradually increases (Sedeaud et al., 2014; Weyand, & Davis, 2005). This fact is in agreement with the research included in this study, where middle- and long-distance runners were 1.81 ± 0.05 m and 1.72 ± 0.04m tall respectively (Arrese, & Ostariz, 2006), while ultra-marathoners were in the range of 1.75 ± 6 to 1.77 ± 9 m (Hoffman, 2008). Middle- and long-distance females were 1.69±5.36 m (Šolaja et al., 2017) and 161.05±5.40 m tall respectively (Yang et al., 2015), whereas ultra-marathoners ranged from 161 ± 7 to 1.66 ± 8 m (Hoffman, 2008). In the study of Zillmann et al. (2013) it is shown that taller runners are slower than the shorter ones which is not in the agreement with other analyzed research in this study.

Based on the results obtained by different authors (Sedeaud et al., 2014), it can be concluded that body weight is in correlation with the results achieved in running, in both males and females (Weyand, & Davis, 2005). In the study of Arrese and Ostariz (2006), middle-distance runners' body weight was 69.33 ± 4.9 and 52.3 ± 8.48 in males and females respectively, long-distance 59.33 ± 3.34 and 45.58 ± 6.82, while ultra-marathoners had body weight of 70.5 ± 6.4 to 73.2 ± 11.5 and 57.2 ± 8.2 to 52.0 ± 3.5 (Hoffman, 2008). From the abovementioned, it can be concluded that middle- and long-distance runners are lighter than ultra marathons regardless of the gender. In the study carried out by Knechtle et al. (2009) low weight runners also achieve better results in ultra marathon races. These results indicate that these parameters should not be taken as predictors in the selection and prediction of competition results.

The sum of skin folds is an important result predictor in middle- and long-distance running (Bale et al., 1986; Legaz & Eston, 2005; Arrese & Ostariz, 2006) and it can be calculated using defined formulas percentage of body fat (Siri, 1961; Heath, & Carter, 1967; Jackson & Pollock, 1985; Ball et al., 2004; Legaz & Eston, 2005; Lucia et al., 2006). Thus, in the analyzed research in this paper the authors came to the conclusion that low percentage of body fat is a characteristic of Kenyan elite runners (5.3 ± 1.6%) (Kong, & Heer, 2008). The results of the studies of Arrese and Ostariz (2006) and Legaz and Eston (2005) indicate that lower limbs skin fold thickness is in a positive correlation with racing results in several distances and that this parameter can be a useful predictor in achieving good racing results. Vučetić et al. (2005) and Vučetić et al. (2008) showed that middle-distance runners have higher skin fold thickness of upper arms than long-distance runners. On the other hand, skin fold thickness of ultra-marathoners indicates little to moderate association with achieved racing results (Knechtle, & Rosemann, 2009). The sum of skin fold thickness can be taken as a limitation of this study because in the analyzed studies the calculation of the sum of skin fold thickness differs from study to study, where the number of collection points of the sum of skin folds ranged from 3 to 10.

The analyzed studies showed that marathoners are specific because of their smaller circumferences in hips and lower limbs (Vučetić et al., 2005), elite Kenyan distance runners because of their slim limbs (Kong, & Heer, 2008) and well-trained ultra-marathoners a bigger circumference of the upper arm skin fold has a negative correlation with the results achieved in races (Knechtle et al., 2009). Within the Chinese women's marathon team, the circumference of the thigh, the length of the lower extremities and the sum of skin folds were the main indicators of success in the selection of international and national ranks. Female athletes of international rank have thinner thighs and smaller skin fold values (Yang at al., 2015).

CONCLUSION

The analysis of the results of previous research shows that morphological characteristics of runners have a significant impact on race performance and achievement of better results in competitions. Measurements of total and partial body composition and anthropometric parameters may be useful for selection, prediction and improving running performance as well as for preventing injuries and health risk assessment. Slim limbs, longer legs, lower total skin fold thickness and lower body fat percentage are some characteristics that can be good predictors of competitive success and a model to be tended during the preparation period of male and female endurance runners.

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UTICAJ MORFOLOŠKIH KARAKTERISTIKA NA PERFORMANS TRČANJA DUGOPRUGAŠA

Trčanje je popularna forma fizičke aktivnosti i može biti realizovana kroz više različitih distanci. Morfološke karakteristike, kao što su debljina kožnog nabora, obim butina i njihova dužina, telesna masa i procenat telesnih masti imaju uticaj na trčanje na duge staze. Cilj ovog sistematskog preglednog rada je prikupljanje i analiza istraživanja koji su se bavili uticajem morfoloških karakteristika na performansu trčanja kod dugoprugaša. Na osnovu pretraženih elektronskih baza i postavljenih kriterijuma, 20 istraivanja je uključeno u analizu. Visok nivo statističke značajnosti kao predikora imaju dužina ekstremiteta, kao i zbir kožnih nabora. Rezultati analiziranih istraživanja pokazuju da su tanki udovi, duže noge, manji sveukupni zbir kožnih nabora i niži procenat telesnih masti neki od karakteristika koji mogu biti dobri predilktori takmičarskog uspeha i model kojem treba težiti tokom pripremnog perioda kod žena i muškaraca dugoprugaša.

Ključne reči*: antropometrija, telesna kompozicija, izdržljivost, trčanje.*