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What is associated with race performance in male 100-km ultra-marathoners – anthropometry, training or marathon best time?

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Abstract

We investigated the associations of anthropometry, training, and pre-race experience with race time in 93 recreational male ultra-marathoners (mean age 44.6 years, $s = 10.0$; body mass 74.0 kg, $s = 9.0$; height 1.77 m, $s = 0.06$; body mass index 23.4 kg $\cdot$ m^{-2}, $s = 2.0$) in a 100-km ultra-marathon using bivariate and multivariate analysis. In the bivariate analysis, body mass index ($r = 0.24$), the sum of eight skinfolds ($r = 0.55$), percent body fat ($r = 0.57$), weekly running hours ($r = -0.29$), weekly running kilometres ($r = -0.49$), running speed during training ($r = -0.50$), and personal best time in a marathon ($r = 0.72$) were associated with race time. Results of the multiple regression analysis revealed an independent and negative association of weekly running kilometres and average speed in training with race time, as well as a significant positive association between the sum of eight skinfold thicknesses and race time. There was a significant positive association between 100-km race time and personal best time in a marathon. We conclude that both training and anthropometry were independently associated with race performance. These characteristics remained relevant even when controlling for personal best time in a marathon.

Keywords: *Skinfolds, body fat, athlete, endurance*

Introduction

Running is a popular sports discipline and can be performed over many distances (Marti, Abelin, & Minder, 1988; Nettleton & Hardey, 2006). An abundant variety of physiological, anthropometric, and training variables appear to influence running performances depending upon the length and duration of performance (Anderson, 1996; Morgan, Martin, & Krahenbuhl, 1989; Pate, Macera, Bailey, Bartoli, & Powell, 1992; Saunders, Pyne, Telford, & Hawley, 2004).

Anthropometric properties have different associations regarding running distances. Height seems to be associated with performance in running 10 km (Bale, Bradbury, & Colley, 1986) and marathons (Loftin et al., 2007), while body mass index is related to marathon (Hagan, Upton, Duncan, & Gettman, 1987) and ultra-marathon performance (Hoffman, 2008). In addition to body mass index, body fat seems to have an effect on running time and is positively associated with marathon performance times (Hagan et al., 1987). The relationship between skinfold thicknesses and running performance has been investigated in several studies. Hagan and colleagues (Hagan, Smith, & Gettman, 1981) demonstrated that, in addition to other variables, the sum of seven skinfold thicknesses was weakly correlated with marathon performance time. Bale and colleagues (Bale et al., 1986) found that the total sum of skinfold thicknesses, the type and frequency of training, and the number of years running were the best predictors of running performance and success in the 10-km distance. In more recent studies, a relationship between the thicknesses of selected skinfolds and running performance has been demonstrated in elite runners of distances from 100 m to 10 km and the marathon (Arrese & Ostáriz, 2006; Legaz & Eston, 2005). Strong and positive correlations were found between the front thigh and medial calf skinfolds and 10-km race times in male runners (Arrese & Ostáriz, 2006). However, in two older studies no associations of skinfold thickness and body fat with race time were observed. Conley and Krahenbuhl (1980) reported that the sum of six skinfolds was not related to 10-km race time, and Kenney and Hodgson (1985) found no association between percent body fat and 5-km race time. It has

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been reported that the skinfold thicknesses of the lower limb are a result of intense training in running (Legaz & Eston, 2005). Legaz and Eston (2005) concluded from their longitudinal study of high-class runners that run training led to a decrease in the sum of six skinfolds and the skinfold thickness at the abdominal, front thigh, and medial calf sites. It was assumed that the lower limb skinfold thicknesses might be a useful predictor of running performance (Arrese & Ostáriz, 2006; Legaz & Eston, 2005). Anthropometric properties and their association with exercise performance during short and middle-distance running, as well as marathon running, have been investigated in several studies (Arrese & Ostáriz, 2006; Bale, Rowell, & Colley, 1985; Bale et al., 1986; Berg, Latin, & Coffey, 1998; Christensen & Ruhling, 1983; Knechtle, Knechtle, Rosemann, & Senn, 2010e; Legaz & Eston, 2005; Maldonado, Mujika, & Padilla, 2002). However, there is little scientific data about the association of anthropometry with race performance in ultra-marathon running (Hoffman, 2008; Knechtle, Duff, Welzel, & Kohler, 2009b; Knechtle, Knechtle, Schulze, & Kohler, 2008).

In addition to anthropometry, volume and intensity in training seem to influence running performance in long-distance runners up to the marathon distance. In marathon finishers, the longest mileage covered per training session is the best predictor for a successful completion of a marathon (Yeung, Yeung, & Wong, 2001). Scrimgeour and colleagues (Scrimgeour, Noakes, Adams, & Myburgh, 1986) found that runners training more than 100 km per week have significantly faster race times over 10 km to 90 km than athletes covering less than 100 km. Bale et al. (1986) demonstrated in 60 male runners, that elite runners with a higher training frequency, higher weekly training volume, and longer running experience had better 10-km performance. According to Hewson and Hopkins (1996), a correlation exists between seasonal weekly duration of moderate continuous running and runners specializing in longer distances. As well as volume, intensity in running is important. According to Billat and colleagues (Billat, Demarle, Slawinski, Paiva, & Koralsztein, 2001), top-class marathon runners train for more total kilometres per week and at a higher velocity than runners at a lower level. Peak running velocity in training is highly related to 5-km run times for both male and female athletes (Scott & Houmard, 1994). When training in marathoners was analysed in detail, workout days, total workouts, total kilometres, mean kilometres per workout, longest mileage covered per training session, total training minutes, maximum kilometres run per week, mean kilometres per week, and mean kilometres per day appeared to have an effect on marathon performance (Hagan et al., 1981, 1987, Yeung et al., 2001). Scrimgeour et al. (1986) investigated race distances up to 90 km; however, there are no data on the potential association of training parameters and race performance in ultra-marathoners competing over distances longer than 90 km.

In addition to training volume, previous race experience might also be of importance. In 24-h ultra-runners (Knechtle, Wirth, Knechtle, Zimmermann, & Kohler, 2009c) and in mountain ultra-marathoners (Knechtle, Knechtle, & Rosemann, 2010b), personal best time was related to race performance. In multi-stage ultra-marathoners, in a 1200-km race over 17 days, the only difference between finishers and non-finishers was the faster personal best time in a marathon by the finishers (Knechtle, Duff, Schulze, Rosemann, & Senn, 2009a).

There are several distances in ultra-marathon running of more than the classic marathon distance of 42.195 km. A 100-km run is the first step for runners wishing to compete in ultra-running such as 24-h runs (Knechtle et al., 2009c) or multi-stage ultra-runs (Knechtle et al., 2009a, 2009b, 2010b). Ultra-running means distances longer than the classic marathon distance of 42.195 km. Ultra-marathon runners have a lower body mass index compared with sedentary individuals (Tokudome et al., 2004) and have low amounts of fat on the abdomen and legs (Hetland, Haarbo, & Christiansen, 1998). These low amounts of body fat are thought to be the result of a high training volume in ultra-running (Hetland et al., 1998) and this high training volume may lead to improved performance (Bale et al., 1985). It is likely that a thinner upper body with low circumferences of the upper arm is advantageous for ultra-runners of distances of more than 300 km (Knechtle et al., 2009b) or even 1200 km (Knechtle et al., 2008).

The main aim of the present study was to use multivariate analyses to determine the strength and nature of the associations of anthropometric characteristics and training variables with 100-km run performance. A secondary aim was to determine whether marathon performance time, a variable of pre-race experience, was also independently predictive of 100-km race time.

Materials and methods

Participants

The organizer of the of the "100 km run Biel", Switzerland, invited all participants of the races in 2007 to 2009 to take part in the study. About 2000 male Caucasian runners started in the race each year; a total of 101 male ultra-runners were interested in our investigation over this 3-year period. The athletes were informed of the experimental risks and gave their informed written consent. The study received approval from the Institutional Review Board for Use of Human Subjects of Canton St. Gallen, Switzerland. Ninety-three athletes (mean age 44.6 years, $s = 10.0$; body mass 74.0 kg, $s = 9.0$; height 1.77 m, $s = 0.06$; body mass index 23.4 kg $\cdot$ m^{-2}, $s = 2.0$) in our study group finished the race within the time limit.

Race

The "100 km run Biel", Berne, Switzerland, takes place during the night of the first weekend in June. The runners start the 100-km run at 22.00 h. They have to climb a total altitude of 645 m. During these 100 km they have 17 aid stations offering a variety of foods and beverages. The athletes are allowed support from a cyclist with additional food and clothing, if necessary. In all 3 years, the general weather conditions were good with the temperature at the start being 15–18°C, lows at night of 8–10°C, and highs of 25–28°C the following day. There was no rain or wind.

Methods

Immediately before the start of the race, body mass, height, length of leg, and the skinfold thickness at eight sites were measured in our participants to calculate body mass index, the sum of eight skinfolds, and percent body fat using the anthropometric method. Furthermore, the ratio of extremity to trunk skinfolds (E/T, triceps, front thigh/subscapular, iliac crest, abdominal) was calculated following Legaz and Eston (2005). In all 3 years, skinfold data were obtained using a skinfold calliper (GPM-Hautfaltenmessgerät, Siber & Hegner, Zurich, Switzerland) and recorded to the nearest 0.2 mm. The skinfold measurements were taken once for the entire eight skinfolds and the procedure was then repeated twice more by the same investigator; the mean was then used for the analyses. Readings were taken 4 s after applying the callipers (Becque, Katch, & Moffatt, 1986). One trained investigator took all the skinfold measurements as inter-tester variability is a major source of error in such measurements. An intra-tester reliability check was conducted on 27 male and 11 female runners before testing. The intra-class correlation coefficient (ICC) within the two judges was excellent for both men and women for all anatomical measurement sites (ICC > 0.9; Knechtle et al., 2010a). Body mass was measured using a commercial scale (Beurer BF 15, Beurer GmbH, Ulm, Germany) to the nearest 0.1 kg. Height was determined using a stadiometer to the nearest 1 cm. The percentage of body fat was calculated using the following anthropometric formula according to Ball and colleagues (Ball, Altena, & Swan, 2004): Percent body fat $= 0.465 + 0.180(\Sigma 7SF) - 0.0002406(\Sigma 7SF)^2 + 0.0661(\text{age})$, where $\Sigma 7SF$ = sum of skinfold thicknesses of pectoralis, axilla, triceps, subscapular, abdomen, iliac crest, and front thigh. This formula was evaluated in 160 men aged 18–62 years old and cross-validated using dual energy X-ray absorptiometry (DXA). The mean differences between DXA percent body fat and calculated percent body fat ranged from 3.0% to 3.2%. Significant ($P < 0.01$) and high ($r > 0.90$) correlations were observed between the anthropometric prediction equations and DXA.

Upon recruitment to the study, the athletes were asked to maintain a comprehensive training diary of training sessions in preparation for the race. The training record consisted of the number of weekly training units regarding duration, kilometres and pace, weekly kilometres run, and weekly hours run. The athletes recorded their speed when running during training in minutes per kilometre. Furthermore, they reported on the number of years that they had actively participated in running, as well as the number of marathons, and their personal best marathon performance. Personal best marathon performance was defined as their best time achieved on a flat track in a city marathon.

Statistical analysis

The Shapiro-Wilk test was used to check for normality of distribution. Non-normally distributed data are presented as median (inter-quartile range, IQR). As a first step, the association of the variables of pre-race experience and training (personal best time in a marathon, average weekly training volume in hours and kilometres run, speed in running during training) and age, as well as anthropometry (body mass, height, length of leg, body mass index, the sum of eight skinfolds, the ratio of extremity to trunk skinfolds, and percent body fat) with total race time was investigated using bivariate Spearman correlation analysis. In the second step, least-squares multiple linear regression analysis was used to further investigate the independent relationship of significant variables in the bivariate analysis with race time. Soundness of fit of multiple regression assumptions was checked by residual examination (i.e. normality distribution of residuals, test for homoscedasticity), and the possibility of extra-linear variation in the outcome–predictor relationship was tested by introducing quadratic terms of predictor variables into the model (Kirkwood & Sterne, 2003). Multicollinearity between predictor variables in the regression model was assessed by computing variance inflation factors (VIF) assuming a multicollinearity problem with a VIF > 10 (Slinker & Glantz, 1985). A two-sided probability value of less than 0.05 was accepted as significant for all inference tests.

Results

Of the 101 study participants, 93 athletes finished the race within 699 (592–762) min. One runner finished in the top three and eight had to withdraw due to medical problems. The race time of the participants showed a normal distribution in relation to the course record of 397 min held since 1996 by Peter Camenzind (SUI), with 95% of them performing between 1.34 and 2.17 times above the best time ever performed in this race.

In the bivariate analysis (see Table I), body mass index, the sum of eight skinfolds, and percent body fat were positively related to race time. Training variables such as volume and intensity in training were inversely related to race time. Personal best time in a marathon was highly significantly and positively related to race time. All investigated variables of pre-race experience and training showed an association with race time in the bivariate analysis. Results of the multiple regression analysis to further explore the independent association between race time and both anthropometric and training characteristics are given in Table II. Multicollinearity problems were related to the bivariate association between the two highly correlated covariates percent body fat and the sum of eight skinfolds. Average weekly kilometres as well as average speed in running were significantly and negatively associated with race performance, whereas the sum of eight skinfolds showed an independent and positive association with race time. Average weekly kilometres run remained significantly associated with race time, whereas average speed in running and the sum of eight skinfolds were of borderline significance ($P = 0.08$ and $P = 0.12$, respectively) when personal best marathon time was also included in the regression model. There was evidence of a curvilinear association between personal best marathon time and 100-km race time, which is displayed graphically in Figure 1. Residual analysis of the regression models (with and without best time in a marathon as covariate) showed a departure from the normality distribution, with no evidence of heteroscedasticity. As departure from normality may affect estimates of standard errors by parametric methods, we derived alternative standard errors using bootstrapping (Kirkwood & Sterne, 2003). Results remained unchanged when the outcome variable (race time) was log-transformed.

Discussion

The main finding of this study was that anthropometric variables (lower sum of eight skinfolds) and training variables (higher volume and intensity) were independently associated with a better performance in a 100-km ultra-marathon.

We expected to find associations of skinfold thickness and body fat with race time based on existing literature about the association between anthropometry and running performance. Although, in the bivariate analysis, we found associations of body mass index, percent body fat, and the sum of skinfolds with race time, we also found associations of both volume and intensity of training with race time. When controlled for potential confounding by means of multiple regression analysis, both training variables and the sum of eight skinfolds remained associated with race time, indicating that: (1) a higher training volume (weekly kilometres run) in combination with a higher intensity (speed) was

Table I. Relationships of race time with age, anthropometry, training variables and personal best marathon time using bivariate analysis ($n = 93$).

Predictor variables	Median	*IQR*	ρ	*P*
Age (years)	45.0	39.5–50.0	0.18	0.07
Body mass (kg)	73.5	68.4–78.0	0.15	0.13
Height (m)	1.78	1.74–1.82	0.05	0.63
Body mass index ($kg \cdot m^{-2}$)	23.0	22.0–24.0	0.24	0.01
Length of leg (cm)	87.0	84.0–89.5	0.08	0.46
Extremity to trunk ratio	0.59	0.46–0.73	−0.10	0.34
Sum of eight skinfolds (mm)	76.8	61.0–104.5	0.55	<0.0001
Percent body fat (%)	15.4	12.5–18.8	0.57	<0.0001
Average weekly hours running	7	5–9	−0.29	0.0049
Average weekly kilometres running	70.0	51.7–91.7	−0.49	<0.0001
Average speed running during training ($km \cdot h^{-1}$)	10.9	10.0–11.7	−0.50	<0.0001
Personal best time in a marathon (min) [a]	203	180–220	0.72	<0.0001

[a]Based on 89 individuals who had already finished a marathon. ρ-values represent Spearman correlation coefficients.

Table II. Relationships of race time with selected anthropometric and training variables ($n = 89$).

	β	Standard error (bootstrap)	P
Body mass index	−3.0	4.3	0.48
Sum of eight skinfolds	0.95	0.30	0.002
Average weekly kilometres running	−1.8	0.6	0.002
Average weekly hours running	5.7	6.4	0.38
Average speed running during training	−21.5	8.5	0.011

Note: Independent association between race time as outcome variable and athletes' variables of anthropometry and training. All variables showing a significant bivariate association with race time according to Table I have been included in the model as covariates. Percent body fat was excluded due to problems of multicollinearity. Personal best time in a marathon was not included in the model due to the complex interrelationship between pre-race experience and the covariates in the model in predicting race time. The coefficient of determination (R^2) of the model was 42.0%; standard errors were derived using bootstrapping.

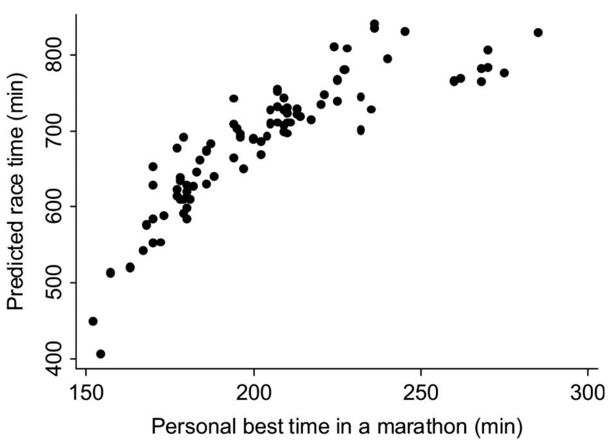

Figure 1. Independent association between predicted race time (y-axis) and personal best time in a marathon (x-axis) controlled for anthropometric and training variables presented in Table II for the 93 ultra-runners. There was a curvilinear relationship between personal best time in a marathon and race time in a 100-km ultra-marathon. A marathon time up to 240 min (4 h) showed a linear relationship with race time in a 100-km ultra-marathon. A marathon time of more than 240 min failed to show a relationship with 100-km ultra-marathon race time.

associated with a better performance; (2) although anthropometry and training were interrelated, the thickness of skinfolds remained independently associated with race time in a 100-km ultra-marathon.

In the bivariate analysis, we found associations of body mass index, sum of skinfolds, and percent body fat with race time. The sum of eight skinfolds showed an independent association with race time when controlling for training variables. We therefore must assume that training variables are more important than anthropometric variables for race outcome in a 100-km ultra-marathon. Several studies of runners up to the marathon distance have shown that increased volume and intensity in training is of importance for running performance. Top-class marathoners train for more total kilometres per week and at a higher velocity than high-level runners (Billat et al., 2001). Christensen and Ruhling (1983) concluded that improved performance in marathon runners was associated with higher aerobic capacity and years of training rather than with body dimensions. Scrimgeour et al. (1986) showed that runners training for more than 100 km per week had significantly faster running times in running events of between 10 km and 90 km compared with runners training less.

In the bivariate analysis, personal best time in a marathon showed the highest correlation coefficient with race time. Results from the multiple regression analysis revealed a significant non-linear association between race time in a 100-km run and personal best time in a marathon. Although marathon time showed the strongest correlation with actual race performance in the bivariate analysis, it did not completely dominate the influence of anthropometric and training characteristics on the 100-km performance when included as an additional covariate in the regression model. Average weekly kilometres run remained significantly related to race time, while average speed and skinfold thickness still reached borderline significance, indicating the important independent role of both training and anthropometry in a 100-km ultra-marathon beyond the marathon distance.

Personal best marathon time is influenced by a wide range of physiological, psychological, and behavioural factors, including but not limited to anthropometric and training variables. Inclusion of personal best marathon time as a predictor variable in the multivariate analyses can help identify the influence of additional factors, which may include the difficult to define concept of "pre-race experience". In addition, the characteristics of successful classic marathoners cannot be extrapolated to ultra-marathoners. These differences might explain the significant extra-linear variation between race performance and marathon best time taking into account the complex interrelationship between training, anthropometry, and pre-race experience that contributed to the performance. The positive association between a marathon best time and race performance coupled with training volume has been previously described in ultra-endurance mountain bikers (Knechtle, Knechtle, Rosemann, & Senn, 2010c) and is in line with a study that investigated non-professional ultra-triathletes (Knechtle, Knechtle, Rosemann, & Senn, 2010d). In the present study, personal best time in a marathon was self-reported and although one might question the role of a self-reported measure especially as a surrogate marker of pre-race experience, we restricted our primary multivariable analysis to training variables and anthropometry (see Table II).

Limitations of the study

This cross-sectional study is limited regarding the influence and effects of anthropometry and both volume and intensity of training on race performance in ultra-endurance runners, since only an intervention trial can fully address this question. Other limitations are the lack of an evaluation of fitness of the athletes. However, we included performance as a percentage of the course record. The nature of a field study design with voluntary participation allowed no random allocation of participation, thus generalization of the results might be questioned due to a potential selection bias. To further characterize our study sample, we compared the race time of each participant in relation to the course record of 397 min. The assessment of this "relative" measure of performance showed a normal distribution, indicating that our recruited study sample does not only consist of a small homogenous sample of runners (i.e. only very fast or very slow in relation to the course record) but represents a wide range of performance time, making the sample acceptable for recreational ultra-marathoners. Other aspects such as nutrition and influence of the environment were not considered. Unfortunately, we have no data about energy deficit (Kimber, Ross, Mason, & Speedy, 2002) or disorder in fluid or electrolyte metabolism (Speedy et al., 1999) that might have affected race outcome.

Implications of the study and future research directions

In the present ultra-marathoners, we found that training volume in combination with training intensity was able to predict 100-km race time. In addition, skinfold thickness was independently associated with race time, suggesting that factors other than training (i.e. genetic variations) contributed to the anthropometric measures, thus influencing race time. Longitudinal studies are needed to further disentangle the complex interrelationship between training and anthropometry and ultra-marathon performances. In addition, measures of pre-race experience, reflecting not only a best marathon time at a variable point in the past, should be better characterized and their role in predicting performance investigated further.

Conclusions

The main finding of the present study was that anthropometric variables, such as a low sum of eight skinfolds, and training variables, such as high volume and intensity, are independently associated with a fast performance in a 100-km ultra-marathon. There was also a significant curvilinear association between 100-km race time and personal best time in a marathon. Ultra-runners with $\sim 15\%$ body fat, running about 70 km per week at a mean speed of ~ 11 km $\cdot$ h^{-1}, and with a personal best marathon time of about 200 min may finish a 100-km ultra-marathon in around 700 min.

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