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Predictor Variables for Marathon Race Time in Recreational Female Runners

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Abstract

***Purpose*: We intended to determine predictor variables of anthropometry and training for marathon race time in recreational female runners in order to predict marathon race time for future novice female runners.**

***Methods*: Anthropometric characteristics such as body mass, body height, body mass index, circumferences of limbs, thicknesses of skin-folds and body fat as well as training variables such as volume and speed in running training were related to marathon race time using bi- and multi-variate analysis in 29 female runners.**

***Results*: The marathoners completed the marathon distance within 251 (26) min, running at a speed of 10.2 (1.1) km/h. Body mass (r=0.37), body mass index (r=0.46), the circumferences of thigh (r=0.51) and calf (r=0.41), the skin-fold thicknesses of front thigh (r=0.38) and of medial calf (r=0.40), the sum of eight skin-folds (r=0.44) and body fat percentage (r=0.41) were related to marathon race time. For the variables of training, maximal distance ran per week (r=-0.38), number of running training sessions per week (r=-0.46) and the speed of the training sessions (r=-0.60) were related to marathon race time. In the multi-variate analysis, the circumference of calf (P=0.02) and the speed of the training sessions (P=0.0014) were related to marathon race time. Marathon race time might be partially (r^2=0.50) predicted by the following equation: Race time (min)=184.4+5.0 x (circumference calf, cm) –11.9 x (speed in running during training, km/h) for recreational female marathoners.**

***Conclusions*: Variables of both anthropometry and training were related to marathon race time in recreational female marathoners and cannot be reduced to one single predictor variable. For practical applications, a low circumference of calf and a high running speed in training are associated with a fast marathon race time in recreational female runners.**

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INTRODUCTION

Running is very popular in both genders and all ages and can be performed over various distances [1,2]. Different anthropometric, physiological, and training characteristics seem to influence running performances depending upon the length and duration of an endurance effort [3-19].

Among the anthropometric variables, the relationship of skin-fold thickness to running performance has been discussed for a number of years. Hagan et al demonstrated that the sum of seven skin-fold thicknesses was correlated to marathon performance time [7]. Bale et al reported that the total sum of skin-fold thicknesses, the type and frequency of training, and running experience such as the number of years running were the best predictors of running performance and success in 10,000 m running [8].

Likewise, Arrese and Ostáriz reported high correlations between both the front thigh and the medial calf skin-fold thickness and performance over 1,500 m in highly trained male runners and correlations between the front thigh skinfold and the medial skin-fold and 400 m distance in female top athletes [10]. A correlation of thickness of selected skin-folds with running performance has been reported for the top-class runners of distances from 100 m to 10,000 m and the marathon distance [10,11]. High correlations were found for the front thigh and medial calf skin-fold thickness with 10,000 m race times in male runners [10]. Marathon race times and both the iliac crest skin-fold and the abdominal skin-fold were associated in female runners [10]. Although Conley and Krahenbuhl [9] found no relation between the sum of six skin-folds and the 10,000 m race time in 12 male runners, and Kenney and Hodgson [12] reported no association between percent body fat and a 5,000 m race time in eight male runners, the evidence suggests gender-specific differences of skin-folds in the prediction of marathon performance [13].

There are differences between the genders, their skin-fold thicknesses and the correlation with race time reported for both female and male half-marathoners. A recent study investigating male and female half-marathoners described positive correlations between both the abdominal and calf skin-fold thicknesses and the race time in male half-marathoners [14], whereas in the female recreational half-marathoners there were positive correlations between the pectoral, mid-axilla, subscapular, abdominal and suprailiac skin-fold thickness and half-marathon race times [15].

For runners, there is also an association between volume and intensity of training sessions and the running performance described [8]. The training session days, the number of total training sessions, the average number of kilometres covered per training session, the total and the longest distance covered during a training session, the total of training minutes, the average and the maximal run per week; and the average distance covered per day were related to marathon performance [7,16,17]. Yeung et al reported, that in marathon finishers, the marathon performance was related to the longest mileage covered per training session [17]. In female marathon runners, the number of years training and the number of training sessions per week were the best predictors of competitive performances at the marathon distance [18]. However, not only the training volume, also the intensity of training sessions was important. Billat et al showed that top marathon runners trained for more total kilometres per week, and at a higher speed, than runners at a lower level [19].

This background shows the relationship of anthropometric characteristics such as skin-fold thickness and the training parameters to race performance of marathon runners. Most of these investigations were performed using high-level runners [10,11]. In addition, these studies focused either on the aspect of anthropometry or training. The interaction between changes in anthropometric characteristic and training has rarely been investigated [11]. In general, the largest group of competitors in marathons are non-professional recreational runners. The association of anthropometric and training characteristics in recreational male and female half marathon runners has already been described [14,15]. The intention of the present study was to determine predictor variables for marathon race time in recreational female marathoners.

Based on the existing literature, it was hypothesized that variables of both anthropometry and training would also be related to marathon race time in recreational female runners. We intended to create an equation using basic measurements of anthropometry and training to predict a marathon race time for future novice female half marathoners. Any athlete could then apply this equation to predict her marathon race time without the need of highly sophisticated equipment.

METHODS AND SUBJECTS

Subjects:

We performed a cross-sectional observational field study at ‘Basel Marathon’ in Switzerland. The organiser contacted all female participants of the race in 2010 via a separate newsletter, three months before the race, in which they were asked to participate in the study. The study was approved by the Institutional Review Board of the Canton of St. Gallen, Switzerland. The athletes were informed of the experimental procedures and gave their informed written consent. A total of 123 female athletes started in the marathon; 29 female runners were interested in participating in our investigation. All interested female runners were included in the study with no criteria for exclusion, except that they had to finish the race within the time limit. All participants finished the race within the time limit of 5:30 h:min.

The Race:

The marathon took place on 12th September 2010, in the city of Basel, Switzerland. The athletes started at 08:30 a.m. and had to run two laps on asphalt with a total altitude of 200 m. The weather was fine and dry. The temperature was 13 °Celsius at the start and the relative humidity was at 63%. The organiser provided nutrition and drinks every 3.5 km.

Measurements and Calculations:

The afternoon of the day before the start of the race, body mass, body height, length of the leg, limb circumferences and the thicknesses of skin-folds were measured. With this data, we calculated body mass index and body fat percentage using an anthropometric method. Body mass was measured to the nearest 0.1 kg using a Beurer® BF15 scale (Beurer GmbH, Ulm, Germany). Body height was determined to the nearest 1 cm using a stadiometer. Body mass index (kg/m^2) was calculated using body mass and body height. Limb circumferences were measured at mid-upper arm, mid-thigh and mid-calf. The length of the leg was measured from *trochanter major* to *malleolus medialis*. Skin-fold thicknesses were measured by the same investigator at the following eight sites: pectoral, mid-axilla, triceps, subscapular, abdominal, suprailiac, front thigh and medial calf. Skin-fold data was obtained using a skin-fold calliper (GPM-Hautfaltenmessgerät, Siber & Hegner, Zurich, Switzerland) and recorded to the nearest 0.2 mm. All anthropometric measurements were taken three times on the right side of the body and the mean of the three measurements was used for the analyses. The timing of the taking of the skin-fold measurements was standardised to ensure reliability.

One trained investigator took all the skin-fold measurements as inter-tester variability is a major source of error in skin-fold measurements. An intra-tester reliability check was conducted on 11 female runners prior to testing. Intra-class correlation (ICC) within the two judges was excellent for both men and women for all anatomical measurement sites (ICC>0.9). For the sum of eight skin-folds for measurer 1, bias (average difference between measure 1 and 2) was -0.515, standard deviation of the average difference was 1.492, and 95% limits of agreement were between -3.439 and 2.409 [20]. Readings were performed 4 s after applying the calliper, according to Becque et al. [21].

Percent body fat was estimated using the formula: Percent body fat = -6.40665 + 0.41946 (Σ3SF) – 0.00126 (Σ3SF)^2 + 0.12515 (Hip) + 0.06473 (age) using the formula of Ball *et al.* [22]. Σ3SF was taken as the sum of the three skin-fold thickness of the triceps, suprailiac; and front thigh skin-fold. Hip was the circumference of the hip.

Volunteers were asked to maintain a comprehensive training diary during the three-month period before the race. The training records consisted of the number of training units with duration, kilometres and pace, weekly kilometres ran, weekly hours ran, and minimal and maximal kilometres ran per week. The athletes recorded their running speed during training in km/min and reported on the number of years that they had actively participated in running.

Statistical Analysis:

Normally distributed data are presented as mean and standard deviation (SD). In a first step, the association of the variables of anthropometry, training and pre-race experience with total race time was investigated using bi-variate correlation analysis. In a second step, multiple linear regression analysis was used to further investigate the relationship of variables with significance in the bi-variate analysis to race time. The best predictor variables were then used to create an equation that could predict the marathon race time. Bland-Altman analysis was used to determine absolute limits of agreement between predicted and effective race time. A probability value of less than 0.05 was accepted as significant.

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Table 1: Association between age and selected anthropometric variables and marathon race time for the 29 runners

Measures	Mean (SD)	Pearson *r*	*P* value
Age (years)	47.1 (8.7)	0.02	NS
Body mass (kg)	59.1 (6.3)	0.37	0.04
Body height (m)	1.66 (0.06)	0.05	NS
Body mass index (kg/m^2)	21.3 (1.6)	0.46	0.01
Length of leg (cm)	81.6 (4.1)	0.05	NS
Circumference of upper arm (cm)	26.3 (1.7)	0.27	NS
Circumference of thigh (cm)	54.1 (3.5)	0.51	0.004
Circumference of calf (cm)	36.2 (2.0)	0.41	0.02
Pectoral skin-fold (mm)	6.9 (2.9)	0.04	NS
Mid-axilla skin-fold (mm)	8.7 (2.6)	0.33	NS
Triceps skin-fold (mm)	12.2 (2.9)	0.31	NS
Subscapular skin-fold (mm)	10.5 (4.4)	0.32	NS
Abdominal skin-fold (mm)	13.3 (5.7)	0.34	NS
Suprailiac skin-fold (mm)	18.4 (6.6)	0.29	NS
Front thigh skin-fold (mm)	23.3 (7.7)	0.38	0.04
Medial calf skin-fold (mm)	9.1 (4.2)	0.40	0.02
Sum of eight skin-folds (mm)	102.7 (26.8)	0.44	0.01
Body fat percentage (%)	26.7 (4.2)	0.41	0.02

SD: Standard Deviation; NS: Non-Significant

RESULTS

The 29 athletes completed the marathon distance within 251 (26) min, running at a speed of 10.2 (1.1) km/h. In the bi-variate analysis, body mass (*r*=0.37, *P*=0.04), body mass index (*r*=0.46, *P*=0.01), the circumference of thigh (*r*=0.51, *P*=0.004) and calf (*r*=0.41, *P*=0.02), the skin-fold thickness at front thigh (*r*=0.38, *P*=0.04) and medial calf (*r*=0.40, *P*=0.02), the sum of eight skin-folds (*r*=0.44, *P*=0.01) and body fat percentage (*r*=0.41, *P*=0.02) were related to race time considering age and anthropometric characteristics (Table 1).

For the training variables, the maximal distance ran per week (*r*=-0.38, *P*=0.04), the number of running training sessions per week (*r*=-0.46, *P*=0.01) and the running speed of the training sessions (*r*=-0.60, *P*=0.0005) were associated with marathon race time (Table 2).

When the anthropometric and training variables significant after bi-variate analysis were inserted into a multi-variate regression model (Table 3), the

Table 2: Association between selected training variables, previous performance and marathon race time for the 29 runners

Measures	Mean (SD)	Pearson *r*	*P*
Years as active runner	7.9 (5.5)	- 0.07	NS
Weekly kilometres ran (km)	34.6 (12.0)	- 0.22	NS
Minimal distance ran per week (km)	18.1 (10.4)	- 0.04	NS
Maximal distance ran per week (km)	57.2 (13.1)	- 0.38	0.04
Hours ran per week (h)	5.2 (1.2)	- 0.21	NS
Number of running training sessions per week	3.8 (0.9)	- 0.46	0.01
Distance per running training session (km)	12.9 (2.8)	- 0.02	NS
Duration of running training sessions (min)	73.8 (20.1)	0.04	NS
Speed of the training sessions (km/h)	9.7 (1.4)	- 0.60	0.0005

SD: Standard Deviation; NS: Non-Significant

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Table 3: Associations between significant characteristics after bivariate analysis and race time (using multiple linear regression, *n*=29)

Variables	regression coefficient	standard error	*P*
Body mass	- 2.21	1.18	0.07
Body mass index	5.64	3.50	0.12
Circumference of thigh	1.60	1.95	0.42
Circumference of calf	6.13	2.81	0.04
Front thigh skin fold	- 0.36	0.91	0.69
Medial calf skin fold	2.38	1.34	0.09
Sum of eight skin folds	0.26	0.37	0.49
Body fat percentage	- 2.42	2.94	0.42
Maximal distance ran per week	- 0.69	0.33	0.05
Number of running training sessions per week	- 1.21	4.98	0.81
Speed of the training sessions	- 10.75	2.82	0.0014

The coefficient of determination (r^2) of the model was 78%. Circumference of calf and speed of the training sessions were related to race time.

circumference of the calf (*P*=0.04) (Fig. 1) and the running speed of the training sessions (*P*=0.001) (Fig. 2) were related to marathon race time.

We found anthropometric characteristics and training variables with a significant association with marathon race time. In order to find potential association between these significant variables, we performed separate correlation analyses between these significant variables (Table 4). However, the anthropometric characteristics were not related to the training variables.

Marathon race time might be partially (r^2=0.50) predicted by the equation race time (min) = 184.4 + 5.0 x (circumference calf, cm) – 11.9 x (speed in running during training, km/h). The predicted race time using this equation was 249.5 (19.8) min and correlated significantly (*r*=0.71, *P*<0.0001) to the achieved race time (Fig. 3). Figure 4 shows the level of agreement using the Bland-Altman method (Bias = -40.5 ± 37.4 min) between the effective and the predicted race time. Intra class correlation (ICC) between effective and predicted race time was 0.67.

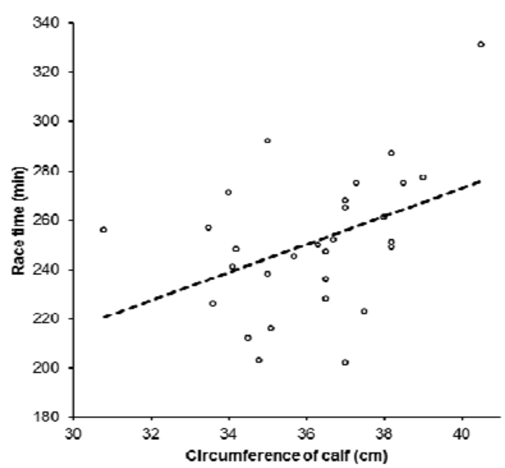

Fig. 1: The circumference of the calf was significantly and positively related to marathon race time (*n*=29) (*r*=0.41, *P*=0.02)

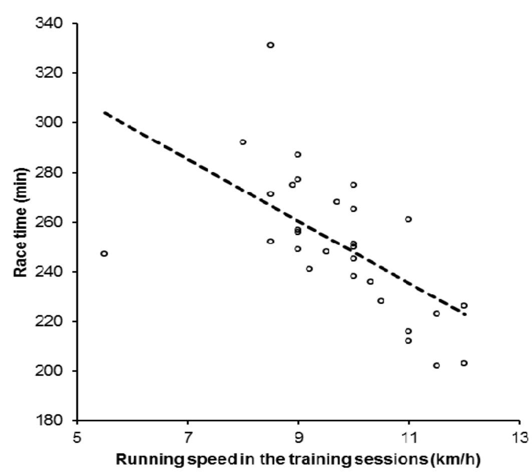

Fig. 2: The running speed in the training sessions was significantly and negatively related to marathon race time (*n*=29) (*r*=- 0.60, *P*=0.0005)

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Table 4: Association of training variables with pre-race skin-fold thicknesses and body fat

Variable	Maximal distance ran per week	Number of running training session per week	Speed of the training sessions
Circumference of thigh	0.02	- 0.09	- 0.22
Circumference of calf	0.30	- 0.05	- 0.08
Skin-fold front thigh	- 0.24	- 0.27	- 0.24
Skin-fold medial calf	0.04	0.06	0.02
Sum of eight skin-folds	- 0.11	- 0.18	- 0.18
Percent body fat	- 0.04	- 0.14	- 0.20

DISCUSSION

We hypothesized an association between body mass, body mass index and body fat with the marathon race time, according to the existing literature, describing a relationship between body mass [7, 8], body mass index [15, 23] and body fat [15] with race time in female long-distance runners. We could confirm these previous findings for body mass, body mass index and body fat percentage in the present recreational female marathoners after bi-variate analysis. According to the existing literature of Arrese and Ostáriz describing a significant relationship between selected upper body skin-fold thickness such as at iliac crest and abdominal site and the race time for high-level female marathon runners, a potential association between upper body skin-fold thicknesses and the marathon race time might be expected also in recreational runners [10]. However, neither the suprailiac nor the abdominal skin-fold thicknesses were related to marathon time in the present recreational runners whereas front thigh and medial calf skin-folds were associated with marathon race time. A possible explanation for these different findings might be the anthropometry of the subjects. Arrese and Ostáriz examined elite long-distance runners with a lower body mass index, a thinner upper skin-fold thickness and with a younger age [10]. In comparison, we measured anthropometric parameters in female recreational marathoners, who had a higher body mass index, were older and had thicker skin-fold thicknesses. Another explanation for these different findings can be the different training volumes of the subjects.

Knechte et al reported no associations between

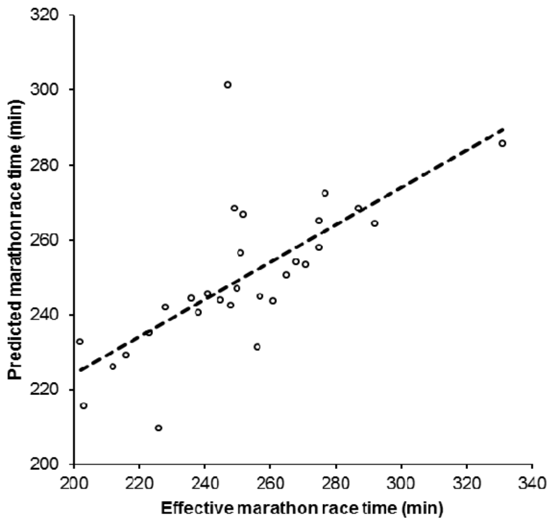

Fig. 3: The predicted marathon race time correlated significantly to the achieved marathon race time (*n*=29) (*r*=0.71, *P*<0.0001)

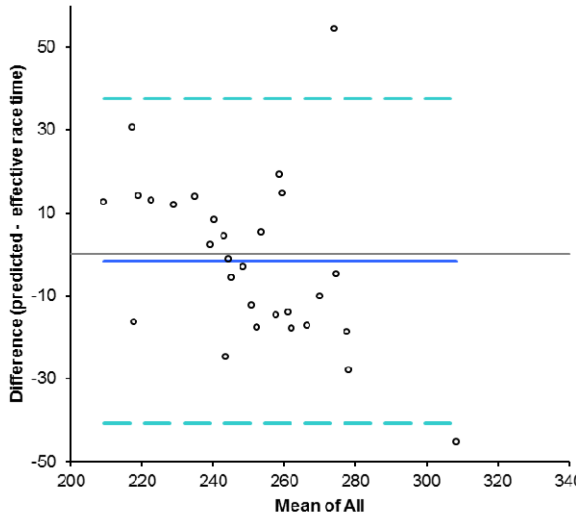

Fig. 4: Bland-Altman plots comparing predicted with effective race time

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skin-fold thicknesses and race performance in female triathletes, but a correlation between the speed in running during training, body fat and the sum of eight skin-fold thicknesses in females [24, 25]. We were not able to confirm the results of Arrese and Ostáriz investigating 11 female high-level marathoners [10]. However, we found a relationship between the skinfold-fold thickness of both the front thigh and medial calf and the marathon race time, which Arrese and Ostáriz described for the 400-m race time in female high-level runners (front thigh skin-fold: r=0.71, P=0.022; medial calf skin-fold: r=0.81, P=0.0.005, respectively) [10]. These different results might be due to the anthropometry of our recreational runners. The female top runners of Arrese and Ostáriz with a body mass of 45.6 kg and a body height of 1.58 m had a body mass index of 18.3 kg/m^2 compared to the body mass index of 21.3 kg/ m^2 of our female runners [10]. We presume that our recreational female marathoners with a higher body mass index had also a higher body fat percentage, and subsequently also thicker skin-folds in comparison to the female high-level marathon runners of Arrese and Ostáriz [10].

According to our knowledge, there are no studies about a significant relationship between the circumference of thigh and calf and the marathon race time in male and female runners. We found a significant and positive correlation between the circumference of thigh and the circumference of calf and the race time of recreational female marathoners. After bi-variate analysis, however, only the circumference of the calf was related to the race time. Arrese and Ostáriz reported an association between the skin-fold thickness of the thigh and the calf and the long-distance running performance [10]. Knechtle et al, however, showed an association between the thickness of the calf skin-fold and the race time in male mountain ultra-marathoners [26]. An explanation for these different findings could be that both Arrese and Ostáriz [10] and Knechtle et al [26] investigated male runners. However, Arrese and Ostáriz [10] examined male runners in 10,000 m flat running performance, while Knechtle et al [26] investigated mountain ultra-marathoners. Probably the up and downhill running influenced the thickness of the thigh and the calf in a different way, compared to a flat course. The physiological associations between the circumference of the calf, the skin-fold thickness and the running performance should be investigated in future studies.

We hypothesised a potential association between training parameters and the marathon race time in recreational female runners, according to existing literature. Hagan et al [7,15] and Yeung et al [16] described for marathoners a relationship between the training session days, the number of total training sessions, the total kilometres covered during a training session, the mean number of kilometres covered per training session, the longest mileage covered per training session, the total training minutes, the maximal kilometres ran per week, the mean kilometres covered per week and the mean kilometres covered per day and the marathon race time. In the present female marathoners, however, only the maximal distance ran per week, the number of running training sessions per week and the running speed of the training sessions were significantly related to the marathon race time after bi-variate analysis. No significant association between the years as active runner, the weekly kilometres ran, the minimal distance ran per week, the hours ran per week, the distance per running training session and the duration of running training sessions and the marathon race time could be found. We could confirm only a part of the results of the existing literature [7,15,16]. Knechtle et al reported a significant association between swimming speed while training and race time in male and female open-water ultra-endurance swimmers [27]. In contrast to these results, Knechtle et al showed no relationship between the speed during training and speed in racing for swimming, cycling or running in female Ironman-triathletes [24]. However, we can assume that maximal volume of kilometres and the speed in training sessions are more important for a fast marathon race time than the duration of training sessions. Further, the speed in training has an influence on race time in different types of sport.

We found no associations between the significant anthropometric parameters and the significant training variables in these female recreational marathoners. Legaz and Eston reported from a study with high-level long-distance runners a decrease of skin-fold thicknesses in correlation with training intensity and a

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lower body fat in combination with a high training level [10]. Knechtle et al showed no relationship between training and body fat in recreational female and male Ironman triathletes [24]. However, the same authors described an association between speed in running during training and percent body fat in female Ironman triathletes [24]. Seemingly, the level of body fat might be determined by other factors such as diet, genetics, or intensity of training. These different findings can be explained by gender differences, different levels of the athletes and different sports disciplines.

Strength, weakness, limitations and implications for future research:

The principal strength of this study is that we can present an equation to predict marathon race time for future recreational female marathoners without the need of highly sophisticated technical equipment. This study is, however, limited due to the rather small sample size of female athletes. One problem is the rather low participation of females in endurance events [28]. In this context, other studies investigating female endurance athletes had partly fewer subjects such as Arrese and Ostáriz [10], examining only 11 female high-level marathoners, or Gulbin and Gaffney [29] in their study of 242 Ironman athletes including only 12 female and 230 male athletes. Another limitation is the fact, that we did not measure other variables such as maximal oxygen consumption (VO_2max), motivation, running efficiency, nutritional status and anaerobic threshold and their influence on the race time, because these variables might also influence race performance. In a recent laboratory study using 12 subjects, the velocity at both lactate threshold and maximum lactate steady state explained 85% and 87% of the variance in running performance [30]. The inclusion of physiological variables might increase the coefficient of correlation for the equation to predict a marathon race time. Also, a recent study showed that, in addition to gender, body size and training, pre-race day carbohydrate intake can significantly and independently influence marathon running performance [31]. For practical applications, a low circumference of calf and a high running speed in training are associated with a fast marathon race time in recreational female runners.

CONCLUSION

To summarize, both variables of anthropometry and training were related to marathon race time in these recreational female runners. After multi-variate analysis, there was a significant association between both the circumference of the calf and the speed of the training sessions and the marathon race time. For future novice female marathoners intending to start for the first time in a marathon, race time might be partially predicted (r^2=0.50) by using the equation: Race time (min) = 184.4 + 5.0 x (circumference calf, cm) – 11.9 x (speed in running during training, km/h). For practical applications, a low circumference of calf and a high running speed in training are associated with a fast marathon race time in recreational female runners.

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Conflict of interests: None

REFERENCES

1. Marti B, Abelin T, Minder CE. Relationship of training and life-style to 16-km running time of 4000 joggers. The ’84 Berne “Grand-Prix” Study. *Int J Sports Med* 1988;9:85-91.

2. Nettleton S, Hardey M. Running away with health: the urban marathon and the construction of 'charitable bodies'. *Health (London)* 2006;10:441-460.
3. Anderson T. Biomechanics and running economy. *Sports Med* 1996;22:76-89.
4. Morgan DW, Martin PE, Krahenbuhl GS. Factors affecting running economy. *Sports Med* 1989;7:310-30.
5. Pate RR, Macera CA, Bailey SP, et al. Physiological, anthropometric, and training correlates of running economy. *Med Sci Sports Exerc* 1992;24:1128-33.
6. Saunders PU, Pyne DB, Telford RD, Hawley JA. Factors affecting running economy in trained distance runners. *Sports Med* 2004;34:465-85.
7. Hagan RD, Smith MG, Gettman LR. Marathon performance in relation to maximal aerobic power and training indices. *Med Sci Sports Exerc* 1981;13:185-9.
8. Bale P, Bradbury D, Colley E. Anthropometric and training variables related to 10-km running performance. *Br J Sports Med* 1986;20:170-3.
9. Conley DL, Krahenbuhl GS. Running economy and distance running performance of highly trained athletes. *Med Sci Sports Exerc* 1980;12:357-60.
10. Arrese AL, Ostáriz ES. Skinfold thicknesses associated with distance running performance in highly trained runners. *J Sports Sci* 2006;24:69-76.
11. Legaz A, Eston R. Changes in performance, skinfold thicknesses, and fat patterning after three years of intense athletic conditioning in high level runners. *Br J Sports Med* 2005;39:851-6.
12. Kenney WL, Hodgson JL. Variables predictive of performance in elite middle-distance runners. *Br J Sports Med.* 1985;19:207-209.
13. Legaz A, Munguía Izquierdo D, Serveto Galindo JR. Physiological measures associated with marathon running performance in high-level male and female homogenous groups. *Int J Sports Med.* 2006;27:289-95.
14. Knechtle B, Knechtle P, Barandun U, et al. Predictor variables for half marathon race time in recreational male runners. *Open Access J Sports Med* 2011;2:113-9.
15. Knechtle B, Knechtle P, Barandun U, et al. Predictor variables for half marathon race time in recreational female runners. *Clinics* 2011;66:287-91.
16. Hagan RD, Upton SJ, Duncan JJ, Gettman LR. Marathon performance in relation to maximal aerobic power and training indices in female distance runners. *Br J Sports Med.* 1987;21:3-7.
17. Yeung SS, Yeung EW, Wong TW. Marathon finishers and non-finishers characteristics: A preamble to success. *J Sports Med Phys Fitness.* 2001;41:170-6.
18. Bale P, Rowell S, Colley E. Anthropometric and training characteristics of female marathon runners as determinants of distance running performance. *J Sports Sci.* 1985;3:115-26.
19. Billat VL, Demarle A, Slawinski J, et al. Physical and training characteristics of top-class marathon runners. *Med Sci Sports Exerc.* 2001;33:2089-97.
20. Knechtle B, Joleska I, Wirth A, et al. Intra- and inter-judge reliabilities in measuring the skin-fold thicknesses of ultra-runners under field conditions. *Percept Mot Skills* 2010;111:105-210.
21. Becque MD, Katch VL, Moffatt RJ. Time course of skin-plus-fat compression in males and females. *Human Biol* 1986;58:33-42.
22. Ball SD, Swan P, Desimone R. Accuracy of anthropometry compared to dual energy x-ray absorptiometry. A new generalizable equation for women. *Res Q Exerc Sport* 2004;75:248-58.
23. Lucia A, Esteve-Lanao J, Oliván J, et al. Physiological characteristics of the best Eritrean runners' exceptional running economy. *Appl Physiol Nutr Metab* 2006;31:530-40.
24. Knechtle B, Wirth A, Rosemann T. Is body fat a predictor variable for race performance in recreational female ironman triathletes? *Med Sport* 2011;15:6-12.
25. Knechtle B, Knechtle P, Rosemann T. Upper body skinfold thickness is related to race performance in male Ironman triathletes. *Int J Sports Med* 2011;32:20-7.
26. Knechtle B, Rosemann T. Skin-fold thickness and race performance in male mountain ultra-marathoners. *J Hum Sports Exerc* 2009;4:211-20.
27. Knechtle B, Baumann B, Knechtle P, Rosemann T. What influences race performance in male open-water ultra-endurance swimmers: anthropometry or training? *Human Mov* 2010;11:91-5.
28. Knechtle B, Knechtle P, Rosemann T, Lepers R. Is body fat a predictor of race time in female long-distance inline skaters? *Asian J Sports Med* 2010;1:131-6.
29. Gulbin JP, Gaffney PT. Ultraendurance triathlon participation: typical race preparation of lower level triathlets. *J Sports Med Phys Fitness* 1999;39:12-5.
30. Tolfrey K, Hansen SA, Dutton K, et al. Physiological correlates of 2-mile run performance as determined using a novel on-demand treadmill. *Appl Physiol Nutr Metab* 2009;34:763-72.
31. Atkinson G, Taylor CE, Morgan N, et al. Pre-race dietary carbohydrate intake can independently influence sub-elite marathon running performance. *Int J Sports Med* 2011;32:611-7.

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