Running performance, not anthropometric factors, is associated with race success in a Triple Iron Triathlon

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Running performance, not anthropometric factors, is associated with race success in a Triple Iron Triathlon

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ABSTRACT

Objectives: To investigate the influence of anthropometric parameters on race performance in ultra-endurance triathletes.

Design: Descriptive field study.

Setting: The Triple Iron Triathlon Germany 2006 in Lensahn over 11.6 km swimming, 540 km cycling and 126.6 km running.

Subjects: 17 male Caucasian triathletes (mean (SD) 39.2 (7.5) years, 80.7 (8.9) kg, 178 (5) cm, BMI 25.4 (2.4) kg/m^2).

Interventions: None.

Main outcome measurements: Determination of body mass, body height, skin fold thicknesses, circumferences of extremities, as well as calculation of body mass index (BMI), skeletal muscle mass (SM), per cent SM (%SM) and per cent body fat (%BF) in order to correlate measured and calculated anthropometric parameters with race performance.

Results: Body mass, body height, skin fold thicknesses, circumferences of extremities, BMI, %SM and %BF had no effect ($p>0.05$) on race performance. No significant correlation ($p>0.05$) was observed between total race time and any of the directly measured and calculated anthropometric properties. A significant correlation ($p<0.05$) was observed between total race time and both running time ($r^2 = 0.87$) and cycling time ($r^2 = 0.62$). In contrast, no significant correlation ($p>0.05$) was shown between swimming time and total race time.

Conclusions: There is no significant association between anthropometric parameters and race performance in ultra-endurance triathletes. Running performance rather than cycling performance seems to be the most important factor in order to be successful in a Triple Iron Triathlon. Swimming performance seems to be of low importance.

In endurance performance, an abundant variety of different factors influencing performance have been found. Apart from physiological parameters, numerous anthropometric parameters show an effect on endurance performances in runners and triathletes, such as body mass,[1 2] body mass index,[3] body fat,[3] length of the upper leg,[4] length of limbs,[5] body height,[1 6] circumference of the thigh,[4] total skin fold[1] and skin fold thickness of the lower limb.[7 8] Anthropometric properties and exercise performance during short and middle-distance running, marathons and triathlons over an Ironman distance have been previously investigated,[2 7 8] but data from ultra-distance performances is rare. In this current investigation, the anthropometric data of 17 successful finishers of the Triple Iron Triathlon Germany 2006 over 11.4 km swimming, 540 km cycling and 126.6 km running were analysed in respect of their association with race performance. We expected that a low BMI would have an effect on race performance. Furthermore, we assumed that a high percentage of body fat may impair race performance. The aim of the current study was to explore the anthropometric factors that are predominantly responsible for race success during an ultra-triathlon over the three times Ironman distance.

SUBJECTS AND METHODS

Subjects

All participants of the Triple Iron Triathlon Germany 2006 in Lensahn, Schleswig-Holstein, Germany, were contacted by a separate newsletter from the organiser 3 months before the race, and asked to participate in our investigation. Twenty-nine Caucasian triathletes (one woman, 28 men) intended to start. Twenty-five athletes (one woman, 24 men) entered the race; the only woman and 21 men finished the race successfully within the time limit. Twenty-two male athletes entered our study. They all gave their informed written consent. From these subjects, 17 male triathletes (mean (SD) age 39.2 (7.5) years, body mass 80.7 (8.9) kg, body height 178 (5) cm, BMI 25.4 (2.4) kg/m^2) finished the race successfully within the time limit whereas five athletes (mean (SD) age 41.8 (12.2) years, body mass 85.8 (9.1) kg, body height 179 (3) cm, BMI 26.7 (3.0) kg/m^2) had to give up due to medical reasons. The successful finishers trained 18.9 (7.4) (6 to 33) hours per week in the preparation for this race and could show an average experience of 18 (2 to 55) finished ultra-endurance races of 24 h and more before the start.

The race

From 28 July to 30 July 2006, the 15th edition of the Triple Iron Triathlon Germany 2006 in Lensahn, Schleswig-Holstein, Germany, took place over 11.6 km swimming, 540 km cycling and 126.6 km running. On Thursday 28 July, at 07:00 am, the race started. The swimming was in a heated outdoor pool of 50 m with a constant temperature of 25° Celsius and wet suits were allowed. After passing the transition area, athletes had to cycle 67 laps of a hilly course of 8 km in the surroundings of the town. After cycling, they had to change to the run course of 96 laps of 1.31 flat km in the town of Lensahn. The cycling was nearly free of road traffic and the running course was completely free of traffic and illuminated during the night. All athletes had their own support crew for nutrition and changes of equipment. The athletes had to arrive at the finish line within 58 h. The weather on the first day was cloudy and no rain was falling, with a maximal temperature of 28° Celsius. In the first night toward the sunrise, cold and rain appeared. The second day was initially cloudy, then in the afternoon the sun appeared and the temperature rose to maximally 28° Celsius.

Measurements and calculations

In the evening before the start, body mass, circumference of upper arm, thigh and calf as well as skin fold thickness at eight regions were measured. Body mass was measured with a commercial scale (Beurer BF 15, Beurer GmbH, Ulm, Germany) to the nearest 0.1 kg. Circumference of the upper arm and calf was measured at the largest circumference of the limb; circumference at the thigh was determined 20 cm above the upper pole of the patella.

All circumferences were measured to the nearest 0.1 cm. Skin fold thicknesses of chest, midaxillary (vertical), triceps, subscapular, abdominal (vertical), suprailiac (at anterior axillary), thigh and calf were measured with a skin fold calliper (GPM-Hautfaltenmessgerät, Siber & Hegner, Zurich, Switzerland) to the nearest 0.2 cm. Skin fold thicknesses and circumferences of the extremities were measured on the right side of the body, according to Lee *et al*.[9] Every measurement was taken by the same person, three times, and then the mean value was used for calculation. Skeletal muscle mass (SM) was calculated using the following formula: $SM = Ht \times (0.00744 \times CAG^2 + 0.00088 \times CTG^2 + 0.00441 \times CCG^2) + 2.4 \times sex - 0.048 \times age + race + 7.8$, where Ht = height, CAG = skin fold-corrected upper arm girth, CTG = skin fold-corrected thigh girth, CCG = skin fold-corrected calf girth, sex = 1 for male, race = 0 for white, according to Lee *et al*.[9] Per cent skeletal muscle mass (%SM) was achieved by dividing SM by BM and multiplying by 100%. Per cent of body fat (%BF) was calculated using the following formula: $\%BF = 0.465 + 0.180(\Sigma 7SF) - 0.0002406(\Sigma 7SF)^2 + 0.0661(age)$, where Σ7SF = sum of skin fold thickness of chest, midaxillary, triceps, subscapular, abdomen, suprailiac and thigh mean, according to Ball *et al*.[10] Fat mass was calculated from body mass and %BF.

Statistical analysis

Directly measured (body mass, height, skin fold thicknesses, limb circumferences) and calculated (BMI, %BF, %SM) anthropometric parameters were correlated with total race times as well as with the race time of the single disciplines. Statistical analysis was performed with the R software package.[11] Spearman's rank correlation analysis was used to look for the relevant factors of running time. A rank-based test was used as not all parameters are normally distributed. No regression analysis was used, as the aim of the current study was to explore the performance-relevant anthropometric properties rather than to predict athletes' performance in future competitions. The tested factors are the directly measured anthropometric properties, the calculated anthropometric properties, and the competition times of the single disciplines. Furthermore, anthropometric differences between finishers ($n = 17$) and non-finishers ($n = 5$) were compared with the Mann–Whitney test. No correction for multiple statistical comparisons was used because our study had to be an exploratory investigation and not one in which specific hypotheses were tested on the basis of pre-existing data.

RESULTS

Table 1 shows the anthropometric data of the successful finishers before the race.

No significant ($p > 0.05$) differences of anthropometric parameters were observed between finishers and non-finishers. The winner finished the race in 34:33:54 h:min:s; the last official finisher arrived after 54:24:27 h:min:s at the finish line. The fastest time in swimming was 3:04:12 h:min:s, the fastest time in cycling 17:16:38 h:min:s and the fastest time in running 13:13:12 h:min:s. Race time is not significantly correlated ($p > 0.05$) with the directly measured anthropometric properties (body height, body mass and the skin fold-corrected limb circumferences) or the calculated anthropometric properties BMI, %BF, and %SM (table 1). The squared correlation coefficient between the race time and the anthropometric properties limb circumferences, BMI, per cent skeletal muscle mass and per cent fat mass is always lower than 0.03 with the exception of the suprailiacal skin fold. Figure 1 shows the correlation matrix of the split times for swimming, cycling and running. Race time is significantly correlated ($p < 0.05$) with running time ($r^2 = 0.87$) and cycling time ($r^2 = 0.62$). However, total race time is not significantly correlated ($p > 0.05$) with swimming time.

DISCUSSION

The main finding of our investigation is the fact that we cannot confirm any of the previously found anthropometric factors of runners and triathletes such as body mass,[1 2] body mass index,[3] body fat,[3] length of the upper leg,[4] length of limbs,[5] body height,[1 6] circumference of the thigh,[4] total skin fold[1] and skin fold thickness of the lower limb[7 8] in this study group of successful finishers in a Triple Iron Triathlon. But it seems that the performance in the running and cycling split are the most important factors to be successful in ultra-endurance triathlons whereas swimming performance seems to be of low importance.

Table 1 Anthropometric properties of the athletes before the start of the race and the square correlation coefficient with total competition time (t_{tot}) as well as with discipline time (t_{swim}, t_{cycle}, t_{run})

Parameter	Pre-race	r^2 t_{tot}	r^2 t_{swim}	r^2 t_{cycle}	r^2 t_{run}
Body mass (kg)	80.7 (8.9)	0.090	0.014	0.047	0.124
C upper arm (cm)	27.6 (1.9)	0.026	0.007	0.033	0.056
C thigh (cm)	53.0 (3.6)	0.027	0.063	0.003	0.028
C calf (cm)	36.7 (2.5)	0.060	0.001	0.031	0.021
SF pectoral (mm)	5.1 (1.6)	0.067	0.110	0.007	0.125
SF axillar (mm)	7.7 (2.4)	0.006	0.114	0.066	0.015
SF triceps (mm)	8.9 (3.8)	0.047	0.068	0.159	0.008
SF subscapular (mm)	10.1 (2.2)	0.002	0.205	0.159	0.021
SF abdominal (mm)	13.9 (6.4)	0.000	0.092	0.004	<0.000
SF suprailiacal (mm)	12.7 (6.0)	0.020	0.088	0.031	0.054
SF thigh (mm)	11.5 (3.7)	0.027	0.008	<0.000	0.018
SF calf (mm)	8.5 (2.2)	0.071	0.070	0.006	<0.000
BMI (kg/m²)	25.4 (2.4)	0.003	0.010	0.067	<0.000
Skeletal muscle mass (SM) (kg)	40.0 (3.8)	0.032	0.017	0.007	0.097
Per cent body fat (%BF) (%)	14.4 (3.2)	0.014	0.100	0.016	0.037

The parameters are grouped as directly measured properties (body mass, body height, average skin fold thickness, skin fold-corrected circumferences of extremities) and calculated properties (BMI, SM, %BF) as used for the multiple regression analysis.
BMI, body mass index; C, circumference; SF, skin fold thickness.
Values are given as mean (SD).

Anthropometric factors in triathletes and runners

In triathletes, other morphological factors seem to be of importance compared with the above mentioned parameters. Landers *et al* found that robustness, adiposity, segmental length of limbs and skeletal muscle mass are of importance.[5] But also, in triathletes, an influence of body fat on race performance is known. In recent studies, successful elite triathletes are described as tall, of average-to-light weight and with low levels of body fat.[12] In an Ironman triathlon, starting body weight is significantly related to total finishing time and also to cycling and running time.[2] O'Toole *et al* concluded from their study that male triathletes are similar to cyclists.[13] They compared triathletes with swimmers, cyclists and runners. A comparison of height, weight, and per cent body fat of these triathletes with elite swimmers, cyclists and runners showed the physique of triathletes to be most similar to that of cyclists. But comparing the highest oxygen uptake attained at maximal exercise in any one of the three exercise modes, male triathletes were comparable to swimmers, but had a lower aerobic capacity than cyclists or distance runners.

Looking at our results (fig 1) with ultra-endurance triathletes, running performance has a higher impact on total race performance than cycling performance. Swimming performance seems to have no effect on total race performance in a triathlon, as already shown by Dengel *et al*.[14] They showed, in a triathlon over a 1.2 mile swim, 56 mile cycle and 13.1 mile run, that swimming time is not related to overall triathlon time. Ultra-endurance triathletes seem to be nearer to ultra-runners than to cyclists or swimmers. As shown in fig 1, running time has the most important impact on total race time before cycling and swimming time. Interestingly, swimming required 8.6 (SD 1.4)% of total race time, cycling 48.5 (2.7)% and running 43.6 (3.7)%. Although running performance has a higher impact on total race performance than cycling, athletes expend more time on cycling than on running during the race.

Individual cycling times varied from 1036 to 1527 min (variation coefficient 11.1%) with an average of 1339 (148) min, and running time varied from 792 to 1682 min (variation coefficient 18.4%) with an average of 1215 (224) min. Swimming variation coefficient was 12.5%; variation coefficient of total race time was 11.7%. There must be larger individual differences in running than in cycling, probably related to fatigue and exhaustion during the run. We presume that those athletes who were better prepared for running were able to make the difference in the running section. When an athlete cycles on flat ground, air resistance is dominating and is approximately proportional to the square of speed. In running, power (energy expenditure) is, rather, linearly proportional to speed. From this biomechanical point of view it is obvious that running should also have more impact on race time than cycling if time requirements for both disciplines are equal.

Also, for a short-distance triathlon, the only significant predictor of overall triathlon race time is velocity in running at ventilatory threshold.[15] Millet *et al* demonstrated that over short distances triathletes have a faster swim time but could not exhibit different maximal or submaximal characteristics in cycling and running compared with long-distance triathletes.[16] In triathletes, there is no ideal or unique anthropometric profile

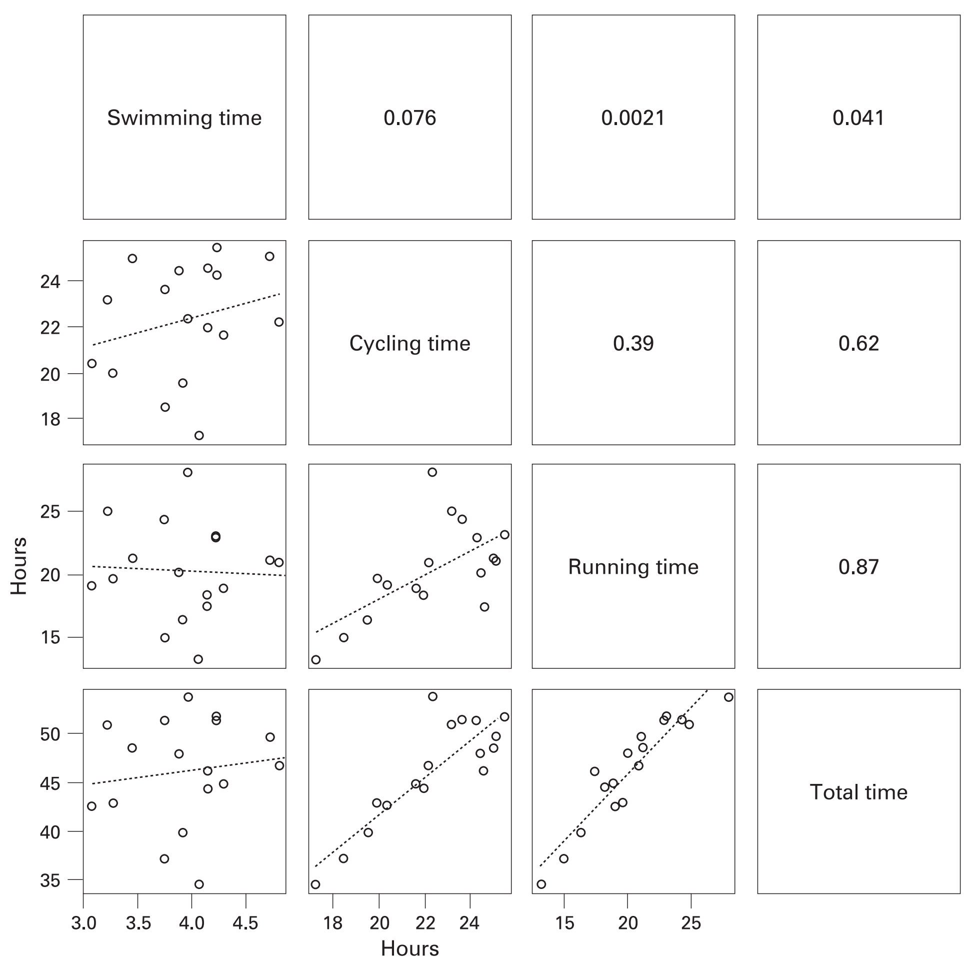

Figure 1 The correlation matrix of the split times and total race time is shown. In the upper panels the squared correlation coefficients are shown. The best correlation is shown between running time and total competition time. The lowest correlation is shown between swimming time and running time.

with respect to performance,[17] and training parameters seem to be of more importance than anthropometric measures in the prediction of race performance.[1 18] For runners, other factors are also discussed. In middle and long-distance runners, the length of the upper leg and thigh girth are related to performance[4] and in marathon runners different physiological parameters can explain the variance in marathon times amongst elite runners.[19] In marathon finishers, the longest mileage covered per training session is the best predictor for a successful completion of a marathon[20] and total training spent at low intensities seems to be associated with improved performance during highly intense events.[21] But an upper limit exists in training volume, above which there are no more improvements.[22]

Body mass, body mass index and running performance

From the above mentioned anthropometric parameters, the effects of body mass and BMI on performance have been investigated in several studies, especially in runners. The positive effect of BMI on performance is known in African endurance athletes. African runners are smaller[23 24] and less heavy than Caucasian runners.[23 25] The BMI of African runners is lower than in Caucasian runners. Kenyan runners have a BMI of 19.2 kg/m^2 compared with 20.6 kg/m^2 for the best Scandinavian runners[26] and Eritrean runners have a BMI of 18.9 kg/m^2 in contrast to 20.5 kg/m^2 for elite Spanish runners.[27] In contrast to these studies, Coetzer *et al* found that the African athletes' smaller body mass had no effect on running performance over 5 km.[28] The superior distance running performance of the African athletes was associated with lower blood lactate concentrations during exercise. It is supposed that the lower BMI[29] and the smaller body size are of importance for the better performance of the African runners.[30] Marino *et al* were able to demonstrate in their study that the smaller body mass enables African runners to compete faster in a warm environment (35°C), because these runners seem to have a greater capacity for heat loss in hot environmental conditions.[30]

Apart from African runners, a relationship also exists in Caucasian female marathon runners between BMI and race performance. The marathon race times for these runners are positively correlated with BMI.[3] The absolute value of the BMI seems to be of importance. The BMI of our ultra-triathletes is higher than the BMI of Kenyan runners. Our triathletes have a BMI of 25.4 kg/m^2 (table 1), which is higher than that of young Kenyan runners with a BMI of 18.6 kg/m^2[31] or adult Kenyan runners with a BMI of 19.2 kg/m^2.[26] The lower limb is also different in African runners compared with Caucasian runners. When Senegalese and Italian runners are compared, African runners have longer and lighter legs[32] and Eritrean runners have a longer lower leg than Spanish athletes in long-distance running.[27] It is supposed that the lower BMI[31] and the smaller body size are of importance for the better performance of the African runners.[30]

Influence of body fat and skin fold thickness on performance in runners

It is known from several studies that body fat has an influence on performance in runners. An excess of subcutaneous adipose tissue increases body mass and requires an increased muscular effort and therefore an increased energy expenditure. In previous studies it has been shown that physical performance is negatively related to body fat and positively related to skeletal muscle mass.[33 34] This was confirmed in a recently published study.

The loss of body fat is specific to selected muscle groups used during training, and race performance is enhanced with decreased skin fold thickness at the lower limb.[8] Body fat seems to have a special influence in runners, especially in African runners. They have a thinner skin fold at the legs and arms,[25] suggesting a smaller mass of adipose subcutaneous tissue. In other studies, the influence of body fat on race performance is controversially discussed. Whilst Hagan *et al* found a positive correlation between marathon performance time and body fat[3] in female marathon runners, the percentage of body fat does not correlate with the finish time.[18] In several older studies, and again in recently published studies, the effect of skin fold thickness on running performance was investigated. In runners, decreased skin fold thicknesses in the lower limbs are described; this may be particularly useful in predicting running performance.[8] They found an association between the decrease in thigh skin fold thickness and improvement in performance, and in the study of Bale *et al* total skin fold, as well as other parameters such as type and frequency of training and the number of years running, were the best predictors of running performance and success at 10 000 m.[1] Arrese and Ostariz showed a high correlation between the thigh and calf skin fold and 1500 m as well as 10 000 m run time.[7]

There are two major differences in the studies of Bale *et al*,[1] Legaz and Eston[8] and Arrese and Ostariz[7] compared with our study. Firstly, in their studies, running performances of 10 000 m and shorter were investigated. In contrast, our ultra-triathletes had to run a total distance of 126.6 km. Secondly, the measured skin fold thicknesses of the lower limb seem to be different. Ultra-triathletes seem to have thicker skin folds (table 1) than runners over shorter distances. Our ultra-triathletes had a skin fold thickness of 11.5 (3.7) mm at the thigh and 8.5 (2.2) mm at the calf compared with 9.4 (4.2) mm at the thigh and 4.6 (1.3) mm in the calf of the runners in the study of Legaz and Eston.[8] Probably the average training volume of 18.9 (7.4) h per week of our ultra-triathletes is too low compared with classical marathon runners.[20 22] The length of the running race seems to be of importance for the correlation between skin fold thickness and race performance. Arrese and Ostariz were able to show that marathon runners have a lower sum of six skin folds than runners of distances up to 10 000 m.[7] They conclude that marathon runners undertake a higher training volume and that in marathon running fat metabolism prevails in training and competition. Interestingly, our ultra-triathletes have, with 65.5 mm (table 1), a clearly higher sum of six skin folds than the marathon runners of Arrese and Ostariz with 44.4 mm. The value of 65.5 mm for our triathletes is near the value of 61.7 mm for the 3000 m runners of Arrese and Ostariz.[7]

What is already known on this topic

In the Ironman triathlon, starting body weight is significantly related to total finishing time and also to cycling and running time.

What this study adds

In the Triple Iron triathlon, anthropometric parameters show no association with race performance, but running performance is associated with race success.

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CONCLUSION

In an ultra-triathlon over 11.6 km swimming, 540 km cycling and 126.6 km running, there is no association between the anthropometric parameters body mass, body height, skin fold thickness, circumference of extremities, %SM and %BF with total race time and split times for swimming, cycling and running. It seems that running performance is the most important factor, followed by cycling performance, in order to be successful in an ultra-endurance triathlon over three times the Ironman distance. Swimming performance seems to be of low importance. Triathletes may have a higher variability in body anthropometry than other endurance athletes because they have to train and perform in three different disciplines. We would welcome studies about the influence of anthropometry on endurance and race performance with triathletes, especially over the Ironman distance.

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REFERENCES

1. **Bale P,** Bradbury D, Colley E. Anthropometric and training variables related to 10 km running performance. *Br J Sports Med* 1986;**20**:170–3.
2. **Sharwood K,** Collins M, Goedecke J, *et al*. Weight changes, sodium levels, and performance in the South African Ironman triathlon. *Clin J Sport Med* 2002;**12**:391–9.
3. **Hagan RD,** Upton SJ, Duncan JJ, *et al*. Marathon performance in relation to maximal aerobic power and training indices in female distance runners. *Br J Sports Med* 1987;**21**:3–7.
4. **Tanaka K,** Matsuura Y. A multivariate analysis of the role of certain anthropometric and physiological attributes in distance running. *Ann Hum Biol* 1982;**9**:473–82.
5. **Landers GJ,** Blanksby BA, Ackland TR, *et al*. Morphology and performance of world championship triathletes. *Ann Hum Biol* 2000;**27**:387–400.
6. **Maldonado S,** Mujika I, Padilla S. Influence of body mass and height on the energy cost of running in highly trained middle- and long-distance runners. *Int J Sports Med* 2002;**23**:268–72.
7. **Arrese AL,** Ostariz ES. Skinfold thicknesses associated with distance running performance in highly trained runners. *J Sports Sci* 2006;**24**:69–76.
8. **Legaz A,** Eston R. Changes in performance, skin fold thicknesses, and fat patterning after three years of intense athletic conditioning in high level runners. *Br J Sports Med* 2005;**39**:851–6.
9. **Lee RC,** Wang Z, Heo M, *et al*. Total-body skeletal muscle mass: development and cross-validation of anthropometric prediction models. *Am J Clin Nutr* 2000;**72**:796–803.
10. **Ball SD,** Altena TS, Swan PD. Comparison of anthropometry to DXA: a new prediction equation for men. *Eur J Clin Nutr* 2004;**58**:1525–31.
11. **R Development Core Team (2005)**. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.
12. **Sleivert GG,** Rowlands DS. Physical and physiological factors associated with success in the triathlon. *Sports Med* 1996;**22**:8–18.
13. **O'Toole ML,** Hiller WDB, Crosby LO, *et al*. The ultraendurance triathlete: a physiological profile. *Med Sci Sports Exerc* 1987;**19**:45–50.
14. **Dengel DR,** Flynn MG, Costill DL, *et al*. Determinants of success during triathlon competition. *Res Q Exerc Sport* 1989;**60**:234–8.
15. **Sleivert GG,** Wenger HA. Physiological predictors of short-course triathlon performance. *Med Sci Sports Exerc* 1993;**25**:871–6.
16. **Millet GP,** Dreano P, Bentley DJ. Physiological characteristics of elite short- and long-distance triathletes. *Eur J Appl Physiol* 2003;**88**:427–30.
17. **Laurenson NM,** Fulcher KY, Korkia P. Physiological characteristics of elite and club level female triathletes during running. *Int J Sports Med* 1993;**14**:455–9.
18. **Christensen CL,** Ruhling RO. Physical characteristics of novice and experienced women marathon runners. *Br J Sports Med* 1983;**17**:166–71.
19. **Legaz Arrese A,** Manguia Izquierdo D, Serveto Galindo JR. Physiological measures associated with marathon running performance in high-level male and female homogeneous groups. *Int J Sports Med* 2006;**27**:289–95.
20. **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.
21. **Esteve-Lanao J,** San Juan AF, Earnest CP, *et al*. How do endurance runners actually train? Relationship with competition performance. *Med Sci Sports Exerc* 2005;**37**:496–504.
22. **Sjödin B,** Svedenhag J. Applied physiology of marathon running. *Sports Med* 1985;**2**:83–99.
23. **Weston AR,** Karamizrak O, Smith A, *et al*. African runners exhibit greater fatigue resistance, lower lactate accumulation, and higher oxidative enzyme activity. *J Appl Physiol* 1999;**86**:915–23.
24. **Weston AR,** Mbambo Z, Myburgh KH. Running economy in African and Caucasian distance runners. *Med Sci Sports Exerc* 2000;**32**:1130–4.
25. **Bosch AN,** Goslin BR, Noakes TD, *et al*. Physiological differences between black and white runners during a treadmill marathon. *Eur J Appl Physiol* 1990;**61**:68–72.
26. **Saltin B,** Larsen H, Terrados N, *et al*. Aerobic exercise capacity at sea level and at altitude in Kenyan boys, junior and senior runners compared with Scandinavian runners. *Scand J Med Sci Sports* 1995;**5**:209–21.
27. **Lucia A,** Esteve-Lanao J, Olivan J, *et al*. Physiological characteristics of the best Eritrean runners – exceptional running economy. *Appl Physiol Nutr Metab* 2006;**31**:530–40.
28. **Coetzer P,** Noakes TD, Sanders B, *et al*. Superior fatigue resistance of elite black South African distance runners. *J Appl Physiol* 1993;**75**:1822–7.
29. **Larsen HB.** Kenyan dominance in distance running. *Comp Biochem Physiol A Mol Integr Physiol* 2003;**136**:161–70.
30. **Marino FE,** Lambert MI, Noakes TD. Superior performance of African runners in warm humid but not in cool environmental conditions. *J Appl Physiol* 2004;**96**:124–30.
31. **Larsen HB,** Christensen DL, Nolan T, *et al*. Body dimensions, exercise capacity and physical capacity level of adolescent Nandi boys in western Kenya. *Ann Hum Biol* 2004;**31**:159–73.
32. **Rahmani A,** Locatelli E, Lacour JR. Differences in morphology and force/velocity relationship between Senegalese and Italian sprinters. *Eur J Appl Physiol* 2004;**91**:399–405.
33. **Leedy HE,** Ismail AH, Kessler WV, *et al*. Relationships between physical performance items and body composition. *Res Q Exerc Sport* 1965;**36**:158–63.
34. **Riedenau RP,** Welch BE, Crips CE, *et al*. Relationship of body fat to motor fitness test scores. *Res Q Exerc Sport* 1968;**29**:200–3.