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SIMILARITY OF ANTHROPOMETRIC MEASURES FOR MALE ULTRA-TRIATHLETES AND ULTRA-RUNNERS[1, 2]

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Summary.—Previous research concluded that Triple Iron ultra-triathletes were close to runners in anthropometry. We assessed similarities in anthropometry between 64 Triple Iron triathletes who competed over 11.4 km swimming, 540 km cycling, and 126 km running versus 95 100-km ultra-marathoners. Variables of anthropometry such as body mass, body height, length and circumferences of limbs, skin-folds and body fat, and training such as volume and speed were compared between ultra-triathletes and ultra-runners. The Triple Iron triathletes completed their race distance within 2,811 min. ($SD = 379$) and the 100-km ultra-marathoners within 691 min. ($SD = 117$). Triathletes were younger, had higher body mass, shorter legs, higher circumference of upper arm and thigh, lower sum of skin-folds, and lower percent body fat compared to runners. Weekly training volume was higher for triathletes, and weekly hours in running and weekly kilometres in running were higher for runners. In the Triple Iron ultra-triathletes, the sum of eight skin-folds correlated to total race time. The circumference of upper arm, the sum of eight skin-folds, and percent body fat correlated with time in the running section .42, .47, and .43, respectively. In the 100-km ultra-marathoners, the sum of eight skin-folds, the skin-fold thickness of thigh, percent body fat, weekly running hours, and weekly running kilometres correlated with race time .55, .40, .56, −.50, and −.51, respectively. However, in the triathletes, none of these training variables was significantly correlated with race time. In the ultra-marathoners, the sum of eight skin-folds, the skin-fold thickness of thigh, percent body fat, weekly running kilometres, and speed in running during training were related to race time (correlations of .55, .40, −.28, and −.51, respectively). Overall, the ultra-triathletes were not similar to ultra-runners in their anthropometric measures and training variables.

Ironman triathlons are ultra-endurance races in which athletes must swim 3.8 km, cycle 180 km, and run 42.195 km. These races are of increasing popularity since the number of participants to qualify for the Ironman

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Hawaii is growing (Lepers, 2008). Apart from the Ironman distance, there are longer triathlons such as the Triple Iron triathlon in which athletes have to complete three times the distance of an Ironman triathlon with 11.4 km swimming, 540 km cycling, and 126.6 km running. For more than 20 years, a growing number of athletes have been racing in these competitions (Knechtle, Duff, Amtmann, & Kohler, 2007; Knechtle, Knechtle, & Rosemann, 2009; Knechtle & Kohler, 2009; Knechtle, Knechtle, Rosemann, & Senn, 2010).

Only a few studies using small samples have been published about Triple Iron ultra-triathletes because seldom do more than 30 to 40 athletes participate in and finish such a challenging race (Knechtle, Duff, Amtmann, *et al.*, 2007; Knechtle, Knechtle, *et al.*, 2009; Knechtle & Kohler, 2009; Knechtle, Knechtle, Rosemann, *et al.*, 2010). In the last 25 years, the number of finishers per year increased from seven to 41 (Knechtle, Knechtle, & Lepers, 2010). In a recent study of 29 Triple Iron ultra-triathletes, the authors concluded these ultra-endurance athletes were close to runners in the relationship between their anthropometry and race performance (Knechtle, Knechtle, *et al.*, 2009). For example, in samples of both, the sum of eight skin-folds was related to total race time and speed in the run section. This finding has been supported by two studies in which Triple Iron ultra-triathletes' running performance was related to their total race time (Knechtle, Duff, Amtmann, *et al.*, 2007; Knechtle & Kohler, 2009).

Analyses of the association between anthropometric measures and performance of runners have found several different anthropometric variables to be correlated to endurance-running performance, such as body mass (Bale, Bradbury, & Colley, 1986; Knechtle, Duff, Welzel, & Kohler, 2009), body height (Bale, *et al.*, 1986; Maldonado, Mujika, & Padilla, 2002; Loftin, Sothern, Koss, Tuuri, Vanvrancken, Kontos, *et al.*, 2007), body fat (Hagan, Upton, Duncan, & Gettman, 1987), total skin-fold thickness (Bale, *et al.*, 1986), skin-fold thicknesses of the lower limb such as the thigh and calf skin-fold (Arrese & Ostáriz, 2006; Knechtle & Rosemann, 2009), the length of leg (Tanaka & Matsuura, 1982; Larsen, Christensen, Nolan, & Søndergaard, 2004), and the circumferences of limbs such as thigh, calf, and upper arm (Lucia, Esteve-Lanao, Oliván, Gómez-Gallego, San Juan, Santiago, *et al.*, 2006; Knechtle, Knechtle, Schulze, & Kohler, 2008; Knechtle, Duff, Welzel, & Kohler, 2009).

As would be expected, characteristics of training such as volume and intensity of training also are associated with performance in runners up to marathon distance. Scrimgeour, Noakes, Adams, and Myburgh (1986) found that runners training for more than 100 km per week have significantly faster race times over 10 to 90 km than athletes covering less than 100 km. Bale, *et al.* (1986) reported for 60 male runners that elite runners with a higher training frequency, higher weekly training volume, and longer running experience had better 10-km performance. Considering the training volume of triathletes, Ironman triathletes typically complete around 9 km swimming, 270 km cycling, and 58 km running per week (Gulbin & Gaffney, 1999). Interestingly, Triple Iron ultra-triathletes train similarly, completing around 8.5 km swimming, 250 km cycling, and 60 km running per week (Knechtle, Knechtle, Rosemann, *et al.*, 2010).

Intensity in running is also of importance. Billat, Demarle, Slawinski, Paiva, and Koralsztein (2001) reported top class marathon runners trained for more total kilometres per week and at a higher velocity than runners performing at a lower level. When training of runners was analysed in detail, several parameters such as number of workout days, total number of workouts, total kilometres, mean kilometres per workout, longest mileage covered per training session, total training minutes, maximum kilometres of running per week, mean kilometres per week, and mean kilometres per day, were associated with faster marathon times (Hagan, Smith, & Gettman, 1981; Hagan, *et al.*, 1987; Yeung, Yeung, & Wong, 2001).

Based on these findings, specific associations between training and pre-race anthropometry in these two kinds of ultra-endurance athletes would be expected. Training of specific muscle groups such as lower body for runners and upper body for swimmers may lead to muscle hypertrophy and a difference in limb circumferences. Ultra-runners, who strictly use their legs and not their arms during training, may show lower relations between their upper arm circumference and their race time than triathletes do, who train swimming and use their upper body in one of their three race disciplines. The ultra-runners may therefore show an association between their upper leg circumference and their race time. Since triathletes have two of their three disciplines where the body is supported (by water, by a bike), they may have higher body fat than ultra runners, whose bodies are never supported except by their legs. However, these potential relationships may be washed out in Triple Iron triathletes due to the long race distances.

In the present investigation, anthropometric measures and training of Triple Iron ultra-triathletes were compared with those for 100-km ultra-runners, based on the suggestion that Triple Iron ultra-triathletes and ultra-runners would have similarities in anthropometry (Knechtle, Knechtle, *et al.*, 2009). It was hypothesized that anthropometric measures and performance of runners, measures of body mass, body height, body fat, total skin-fold thickness, skin-fold thickness of the lower limb such as thigh and calf skin-fold, length of leg, and circumferences of limbs such as thigh, calf, and upper arm circumference would not differ for male Triple Iron ultra-triathletes and male ultra-runners. Further, these variables would be associated with race performance by both groups of athletes and training for running should not differ between ultra-triathletes and ultra-runners.

Method

Participants

To increase the sample size, data were collected from the same race course for two consecutive years from Triple Iron ultra-triathletes in the Triple Ultra-Triathlon Lensahn in Germany in 2007 and 2008, and for three consecutive years from ultra-runners at the 100-km Lauf Biel in Switzerland from 2007 to 2009. All entrants in these races were contacted via a separate newsletter from the organizer at the time they signed up for the race and informed about the investigation. Since women account for only 8 to 10% of the ultra-triathlon starters (Knechtle, Knechtle, & Lepers, 2010), we restricted the sample to male athletes. The athletes were informed of the procedures and gave their informed consent prior to the investigation, which had been approved by the Institutional Review Board for use of Human Subjects of St. Gallen, Switzerland. In the Triple Ultra-Triathlon Lensahn, a total of 88 male athletes started in these two races, 74 participated in the investigation, and 64 finished the race successfully. In the 100-km Lauf Biel, about 2,000 male athletes participated each year; a total of 101 volunteered to participate in this investigation, and 95 completed the run within the time limit. For those athletes who competed in the same races for several years, we only included their first participation in order to avoid multiple participation of the same athlete. No athlete competed in both races. Age, anthropometric measures, and training for both the triathletes and runners are presented in Table 1.

The Races

From 27 to 29 July 2007 and 25 to 27 July 2008, the Triple Ultra-Triathlon Lensahn was held in Lensahn, Schleswig-Holstein, Germany. The race covered a total distance of 11.6 km swimming, 540 km cycling, and 126.6 km running. The 100-km Lauf Biel in Biel, Berne, Switzerland, takes place every year during the night from Friday to Saturday of the first weekend in June.

Measurements and Calculations

Before the start of the race, body mass, body height, the thickness of eight skin-folds (pectoralis, axillar, triceps, subscapular, abdomen, suprailiac, thigh, and calf), percent body fat, the length of the right leg, and the circumferences of limbs (upper arm, thigh, and calf) were measured. Body mass (kg) was assessed using a commercial scale (Beurer BF 15, Beurer, Ulm Germany) to the nearest 0.1 kg. Body height (m) was measured using a stadiometer to the nearest 1.0 cm. Percent body fat (%) was calculated using the following anthropometric formula where percent body fat $= 0.465 + 0.180(\Sigma 7SF) - 0.0002406(\Sigma 7SF)^2 + 0.0661(\text{age})$ and $\Sigma 7SF$ = sum of skin-fold thickness of pectoralis, axillar, triceps, subscapular, abdomen, suprailiac, and thigh mean, according to Ball, Altena, and Swan (2004). This formula

TABLE 1

MEANS AND STANDARD DEVIATIONS FOR AGE AND ANTHROPOMETRIC AND TRAINING VARIABLES OF TRIPLE IRON ULTRA-TRIATHLETES AND 100-KM ULTRA-RUNNERS

Variable	Triple Iron Ultra-triathletes ($n=64$)		100-km Ultra-runners ($n=95$)	
	M	*SD*	*M*	*SD*
Age, yr.	39.8*	8.3	44.5	9.9
Body mass, kg	77.8*	8.2	74.3	9.1
Body height, m	1.78	0.06	1.78	0.06
Length of right leg, cm	85.5*	3.3	86.9	4.0
Circumference of right upper arm, cm	30.5*	2.2	29.5	2.3
Circumference of right thigh, cm	55.9*	3.6	54.5	3.1
Circumference of right calf, cm	39.0	2.4	38.5	2.4
Sum of eight skin-folds, mm	77.9*	24.8	85.5	32.7
Skin-fold thickness of thigh, mm	11.2	5.0	11.4	5.3
Skin-fold thickness of calf, mm	7.3	2.3	6.1	3.0
Percent body fat, %	14.5*	3.4	16.0	4.2
Weekly training volume, hr.	19.3*	8.8	7.2	2.8
Weekly hours of running in training	5.8*	2.1	7.2	2.8
Weekly kilometres of running in training	60.7*	21.6	73.2	28.6
Speed in run training, km/hr.	10.5	1.5	10.7	1.6
Weekly hours of swimming in training	3.1	1.8		
Weekly kilometres of swimming in training	8.4	4.5		
Speed in swim training, km/hr.	2.8	0.6		
Weekly hours of cycling in training	10.3	5.8		
Weekly kilometres of cycling in training	278	139		
Speed in cycle training, km/hr.	27.9	4.2		

*$p<.05$.

was evaluated using 160 men age 18 to 62 years and cross-validated using Dual Energy X-ray Absorptiometry (DXA). The mean differences between DXA percent body fat and the calculated percent body fat ranged from 3.0 to 3.2%. Correlations were significant ($p<.01$) and high ($r>.90$) for the anthropometric prediction equations with DXA. Skin-fold data were obtained using a skin-fold calliper (GPM-Hautfaltenmessgerät, Siber & Hegner, Zurich, Switzerland) and recorded to the nearest 0.2 mm. The skin-fold measurements were taken once for the entire eight skin-folds and then were repeated twice more by the same investigator; the mean of the three times was then used for the analyses. The timing of the taking of the skin-fold measurements was standardised to ensure reliability. According to Becque, Katch, and Moffatt (1986), readings were performed 4 sec. after applying the calliper. One trained investigator took all the skin-fold measurements as intertester variability is a major source of error in skin-fold measurements. An intratester reliability check was conducted on 27 male and 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 > .90; Knechtle, Joleska, Wirth, Knechtle, Rosemann, & Senn, 2010).

Circumferences of limbs and length of the right leg were measured using a nonelastic tape measure (cm; KaWe CE, Kirchner und Welhelm, Germany). Circumference of the upper arm was measured in the middle of the right upper arm (between *acromion* and *olecranon*) to the nearest 0.1 cm; circumference of the front thigh at the same point at which skin-fold thickness of the right thigh was measured (20 cm above the upper margin of the patella), and circumference of the calf at the maximum circumference of the right calf. The length of the right leg was measured between *trochanter major* and *malleolus lateralis*.

From the time of entering the race the athletes were instructed to keep a comprehensive training diary recording their training units to show the distance (km), duration (hr.), and speed (km/hr.) for each training session up to the start of the race. The Triple Iron ultra-triathletes also recorded these measures for running, swimming, and cycling training sessions. The mean duration of the diaries was about 3 mo.

Statistical Analyses

The Shapiro-Wilks test was used to check normality of distributions. Data are presented as mean and standard deviation. Race time was also expressed as a percent of the World records for both the Triple Iron ultra-triathletes and the 100-km ultra-runners in order to better compare performances between the different disciplines and race times. Since the course in Biel was not flat, race time for the 100-km ultra-runners was also expressed as a percent of the course record. The athletes were categorised as two groups (Triple Iron ultra-triathletes and 100-km ultra-runners). The variables of anthropometry and training were compared between these two groups using the Mann-Whitney U-test. Pearson correlations for race time with both anthropometric and training variables were calculated. Given the multiple tests, Bonferroni correction was applied for $n = 21$ variables ($p < .003$).

Results

The Triple Iron ultra-triathletes finished the 11.6-km swim, 540-km bike, and 126.6-km run within 47:19 hr.:min. or 2,811 min. ($SD = 397$), respectively. This equalled 147% ($SD = 19$) of the World record of 31:47 hr:min., held by Luis Wildpanner (Triple Iron Lensahn, 2003). Time in the swim section was related to total race time ($r = .27$, $p = .033$); times in the bike section ($r = .84$, $p < .0001$) and run section ($r = .93$, $p < .0001$) were also significantly associated with total race time. The 100-km ultra-runners completed the race within 11:39 hr.:min., 691 min. ($SD = 117$). This was equal to 185% ($SD = 31$) of the World record of 6:13 hr.:min. set by Takahiro Sunada (Lake Saroma, 1998) and 174% ($SD = 29$) of the course record of

6:37 hr.:min. held by Peter Camenzind (1996). The percentage of race time of the Triple Iron ultra-triathletes was significantly faster ($p < .001$) than performance expressed both as percent of the World record and percent of the course record for the 100-km ultra-runners.

Table 1 shows age, anthropometric measures, and training data for the two groups. The Triple Iron ultra-triathletes were significantly younger, had greater mean body mass, shorter legs, a larger mean circumference of upper arm and thigh, a lower sum of eight skin-folds, and a lower body-fat percent than the ultra-runners. Body mass and percent body fat were related in both the triathletes ($r = .40$, $p = .001$) and the runners ($r = .29$, $p = .005$). The Triple Iron ultra-triathletes were investing more total training hours per week than the 100-km ultra-runners. Ultra-runners, however, were investing more hours and kilometres in running during training than the ultra-triathletes. Running speed in training was not different between the two groups.

For the Triple Iron ultra-triathletes, the sum of eight skin-folds was related to total race time (see Table 2). The circumference of upper arm, the sum of eight skin-folds, and percent body fat were associated with time in the run section. None of the training variables correlated to race time. In

TABLE 2

Correlations of Anthropometric Measures and Training Variables For Ultra-Triathletes and Ultra-runners With Total Race Time and Split Times in the Sub-disciplines For Ultra-triathletes

Variable	Triple Iron Ultra-triathletes				100-km Ultra-runners
	Total Race Time	Time For Swim	Time For Bike	Time For Run	Total Race Time
Age	−.05	−.10	−.03	−.04	.15
Body mass	.26	−.03	.01	.35	.18
Body height	.10	−.02	−.11	.14	.07
Length of right leg	.12	−.06	−.07	.07	.09
Circumference of right upper arm	.31	−.12	.15	.42*	.25
Circumference of right thigh	.13	−.04	−.01	.18	.14
Circumference of right calf	.10	.05	.01	.21	−.07
Sum of eight skin-folds	.38*	.14	.30	.47*	.55*
Skin-fold thickness of thigh	.18	−.03	.11	.27	.40*
Skin-fold thickness of calf	.30	.27	.22	.34	.27
Percent body fat	.35	.11	.28	.43*	.56*
Training volume in hours per week	−.15	−.11	−.24	−.11	−.28
Hours of running per week in training	−.18			−.17	−.50*
Kilometres of running per week in training	−.21			−.19	−.51*
Speed in running during training	−.23			−.17	.15

*$p < .001$; Bonferroni corrected to $p < .003$ for 21 variables.

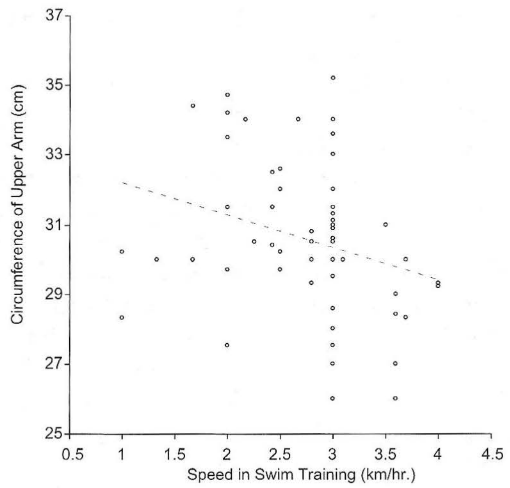

FIG. 1. Scatter plots for circumference of the upper arm versus speed in swim training for the 64 Triple Iron ultra-triathletes ($r=-.28$, $p=.024$; 95%$CI=-.49$, $-.04$)

the 100-km ultra-marathoners, the sum of eight skin-folds, the skin-fold thickness of thigh, percent body fat, weekly running in kilometres, and weekly running kilometres were associated with race time.

For the ultra-triathletes, the circumference of the upper arm was correlated with speed in swim training (cf. scatter plots in Fig. 1); the circumference of thigh was associated with speed in cycle training (cf. scatter plots in Fig. 2). Circumference of upper arm was significantly and posi-

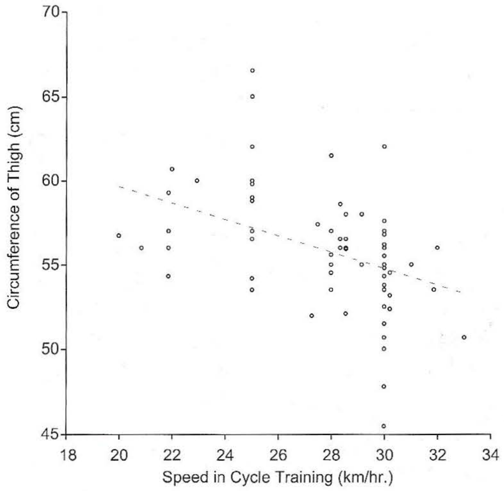

FIG. 2. Scatter plots for circumference of the thigh versus speed in cycle training for the 64 Triple Iron ultra-triathletes ($r=-.43$, $p=.0003$; 95%$CI=-.61$, $-.21$).

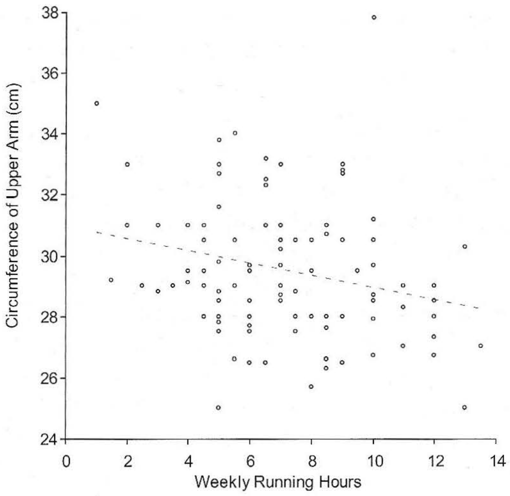

FIG. 3. Scatter plots for circumference of the upper arm versus weekly running hours in the 95 ultra-runners ($r=-.25$, $p=.02$; 95%$CI=-.43$, $-.05$)

tively related to both body mass ($r=.75$, $p<.0001$) and percent body fat ($r=.40$, $p=.0012$); circumference of thigh correlated also with both body mass ($r=.68$, $p<.0001$) and percent body fat ($r=.48$, $p<.0001$). For the ultra-runners, the circumference of upper arm was related to mean weekly running hours (cf. scatter plots in Fig. 3) and kilometres (cf. scatter plots in Fig. 4). Percent body fat was associated with speed in cycle training for the ultra-triathletes ($r=-.40$, $p=.0011$). In the ultra-runners, however, per-

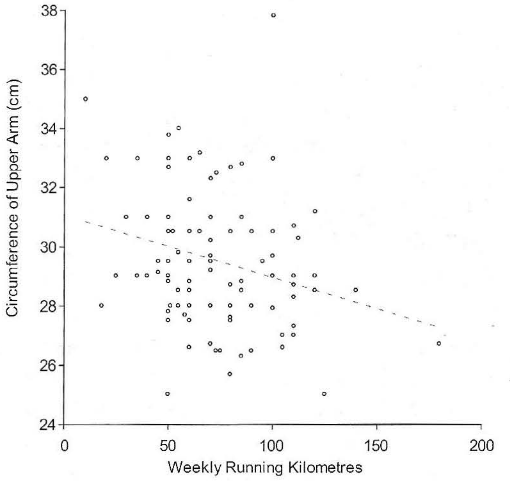

FIG. 4. Scatter plots for circumference of the upper arm versus weekly running kilometres in the 95 ultra-runners ($r=-.26$, $p=.01$; 95%$CI=-.44$, $-.06$)

cent body fat was related to running hours ($r = -.31$, $p = .003$), running kilometres ($r = -.40$, $p < .001$), and running speed in training ($r = -.43$, $p < .0001$).

Discussion

Ultra-runners train and compete in one single discipline and use only their legs. So running training may lead to muscle hypertrophy of the legs and therefore circumference of the upper leg may be related to race time. In contrast, ultra-triathletes need training and competing in three disciplines, where swimming may lead to muscle hypertrophy of the arms which may be associated with race time in the swim split.

Based on recent reports of association of anthropometric measures and performance of runners, it was hypothesized that body mass, body height, body fat, total skin-fold thickness, skin-fold thickness of the lower limb such as thigh and calf skin-fold, length of leg, and circumferences of limbs such as thigh, calf, and upper arm would show no differences between groups of Triple Iron ultra-triathletes and 100-km ultra-runners, and also that these variables would be positively related to total race time for both kinds of athletes. In contrast to this broad hypothesis, only body height, circumference of calf, and thigh and calf skin-fold thicknesses were not different for the two groups. Also, only the sum of eight skin-folds was associated with race time for both the two groups.

A possible explanation for these findings might lie in performance by the athletes. The first hypothesis was based upon recent findings for Triple Iron ultra-triathletes, i.e., the sum of eight skin-folds was associated with running speed in the run section (Knechtle, Knechtle, *et al.*, 2009), so the anthropometric measures were hypothesized to be similar to those of the ultra-runners. However, it is difficult to compare the performance of Triple Iron ultra-triathletes competing in three different skills over approximately 48 hr. with the performance of 100-km ultra-runners finishing their race in approximately 12 hr. However, when the individual race times were expressed as a percentage of the World record, the ultra-runners performed around 40% slower than the ultra-triathletes. One explanation could be the older age of the ultra-runners. However, age was not associated with race time for either group.

Association of Anthropometric Characteristics With Performance in Ultra-endurance Athletes

In several studies of runners, an association between both selected skin-fold thicknesses and the sum of skin-fold thicknesses and race performance was observed (Bale, *et al.*, 1986; Legaz & Eston, 2005; Legaz Arrese, González Badillo, & Serrano Ostáriz, 2005; Arrese & Ostáriz, 2006; Knechtle & Rosemann, 2009). In ultra-runners, however, no association of the sum of skin-fold thicknesses with race performance had been reported. For ultra-runners in multistage ultra-runs, the mean skin-fold thickness (Knechtle, Knechtle, Schulze, *et al.*, 2008) and the sum of skin-folds (Knechtle, Duff, Welzel, *et al.*, 2009) were not related to performance. A single skin-fold thickness such as the calf skin-fold was, however, related to race performance for multi-stage ultra-runners (Knechtle & Rosemann, 2009), as was also reported for runners over 10 km (Arrese & Ostáriz, 2006), for whom both the sum of eight skin-folds and thigh skin-fold thickness were related to race time.

Evidence suggests that ultra-triathletes are closer to ultra-cyclists than are ultra-runners on their anthropometric and training measures. A comparison of height, weight, and percent body fat of Ironman triathletes with the data of elite athletes from swimming, cycling, and running, suggested the typical physique of triathletes was most similar to that of cyclists rather than swimmers or runners (O'Toole, Hiller, Crosby, & Douglas, 1987). Further, the circumferences of upper arm and thigh were larger for the ultra-triathletes than for the ultra-runners and both circumferences were related to intensity of training in swimming and cycling, respectively. For the ultra-runners, their smaller upper arm circumference was related to running volume, but not to intensity of training.

Association of Limb Circumferences With Performance In Ultra-endurance Athletes

The circumference of the upper arm was related to split time in the run for the Triple Iron ultra-triathletes. In two studies of ultra-runners, upper arm circumference was related to performance (Knechtle, Knechtle, *et al.*, 2008; Knechtle, Duff, Welzel, *et al.*, 2009). Upper arm circumference was smaller for ultra-runners than for ultra-triathletes and there was a significant and positive association of the upper arm circumference with the split time in the run for the ultra-triathletes. However, upper arm circumference showed no association with total race time for both the ultra-triathletes and the ultra-runners. The distance of the run in a Triple Iron triathlon is 126.6 km. One may assume that circumference of upper arm is likely related to performance in running distances of more than 100 km (Knechtle, Knechtle, *et al.*, 2008; Knechtle, Duff, Welzel, *et al.*, 2009).

Another finding in the ultra-triathletes was that circumference of upper arm was significantly and negatively related to speed in swim training and circumference of thigh was significantly and negatively associated with speed in cycle training. Correlation analyses do not prove cause and effect, and the limb circumferences were not related to race time in the ultra-triathletes. Since circumferences of upper arm and thigh were higher in the ultra-triathletes than in the runners, the significant and negative association of limb circumferences with intensity and volume in training was probably not due to training but rather a specific anthropometric characteristic of these subjects since both upper arm and thigh circumferences were associated with both body mass and percent body fat. Lower limb circumferences might, however, enhance training at high intensity.

Association of Training Characteristics With Performance in Ultra-endurance Athletes

Although the sum of eight skin-folds was related to race time in both the Triple Iron ultra-triathletes and 100-km ultra-runners, training variables might also be important as previously described for runners (Hagan, *et al.*, 1981; Bale, *et al.*, 1986; Scrimgeour, *et al.*, 1986; Hagan, *et al.*, 1987; Billat, *et al.*, 2001; Yeung, *et al.*, 2001). In the Triple Iron ultra-triathletes, however, no variable of running training was related to race time, but both weekly running kilometres and weekly running hours were related to race time for the 100-km ultra-marathoners. We found a significant and positive association between percent body fat and speed in cycling training for ultra-triathletes, and running hours, running kilometres, and running speed in training for ultra-runners. One might assume that training leads to reduced body fat since Legaz and Eston (2005) could show that intense running training led to decreased skin-fold thickness. However, correlation analysis does not prove cause and effect and the reduced body fat could also be due to diet, and as an effect of the lower body fat with lower body mass, athletes were able to train faster. In Triple Iron triathletes, a certain amount of body fat seems to be essential. In such a race, body fat decreased highly significantly and the decrease in body fat was related to race time (Knechtle, Schwanke, Knechtle, & Kohler, 2008). Additional body fat may allow competing faster, it provides an energy reservoir, and buffers any lapses in nutrition and caloric intake, which can become absolutely critical during these extremely long and difficult endurance races.

Limitations

This investigation is limited in that many of the variables included in the analyses were contained in other variables, leading to multicollinearity. We tried to solve this problem by applying Bonferroni correction. Age was different in the two groups; however, age was not related to performance. In future studies, the groups should be matched by age. A further limitation is that athletes competing in three disciplines were compared to athletes performing in only one discipline. Furthermore, the race times were considerably longer for the ultra-triathletes than for the ultra-runners. We attempted to solve this problem by introducing a normalization, calculating race times as the percent performance of the World record. However, the ultra-runners were approximately 40% slower than the ultra-triathletes.

Conclusions

One may conclude the anthropometric measures of ultra-triathletes were not close to those of 100-km ultra-runners, although the Triple Iron ultra-triathletes have to run the distance of 126.6 km at the end of their race. Presumably, Triple Iron ultra-triathletes are closer to ultra-cyclists which suggests comparison of measures of ultra-triathletes with those of ultra-cyclists. In future studies, age and performance of ultra-endurance athletes must be matched.

REFERENCES

ARRESE, A. L., & OSTÁRIZ, E. S. (2006) Skinfold thicknesses associated with distance running performance in highly trained runners. *Journal of Sports Science,* 24, 69-76.

BALE, P., BRADBURY, D., & COLLEY, E. (1986) Anthropometric and training variables related to 10 km running performance. *British Journal of Sports Medicine,* 20, 170-173.

BALL, S. D., ALTENA, T. S., & SWAN, P. D. (2004) Comparison of anthropometry to DXA: a new prediction equation for men. *European Journal of Clinical Nutrition,* 58, 1525-1531.

BECQUE, M. D., KATCH, V. L., & MOFFATT, R. J. (1986) Time course of skin-plus-fat compression in males and females. *Human Biology,* 58, 33-42.

BILLAT, V. L., DEMARLE, A., SLAWINSKI, J., PAIVA, M., & KORALSZTEIN, J. P. (2001) Physical and training characteristics of top-class marathon runners. *Medicine & Science in Sports & Exercise,* 33, 2089-2097.

GULBIN, J. P., & GAFFNEY, P. T. (1999) Ultraendurance triathlon participation: typical race preparation of lower level triathletes. *The Journal of Sports Medicine and Physical Fitness,* 39, 12-15.

HAGAN, R. D., SMITH, M. G., & GETTMAN, L. R. (1981) Marathon performance in relation to maximal aerobic power and training indices. *Medicine & Science in Sports & Exercise,* 13, 185-189.

HAGAN, R. D., UPTON, S. J., DUNCAN, J. J., & GETTMAN, L. R. (1987) Marathon performance in relation to maximal aerobic power and training indices in female distance runners. *British Journal of Sports Medicine,* 21, 3-7.

KNECHTLE, B., DUFF, B., AMTMANN, G., & KOHLER, G. (2007) Cycling and running performance, not anthropometric factors, are associated with race performance in a Triple Iron Triathlon. *Research in Sports Medicine,* 15, 257-269.

KNECHTLE, B., DUFF, B., WELZEL, U., & KOHLER, G. (2009) Body mass and circumference of upper arm are associated with race performance in ultra-endurance runners in a multi-stage race: the Isarrun 2006. *Research Quarterly for Exercise and Sport,* 80, 262-268.

KNECHTLE, B., JOLESKA, I., WIRTH, A., KNECHTLE, P., ROSEMANN, T., & SENN, O. (2010) Intra- and inter-judge reliabilities in measuring skin-fold thicknesses of ultra runners under field conditions. *Perceptual and Motor Skills,* 111, 105-106.

KNECHTLE, B., KNECHTLE, P., & LEPERS, R. (2010) Participation and performance trends in ultra-triathlons from 1985 to 2009. *Scandinavian Journal of Medicine and Science in Sports,* DOI: 10.1111/j.1600-0838.2010.01160.x.

KNECHTLE, B., KNECHTLE, P., & ROSEMANN, T. (2009) Skin-fold thicknesses and training volume in ultra-triathletes. *International Journal of Sports Medicine,* 30, 343-347.

KNECHTLE, B., KNECHTLE, P., ROSEMANN, T., & SENN, O. (2010) Personal best time, not anthropometry or training volume, is associated with total race time in a Triple Iron triathlon. *The Journal of Strength and Conditioning Research,* DOI: 10.1519/JSC.0b013e3181d09f0f.

Knechtle, B., Knechtle, P., Schulze, I., & Kohler, G. (2008) Upper arm circumference is associated with race performance in ultra-endurance runners. *British Journal of Sports Medicine,* 42, 295-299.

Knechtle, B., & Kohler, G. (2009) Running performance not anthropometric factors is associated with race success in a Triple Iron Triathlon. *British Journal of Sports Medicine,* 43, 437-441.

Knechtle, B., & Rosemann, T. (2009) Skin-fold thickness and race performance in male mountain ultra-marathoners. *Journal of Human Sport and Exercise,* 4, 211-220.

Knechtle, B., Schwanke, M., Knechtle, P., & Kohler, G. (2008) Decrease in body fat during an ultra-endurance triathlon is associated with race intensity. *British Journal of Sports Medicine,* 42, 609-613.

Larsen, H. B., Christensen, D. L., Nolan, T., & Søndergaard, H. (2004) Body dimensions, exercise capacity and physical activity level of adolescent Nandi boys in western Kenya. *Annals of Human Biology,* 31, 159-173.

Legaz, A., & Eston, R. (2005) Changes in performance, skinfold thicknesses, and fat patterning after three years of intense athletic conditioning in high level runners. *British Journal of Sports Medicine,* 39, 851-856.

Legaz Arrese, A., González Badillo, J. J., & Serrano Ostáriz, E. (2005) Differences in skinfold thicknesses and fat distribution among top-class runners. *Journal of Sports Medicine and Physical Fitness,* 45, 512-517.

Lepers, R. (2008) Analysis of Hawaii Ironman performances in elite triathletes from 1981 to 2007. *Medicine & Science in Sports & Exercise,* 40, 1828-1834.

Loftin, M., Sothern, M., Koss, C., Tuuri, G., Vanvrancken, C., Kontos, A., & Bonis, M. (2007) Energy expenditure and influence of physiologic factors during marathon running. *The Journal of Strength and Conditioning Research,* 21, 1188-1191.

Lucia, A., Esteve-Lanao, J., Oliván, J., Gómez-Gallego, F., San Juan, A. F., Santiago, C., Pérez, M., Chamorro-Viña, C., & Foster, C. (2006) Physiological characteristics of the best Eritrean runners—exceptional running economy. *Applied Physiology, Nutrition, and Metabolism,* 31, 530-540.

Maldonado, S., Mujika, I., & Padilla, S. (2002) Influence of body mass and height on the energy cost of running in highly trained middle- and long-distance runners. *International Journal of Sports Medicine,* 23, 268-272.

O'Toole, M. L., Hiller, D. B., Crosby, L. O., & Douglas, P. S. (1987) The ultraendurance triathlete: a physiological profile. *Medicine & Science in Sports & Exercise,* 19, 45-50.

Scrimgeour, A. G., Noakes, T. D., Adams, B., & Myburgh, K. (1986) The influence of weekly training distance on fractional utilization of maximum aerobic capacity in marathon and ultramarathon runners. *European Journal of Applied Physiology,* 55, 202-209.

Tanaka, K., & Matsuura, Y. (1982) A multivariate analysis of the role of certain anthropometric and physiological attributes in distance running. *Annals of Human Biology,* 9, 473-482.

Yeung, S. S., Yeung, E. W., & Wong, T. W. (2001) Marathon finishers and non-finishers characteristics: a preamble to success. *Journal of Sports Medicine and Physical Fitness,* 41, 170-176.

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