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Abstract: The relationship of anthropometric and training characteristics with race time were investigated in 39 male and 24 female open-water ultra-endurance swimmers in a 26.4 km open-water ultra-swim, using bi- and multivariate analyses. For the men, body height, Body Mass Index, length of arm, and swimming speed during training were related to race time in the bivariate analysis. For the women, swimming speed during training was associated with performance in the bivariate analysis. In the multivariate analysis for the men, Body Mass Index and swimming speed during training were related to race time.

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SPEED DURING TRAINING AND ANTHROPOMETRIC MEASURES IN RELATION TO RACE PERFORMANCE BY MALE AND FEMALE OPEN-WATER ULTRA-ENDURANCE SWIMMERS [1, 2]

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Summary.- We investigated in 39 male and 24 female open water ultra-endurance swimmers the relationship of anthropometric and training characteristics with race time in a 26.4 km open water ultra-swim, using bi- and multivariate analysis. For the men, body height ($r = -.46$), Body Mass Index ($r = .52$), length of arm ($r = -.43$) and swimming speed during training ($r = -.59$) were related to race time in the bivariate analysis. For the women, swimming speed during training ($r = -.73$) was associated with performance in the bivariate analysis. In the multivariate analysis for the men, Body Mass Index ($p = .009$) and swimming speed during training ($p = .02$) were related to race time.

In swimmers, various factors are known to influence endurance performance. Apart from physiological parameters, several anthropometric variables show relations with endurance performance. In competitive pool swimmers, body height (Zampagni, Casino, Benelli, Visani, Marcacci, & De Vito, 2008), body fat (Siders, Lukaski, & Bolonchuk, 1993; Tuuri, Loftin, & Oescher, 2002), upper extremity length (Geladas, Nassis, & Pavlicevic, 2005) and skin fold thickness (Anderson, Hopkins, Roberts, & Pyne, 2008) have been related to performance. However, in competitive ultra-endurance pool swimmers in a 12-h ultra swim, no variable of anthropometry was related to total kilometers achieved (Knechtle, Knechtle, & Kohler, 2008).

Apart from anthropometry, training variables are also of importance (Costill, Thomas, Robergs, Pascoe, Lambert, Barr, *et al.,* 1991; Raglin, Koceja, Stager, & Harms, 1996; Stewart, & Hopkins, 2000; Van Heest, Mahoney, & Herr, 2004; Jagomagi, & Jürimäe, 2005; Anderson, Hopkins, Roberts, & Pyne, 2008; Faude, Meyer, Scharhag, Weins, Urhausen, & Kindermann, 2008). In competitive swimming, Anderson *et al.* (2008) reported a combination of fitness and technique factors were important for competitive performance. According to Costill *et al.* (1991), training intensity might be more important than training volume for swimmers. In contrast, Stewart and Hopkins (2000) described that a better performance in swimmers over 50 m to 400 m was associated with greater weekly training mileage. Faude *et al.* (2008) demonstrated no advantage in high training volumes on performance compared with high intensity training at lower volume. A too extensive training is counterproductive. Raglin *et al.* (1996) described in a training study of swimmers which indicated peak training of 8.3 km per day led to a reduction in anaerobic swimming power.

Literature about open-water ultra-endurance swimmers is small. Van Heest *et al.* (2004) reported that elite open-water swimmers were smaller and lighter than competitive pool swimmers. Swimmers with more body fat can endure longer time periods in cold water (Knechtle, Christinger, Kohler, Knechtle, & Rosemann, 2009; Pugh & Edholm, 1955), since swimmers with less subcutaneous fat get out of the water after significantly less time during a swim in water of 9.4 °C compared to 11.0 °C (Keatinge, Khartchenko, Lando, & Lioutov, 2001). However, in a study of male ultra-endurance pool swimmers in a 12-h swim, body fat showed no association with race performance (Knechtle *et al.,* 2008).

The present aim was to assess the relations of both anthropometric and training characteristics with race time for male and female open-water ultra-endurance swimmers. Included were body mass, percent body fat, body height and length of arm and leg for anthropometric variables respecting available literature. Training variables included mean speed in training and mean weekly training volume. These variables are considered to be related to performance in short-distance pool-swimmers.

Since open-water swimmers, in contrast to pool swimmers, have to swim in rather cold water (Knechtle, Christinger, Kohler, Knechtle, & Rosemann, 2009; Pugh & Edholm, 1955), body fat was expected to be highly associated with race time. The working hypothesis was that swimmers with a high percentage of body fat would be faster in an open-water ultra-endurance contest than swimmers with a low percentage. Training was assumed to be moderately related to race time.

METHOD

The race

Open-water ultra-endurance swimmers represent a very small population (Keatinge *et al.,* 2001; Van Heest *et al.,* 2004). To increase sample size, data was collected in three consecutive years at the 'Marathon Swim' in Lake Zurich, Switzerland from 2008 to 2010. Ultra-swimmers from all over the World started in this race, the longest open-water ultra-swimming contest in Europe. The idea of this race, when first held in 1977, was an opportunity for open-water swimmers to prepare for the Channel swim between Dover (England) and Calais (France). Several swimmers preparing to cross the Channel were using this competition as practice. The 21st annual event of the 'Marathon Swim' in Lake Zurich, Switzerland, took place on 3 August 2008, and subsequently on 26 July 2009, and 8 August 2010. The swimmers started in the morning at 07:00 a.m. in Rapperswil and swam to Zurich covering a total distance of 26.4 km within a time limit of 14 hr (840 mins). Athletes had to be followed by a personal support boat with a crew providing nutrition and fluids. The weather in all three years was similar. In 2008, the temperature of the Lake was 22 °C; in both 2009 and 2010, it was 21 °C. In 2008 and 2009, it was dry and the sun was shining, the daily high in both years was 27 °C. In 2010, the sky was cloudy and the daily high reached 26 °C.

Participants

The organizer of the 'Marathon Swim' in Lake Zurich, in the years 2008 to 2010, contacted all participants upon registration for the race, via a separate newsletter, and informed them about the planned investigation. In total, 39 male and 24 female swimmers were study participants. The study was approved by the Institutional Review Board for Use of Human Subjects of St. Gallen, Switzerland, and the athletes gave their informed written consent. The anthropometric data of the participants is presented in Table 1, their training variables in Table 2. All swimmers were trained and experienced open-water swimmers. Five of the swimmers had already swum the Channel.

Measures and Calculations

Body mass was measured using a commercial scale (Beurer BF 15, Beurer GmbH, Ulm, Germany) to the nearest 0.1 kg. Body height was measured using a stadiometer to the nearest 1 cm. Skin fold data was obtained using a skin fold caliper (GPM-Hautfalten-messgerät, 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 (pectoral, triceps, mid-axilla, subscapular, abdominal, suprailiac, front thigh and medial calf) and were then repeated twice by the same investigator; the mean of the three measures was then used for analysis. According to Becque, Katch and Moffat (1986), readings of skin fold thicknesses were performed 4 sec after applying the caliper. The length of the right arm was measured from acromion to the tip of the third finger; the length of the right leg from trochanter major to malleolus lateralis. Percentage of body fat in men was calculated using the following anthropometric formula: Percent body fat = $0.465 + 0.180(\Sigma 7SF) - 0.0002406(\Sigma 7SF)^2 + 0.0661(age)$, where Σ7SF = sum of skin fold thickness of pectoral, triceps, mid-axilla, subscapular, abdominal, suprailiac and front thigh mean, according to Ball, Altena and Swan (2004). For the women, percent body fat was calculated using the following formula: Percent body fat = $-6.40665 + 0.41946 (\Sigma 3SF) – 0.00126 (\Sigma 3SF)^2 + 0.12515 (Hip) + 0.06473 (age)$, using the formula of Ball, Swan and Desimone (2004). Σ3SF was taken as the sum of skin fold thickness of the triceps, suprailiac and front thigh skin fold thicknesses. The hip circumference (Hip) was measured in cm at the widest point of the buttocks.

One trained investigator took all the measurements as inter-tester variability is a major source of error in skin fold measurements. An intra-tester reliability check for skin fold thicknesses 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>0.9) (Knechtle, Joleska, Wirth, Knechtle, Rosemann, & Senn, 2010).

In addition to measurements of the anthropometric variables, athletes were asked upon inscription to the study to record their average weekly training volume in hours, plus the kilometers swum, in preparation for the race. Each athlete maintained a comprehensive training diary consisting of training sessions showing distance and duration. The training diary started upon inscription to the race. The average value in volume (kilometers and hours) and intensity (km/h) were calculated. The number of years as active and competitive swimmer was also obtained.

Statistical Analyses

The Shapiro-Wilks test was applied to check for normality distribution. Normally distributed data are presented as mean and standard deviation (*SD*). Race time was also expressed as a percent of the course record. In a first step, the association of the variables of pre-race experience, training, and anthropometry with total race time was investigated using bivariate correlation analysis. In a second step, multiple linear regression analysis was used to reduce further the relation of significant variables in the bivariate analysis with race time. For all statistical tests significance was set at the .05 level.

RESULTS

The 39 male swimmers finished within 529 (*SD* = 94) min, competing at a mean speed of 3.1 (*SD* = 0.5) km/h. The 24 women swam no slower than the men ($p > .05$), within 576 (*SD* = 122) min and racing at 2.8 (*SD* = 0.5) km/h. Race times of men, expressed as a percent of the course record of 351 min set by Maarouf Mohamed (Egypt) in 1993, were 151 (*SD* = 27) %; in women, expressed as a percent of the record of 359 for women set in 2001 by Nadja Krüger (Switzerland), were 161 (*SD* = 34) % of the course record. Also, when race time was expressed as a percent of the course records, women were no slower than men.

When the sexes were compared, male swimmers were heavier and taller than females, had longer arms and legs and lower body fat than women (Table 1). For training, no differences between the sexes were found (Table 2). For both men and women, speed in training was significantly faster than speed in the race ($p < .01$).

In the bivariate analysis, body height, Body Mass Index and length of arm were related to race time for the men. For the women, no association was found between anthropometric characteristics and race time (Table 3). Swimming speed during training was related to race time for both men and women (Table 4). In the multivariate analysis for men, Body Mass Index and mean speed of the training sessions were related to race time (Table 5).

DISCUSSION

The aim of this study was to investigate the relations of anthropometric and training variables with race time for male and female open-water ultra-endurance swimmers. The hypotheses were that swimmers with a high percentage of body fat would be faster than swimmers with a low percentage, and training was assumed to show a small association with race time. In contrast to the hypotheses, multivariate analysis showed no association between performance and known anthropometric factors in swimmers such as fat mass (Tuuri *et al.*, 2002), upper extremity length (Geladas *et al.*, 2005) and body height (Geladas *et al.*, 2005; Jagomagi & Jürimäe, 2005) in this group of male and female open-water ultra-endurance swimmers; however, speed in swimming during training remained the single predictor variable for race time for both men and women. In men, Body Mass Index was the single anthropometric characteristic related to race time.

What is the Importance of Intensity in Training?

In contrast to the assumption that body fat would be related to performance, mean speed in training was significantly associated with total race time for both male and female swimmers. It seems that both male and female athletes with a high training pace performed better in this ultra-endurance swim, as has already been shown for a smaller sample of male open-water ultra-swimmers (Knechtle, Baumann, Knechtle, & Rosemann, 2010). In the literature, studies on training and swimming performance are for pool swimmers mostly. Costill, *et al.* (1991) noted in a training study of male swimmers that for those who had a high training volume swim performance was not enhanced. However, after a taper period, performance was improved. In another training study of competitive swimmers, a four-week training period of both high volume and low intensity, or low volume and high intensity, improved performance (Faude *et al.*, 2008). Probably the incorporation of resistance training into a training program enhanced swim performance (Girold, Maurin, Dugué, Chatard, & Millet, 2007). Girold, Maurin, Dugué, Chatard, and Millet (2007) reported in a training study of swimmers that programs either combining swimming with dry land strength training or with in-water resistance- and assisted sprint exercise led to a similar gain in sprint performance, which was better than traditional training methods.

Is Training Volume of importance?

Given the low training volume, the participants were assumed not to be successful athletes, but observing that they all finished the race within the time limit one cannot deduce that these athletes were not serious swimmers. The male swimmers in this sample trained, on the average, a total distance of 23 km per week, and the female swimmers 19 km. This is very low and suggests that these swimmers were not serious athletes, particularly for an aerobically demanding, high endurance sport such as marathon swimming. This point is also reflected in the average number of 9 hrs of training per week for the men and 7.5 hrs for the women. In comparison, the average elite competitive swimmer easily trains three to four times this distance each week. To compare, the athletes in the study of Van Heest *et al.* (2004) swam on average just over 12 km per day during a 1-wk training camp. This daily distance is almost equivalent to the average total distance swum by the participants in this study in an entire week. Swimming 26.4 km without a break at an average speed of around 3 km per hour requires trained athletes. Since the mean age of these swimmers is around 40 years, and competitive swimmers are about 20 years younger (Trewin, Hopkins, & Pyne, 2004; Wallace, Slattery, & Coutts, 2009), one might assume that these swimmers had a long history of competitive swimming. Indeed, these athletes had been training for 10 to15 years. In addition, at least two athletes were former competitive swimmers at the national level in their countries, and at least three athletes were elite long-distance triathletes investing more time in cycling and run training than swimming. Presumably an older or senior competitive swimmer is able to maintain a high speed during training at low volumes for years and is therefore able to compete fast in ultra-endurance swimming.

Body Height and Length of Extremities

In the multivariate analysis, no association was found for any of the anthropometric measures with race time for both male and female swimmers except for Body Mass Index for the men. Recent studies on Ironman triathletes also showed that anthropometric characteristics such as body fat was related to race time for men, but not for women (Knechtle, Wirth, Baumann, Knechtle, & Rosemann, 2010; Knechtle, Wirth, Baumann, Knechtle, & Rosemann, 2010). In studies of pool swimmers, body mass, length of extremities, and body height showed relations with swim performance. Geladas *et al.* (2005) reported for boys and girls ages 12 to 14 years that upper extremity length was, in addition to horizontal jump and grip strength, a significant predictor variable of 100-m freestyle performance in boys. For girls, body height, upper extremity and hand length were significantly related to 100-m freestyle times. Jagomagi and Jürimäe (2005) described body height as the most important anthropometrical parameter in 125 female breaststroke swimmers, explaining 11.1% of the 100-m breaststroke times. The association of body weight with swim performance is probably related to sex. Sekulić, Zenić and Zubcević (2007) found that body height was related to performance in male swimmers over 50-m freestyle. Probably the length of the swim distance was the reason that no correlation with total race time was noted. Also no relation of body height and race performance was found where Jagomagi and Jürimäe (2005) reported one.

No Association Between Body Fat and Race Performance?

These athletes, in a race distance of 26.4 km, had to swim a considerably longer distance than pool swimmers. High body fat was expected to be beneficial for race performance in an open-water swim; however, body fat percentage showed no association with total race time. Swimmers crossing the English Channel face temperatures of about 15 °C (Pugh & Edholm, 1955). For ultra-swimmers in open-water competitions, such as the Channel, fat is a better insulator than human muscle (Hatfield & Pugh, 1951). Keatinge *et al.* (2001) could show that swimmers with less thick subcutaneous fat made significantly shorter swims than those with thicker fat layers in water of 9.4 °C to 11 °C. In the Channel between Dover and Calais over 32.2 km, swimmers commonly need about 12 hr, but some up to 20 hr depending upon the circumstances (Pugh & Edholm, 1955). The finding, that high fat mass seems advantageous for swimming performance is probably dependent on sex. However, for female swimmers, also, a high fat mass may impair swimming performance. Tuuri *et al.* (2002) showed for female swimmers greater fat mass was strongly related to lower amounts of exercise. Siders *et al.* (1993) showed that percent body fat was correlated with swimming performance over 100 yd for females.

The water temperature in Lake Zurich was consistently above 20 °C, so that the water temperature obviously was not a problem for these swimmers. Water temperature must be around 10 °C (Keatinge *et al.* 2001) or less (Knechtle, Christinger, Kohler, Knechtle, & Rosemann, 2009) for body fat to be important. It is assumed that swimmers with more body fat can perform longer in cold water (Keatinge *et al.* 2001) so an increase in fat mass is recommended (Acevedo, Meyers, Hayman, & Haskin, 1997) before a swim in cold water. In the study by Keatinge *et al.* (2001), swimmers with the thinnest skin fold thickness (mean skin fold thickness of four skin folds) of 8.56-mm swam for 23 mins in water at 11 °Celsius.

Limitations of the Study

The design of a cross-sectional study is limited regarding the influence and effects of anthropometry and both volume and intensity during training on race performance in athletes, since only a training study can answer this question. Other limitations are lack of fitness evaluation of these athletes. However, performance could be demonstrated, as expressed as a percent of the course record, as being no different between men and women. In this investigation, focus was on anthropometry and training. Other aspects with potential effects on performance such as motivation, nutrition and hypothermia were not considered. Unfortunately there are no data on energy intake and expenditure (Kimber, Ross, Mason, & Speedy, 2002) or on disorder in fluid or electrolyte metabolism (Speedy, Noakes, Rogers, Thompson, Campbell, Kuttner, *et al.,* 1999) which might also influence race outcome. Furthermore, body core temperature was not assessed before and after the swim. Hypothermia, a significant risk in long-distance open water swimmers (Nuckton, Claman, Goldreich, Wendt, & Nuckton, 2000; Brannigan, Rogers, Jacobs, Montgomery, Williams, & Khangure, 2009), can also occur in water of 21 °C (Castro, Mendes, & Nobrega) and may considerably influence performance.

Implications of the Study and Directions for Research

Although anthropometric variables showed associations with race time in the bi- and multivariate analysis, variables of training such as intensity became more important. Obviously, in these ultra-endurance swimmers, training is more important than ‘classical’ anthropometric characteristics such as body height (Zampagni, *et al.,* 2008), body fat (Siders *et al.,* 1993; Tuuri *et al.,* 2002), upper extremity length (Geladas *et al.,* 2005) and skin fold thickness (Anderson *et al.,* 2008), which seem to be more relevant for pool swimmers over short distances. In further study especially the intensity of training should be assessed using parameters such as heart rate or blood lactate. Change of body core temperature should be considered as a further variable.

CONCLUSION

Anthropometric variables such as body fat, body height and length of extremities showed no relation with race time in these ultra-endurance swimmers in an open-water ultra-swimming contest. In this group of ultra-swimmers, speed in training showed an association with race time in a 26.4 km open-water ultra-swim for men and women; also Body Mass Index for men. Further investigation is warranted with a larger sample of athletes to clarify why speed in training is important for performance in open-water ultra-swimmers and not body fat. Intensity of training, especially, should be assessed using parameters such as heart rate or blood lactate.

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TABLE 1

Age and Anthropometry of Male and Female Ultra Swimmers

Measures	Male swimmers (n = 39)		Female swimmers (n = 24)	
	M	*SD*	*M*	*SD*
Age, yr	38.5	8.9	38.6	11.8
Body mass, kg	85.2 *	10.3	69.8	6.4
Body height, m	1.81 *	0.07	1.68	0.04
Body Mass Index, kg/m^2	25.3	3.1	24.7	1.9
Length of arm, cm	82.8 *	3.8	74.8	3.3
Length of leg, cm	87.9 *	5.1	82.6	3.3
Percent body fat, %	20.2 *	5.6	31.3	3.6

Note.- * $p < .01$.

TABLE 2

Training Characteristics of Male and Female Ultra Swimmers

Measures	Male swimmers (n = 39)		Female swimmers (n = 24)	
	M	*SD*	*M*	*SD*
Number of years participating in swimming	15.6	13.3	16.2	8.5
Weekly kilometers swum, km	23.2	11.5	19.4	10.4
Minimal distance swum per week, km	10.9	9.5	10.3	8.3
Maximal distance swum per week, km	36.4	21.8	27.2	18.8
Hours swum per week, h	8.9	5.0	7.5	3.4
Number of swimming training sessions per week	4.8	1.3	4.7	2.2
Distance per swimming training session, km	4.4	1.7	4.2	2.7
Duration of swimming training sessions, min	82.2	23.0	83.7	32.5
Mean speed of the training sessions, km/hr	3.5	0.5	3.4	0.6

TABLE 3

Association of Age and Anthropometry of Male and Female Ultra-Swimmers with Race Time

Measures	Male swimmers (n = 39)		Female swimmers (n = 24)	
	r	p	r	p
Age	.29	.07	.30	.15
Body mass	.15	.36	.13	.55
Body height	- .46	.003	- .24	.25
Body Mass Index	.52	.0007	.35	.09
Length of arm	- .43	.006	- .27	.20
Length of leg	- .39	.01	- .06	.78
Percent body fat	.28	.09	.16	.45

TABLE 4

Association of Training Characteristics of Male and Female Ultra-Swimmers with Race Time

Measures	Male swimmers (n = 39)		Female swimmers (n = 24)	
	r	*p*	*r*	*p*
Number of years participating in swimming	- .16	.34	- .11	.59
Weekly kilometers swum	- .26	.10	- .35	.09
Minimal distance swum per week	- .01	.94	- .35	.08
Maximal distance swum per week	- .14	.38	- .37	.07
Hours swum per week	- .25	.12	- .33	.11
Number of swimming training sessions per week	- .39	.01	- .05	.80
Distance per swimming training session	- .10	.54	.05	.82
Duration of swimming training sessions	.02	.91	- .07	.74
Mean speed of the training sessions	- .59	< .0001	- .73	< .0001

TABLE 5

Relationship of Race Time to Significant Variables after Bivariate Analysis in Male Swimmers in the Multivariate Analysis

	ß	SE	*p*
Body height	- 497	342.7	.15
Body Mass Index	11.1	4.0	.009
Length of arm	- 7.1	5.9	.23
Length of leg	7.8	5.6	.17
Number of swimming training sessions per week	- 14.0	8.9	.12
Mean speed of the training sessions	- 55.8	23.5	.02

Note.- Multiple linear regression analysis with race time as the dependent variable for male swimmers (*n* = 39). ß = regression coefficient; SE = standard error of the regression coefficient; Coefficient of determination (R^2) of the model was 59%.