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ORIGINAL ARTICLE

Does Muscle Mass Affect Running Times in Male Long-distance Master Runners?

Beat Knechtle*[1,2], MD; Christoph Alexander Rüst[1], BM; Patrizia Knechtle[2]; Thomas Rosemann[1], MD, PhD

Authors' Affiliation:

1. Institute of General Practice and for Health Services Research, University of Zurich, Zurich, Switzerland
2. Gesundheitszentrum St. Gallen, St. Gallen, Switzerland

*** Corresponding Author;**
Address: Facharzt FMH für Allgemeinmedizin
Gesundheitszentrum St. Gallen
Vadianstrasse 26
9001 St. Gallen
Switzerland

E-mail: beat.knechtle@hispeed.ch

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Abstract

Purpose: **The aim of the present study was to investigate associations between skeletal muscle mass, body fat and training characteristics with running times in master athletes (age > 35 years) in half-marathon, marathon and ultra-marathon.**

***Methods*: We compared skeletal muscle mass, body fat and training characteristics in master half-marathoners (*n*=103), master marathoners (*n*=91) and master ultra-marathoners (*n*=155) and investigated associations between body composition and training characteristics with race times using bi- and multi-variate analyses.**

***Results*: After multi-variate analysis, body fat was related to half-marathon (*β*=0.9, *P*=0.0003), marathon (*β*=2.2, *P*<0.0001), and ultra-marathon (*β*=10.5, *P*<0.0001) race times. In master half-marathoners (*β*=-4.3, *P*<0.0001) and master marathoners (*β*=-11.9, *P*<0.0001), speed during training was related to race times. In master ultra-marathoners, however, weekly running kilometers (*β*=-1.6, *P*<0.0001) were related to running times.**

***Conclusions*: To summarize, body fat and training characteristics, not skeletal muscle mass, were associated with running times in master half-marathoners, master marathoners, and master ultra-marathoners. Master half-marathoners and master marathoners rather rely on a high running speed during training whereas master ultra-marathoners rely on a high running volume during training. The common opinion that skeletal muscle mass affects running performance in master runners needs to be questioned.**

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INTRODUCTION

Master athletes are defined as athletes of 35 years of age and older [1,2]. These athletes maintain a high level of fitness throughout their lifespan [3]. Due to their regular training, they show only minor changes in aerobic capacity and body composition across years [4-6]. In recent years, several studies described an increased participation of master athletes in different running distances such as marathon [7,8] and ultra-marathon [9-12]. In recent years, master athletes improved their race performance across years in both marathons [7,8] and ultra-marathons [11,12].

Running performance declines with increasing age [13-16]. The time to complete a marathon gradually increases with age, with substantial losses in performance after the age of 70 years [17]. Among the master athletes, the performance of marathoners declines after the age of ~40 years, where the peak levels of performance decreased by ~50% by the age of 80 years [18]. Marathon running performance is generally fastest, as indicated by world record performances, when individuals are between 25 and 35 years old [17]. There seems to be differences regarding the age of peak running performance between distances up to the marathon and ultra-marathon distance. Half-marathoners and marathoners can maintain their peak running times from 20 to 55 years [14,15]. In ultra-

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marathoners, however, the age of peak running performance across life is shorter and between 30 to 49 years [9,11,12].

Factors contributing to the age-related decline in endurance performance in master athletes are central factors such as maximum heart rate, maximum stroke volume, blood volume and peripheral factors such as skeletal muscle mass, muscle fiber composition, fiber size, fiber capillarization and muscle enzyme activity [2]. The decline in endurance performance appears to be primarily due to an age-related decrease in maximum oxygen uptake (VO_2max) [2]. There appears also an age-related decrease in active skeletal muscle mass contributing to a decreased endurance performance [2].

The main reason for the age-related decline in endurance performance is the decrease in VO_2max due to a loss of skeletal muscle mass [19]. With ageing, skeletal muscle atrophy in humans appears to be inevitable. A gradual loss of muscle fibres begins at the age of ~50 years and continues to the age of ~80 years where ~50% of the fibres are lost from the limb muscles [3]. The degree of atrophy of the muscle fibres is largely dependent on the habitual level of physical activity of the individual [3]. With increasing age, both VO_2max [17,19-21] and skeletal muscle mass [18,21] decrease in both untrained [18,21] and trained [19,20] subjects. In non-endurance trained subjects, a large portion of the age-associated decline in VO_2max is explicable by the loss of skeletal muscle mass [18]. In master athletes, an association between oxidative tissue and oxygen uptake has been described where master athletes with the greatest loss in VO_2max showed also the greatest loss in lean body mass [20].

Apart from skeletal muscle mass, also body fat shows changes across lifetime. With increasing age, body fat increases in both untrained [22,23] and master athletes [5,24,25] and a greater fat mass is associated with a greater decline in leg lean mass [23]. It has also been shown that body fat is a strong predictor variable for endurance performances [26-30] such as cycling [26], triathlon [27,28,30] and running [29]. In master athletes, the age-related decrease in both VO_2max [5,6,19] and skeletal muscle mass [4,5,8,17,35] as well as the increase in fat mass [5] can be partially prevented by regular physical training. In master runners, the skeletal muscle continues to have a high aerobic potential, while a decline in muscle cell size and contractile performance are apparent. These changes in the skeletal muscle profile may contribute to distance running performance decline with increasing age [17].

To date, the age-related decline in running performance has been investigated for half-marathoners [14,15], marathoners [14,15] and ultra-marathoners [9,11,12]. For master runners, a decline in performance with age has been reported for distances up to the marathon [1,31,32], but not for ultra-marathoners. The aim of the present study was to investigate associations between skeletal muscle mass, body fat and training characteristics with running times in master athletes (age > 35 years) in different endurance running distances such as half-marathon, marathon and ultra-marathon. We hypothesized that (*i*) skeletal muscle mass would decrease with increasing age, (*ii*) fat mass would increase with increasing age and (*iii*) the age-related decline in skeletal muscle mass would lead to a decrease in running times in master runners of different distances.

METHODS AND SUBJECTS

Demographic and anthropometric characteristics:

All male ultra-marathoners in the '100 km Lauf Biel' and all male runners at the 'Basel Marathon' in Basel, Switzerland, were informed, via an electronic newsletter sent by the organizer three months before the start of the race, plus separate information shown on the race website about the planned investigation. In the 'Basel Marathon', athletes can participate in both a half-marathon and a marathon. Since participation in ultra-endurance races is low per race [12], data were collected from four consecutive years, 2008 to 2011, to increase the sample size of the 100-km ultra-marathoners. In the 'Basel Marathon' athletes were recruited in two consecutive years, from 2010 to 2011. Due to the low female participation in ultra-endurance races [12], we focussed on male runners. Master athletes are defined as athletes with an age of > 35 years [2]. In the '100 km Lauf Biel', 155 male master's level runners were recruited, in the 'Basel Marathon', 103

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male master's level half-marathoners and 91 male master's level marathoners were measured pre-race. Table 1 shows the age, and both the anthropometric characteristics and training variables of the subjects.

Ethical approval was granted for each event by the Institutional Review Board of the Canton of St. Gallen, Switzerland. The athletes were informed of the experimental procedures and gave their written informed consent.

The Races:

The '100 km Lauf Biel' in Biel, Berne, Switzerland, generally takes place during the night of the first weekend in June. The athletes start the ultra-marathon at 10:00 p.m. They have to climb a total altitude of 645 meters. During these 100 km, the organizer provides a total of 17 aid stations offering an abundant variety of food and beverages such as carbohydrate-electrolyte beverage, tea, soup, carbonated cola beverage, water, bananas, oranges, bread and energy bars. The athletes are allowed to be supported by a cyclist in order to have additional food and clothing, if necessary. In the 'Basel Marathon', the athletes have to run in the marathon two laps on asphalt with a total altitude of 200 m, in the half-marathon one lap. No athlete was included more than once and no athlete competed in either the 100-km ultra-marathon or in the marathon.

Measurements and Calculations:

Upon inscription to the study three months before the start of both the '100 km Lauf Biel' and the 'Basel Marathon', the subjects were asked to record their training units showing duration in minutes and distance in kilometres until the start of the race. The investigator provided an electronic file where the subjects could insert each training unit with distance, duration and speed, expressed in km/h. The investigator then calculated the mean weekly hours, the mean weekly kilometres and the mean speed in running during training in the pre-race preparation.

Anthropometric measurements:

Before the start of the race, body mass, body height, the circumferences of the limbs (*i.e.* mid-upper arm, mid-thigh, and mid-calf) and the thicknesses of eight skin-folds (*i.e.* pectoralis, axillar, triceps, subscapular, abdomen, suprailiacal, thigh and calf) were measured on the right side of the body. With this data, percentage of body fat and skeletal muscle mass, using an anthropometric method, were estimated. Body mass was measured using a commercial scale (Beurer BF 15, Beurer GmbH, Ulm, Germany) to the nearest 0.1 kg after voiding of the urine bladder. Body height was determined using a stadiometer to the nearest 1.0 cm (Tanita HR 001 Portable Height Measure, Tanita Europe, Amsterdam, Netherlands). The circumferences and the lengths of the limbs were measured using a non-elastic tape measure (KaWe CE, Kirchner und Welhelm, Germany) to the nearest 0.1 cm. The skin-fold data were obtained using a skin-fold caliper (GPM-Hautfaltenmessgerät, Siber & Hegner, Zurich, Switzerland) and recorded to the nearest 0.2 mm. The skin-fold caliper measures with a pressure of 0.1 mPa ± 5% over the whole measuring range. The skin-fold

Table 1: A comparison of age, anthropometric characteristics and training between the three groups

Parameter	Half- marathoners (*n*=103)	Marathoners (*n*=91)	100-km ultra-Marathoners (*n*=155)
Age (years)	45.2 (7.6)	47.8 (7.9)	47.4 (7.8)
Body mass (kg)	75.9 (8.7)	74.1 (8.5)	75.1 (9.5)
Body height (m)	1.78 (0.06)	1.77 (0.05)	1.78 (0.06)
Body mass index (kg/m^2)	23.8 (2.2)	23.5 (2.3)	23.5 (2.1)
Skeletal muscle mass (kg)	38.7 (3.2)	37.9 (3.3)	38.7 (3.9)
Percentage of body fat (%)	18.2 (4.4)	16.9 (3.4) $^{\#}$	16.4 (4.3) †,§
Weekly running kilometers (km)	33.5 (17.7)	45.3 (22.7) $^{\#}$	71.3 (26.5) †,§
Weekly running hours (h)	3.7 (1.6)	4.9 (2.1) $^{\#}$	7.8 (4.5) †,§
Running speed (km/h)	10.6 (1.4)	11.0 (1.3)	10.1 (2.2)

significantly different between master half-marathoners and master marathoners
† significantly different ($P < 0.05$) between master marathoners and 100-km master ultra-marathoners
§ significantly different ($P < 0.05$) between master half-marathoners and 100-km master ultra-marathoners

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measurements were taken following the ISAK standard once for all seven skin-folds and then the procedure was repeated twice more by the same investigator; the mean of the three measures was then used for the analyses. The timing of the taking of the skin-fold measurements was standardised to ensure reliability. According to Becque et al. [33], readings were performed 4 s after applying the caliper. An intra-tester reliability check was conducted on 27 male athletes prior to testing [34].

Estimation of body fat and skeletal muscle mass:

Percentage of body fat was estimated using the anthropometric formula according to Ball et al. [35] for men with percentage of body fat =

$0.465 + 0.180 \times (\Sigma 7SF) - 0.0002406 \times (\Sigma\ 7SF)^2 + 0.0661 \times (age)$

where Σ7SF is the sum of skin-fold thickness of pectoralis, axillar, triceps, subscapular, abdomen, suprailiacal, and thigh in mm; age is in years. The predicted residual sum of squares (PRESS) r^2 was high (0.90) and the PRESS standard error of estimates (SEE) was excellent (2.2% at the mean) for the equation when applied to a sample of 160 men. Skeletal muscle mass (kg) was estimated using the anthropometric equation of Lee et al. [36] with skeletal muscle mass =

$Ht \times (0.00744 \times CAG^2 + 0.00088 \times CTG^2 + 0.00441 \times CCG^2) + 2.4 \times sex - 0.048 \times age + race + 7.8$

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; age is in years; race: 0 for white men and 1 for black men. This equation was validated using magnetic resonance imagining (MRI) to determine skeletal muscle mass. There was a high correlation between the predicted skeletal muscle mass and the MRI-measured skeletal muscle mass (r^2=0.83, P<0.0001, SEE=2.9 kg). The correlation between the measured and the predicted skeletal muscle mass difference and the measured skeletal muscle mass was significant (r^2=0.90, P=0.009) [36].

Statistical Analyses:

Data were checked for normal distribution and for homogeneity of variances. Data are presented as mean ± standard deviation (SD). A one way analysis of variance (ANOVA) was used to determine differences between groups. A Tukey's post-hoc test was performed when the overall F value of the model was significant to detect differences. To investigate a potential association between anthropometric characteristics, training variables and race time, in a first step, Pearson correlation analysis was used to check for associations between parameters. For the strength of a correlation, r>0.70 indicated a very strong, r=0.40 to 0.69 a strong, r=0.30 to 0.39 a moderate, r=0.20 to 0.29 a weak and r=0.01 to 0.19 a negligible relationship, respectively. Since also other variables than skeletal muscle mass such as body fat and training variables are also related to running times [29], we performed, in a second step, multi-variate analyses to correct the association of skeletal muscle mass, body fat and training variables with race time with co-variates. In this second step, all significant variables of bi-variate analysis entered the multiple linear regression analysis (stepwise, forward selection, P of F for inclusion ≤ 0.05, P of F for exclusion ≥ 0.1) Multicollinearity between the predictor variables was excluded with r>0.9. Statistical significance was accepted with P<0.05 (two-sided hypothesis).

RESULTS

Comparison between groups:

The master half-marathoners, master marathoners and master ultra-marathoners showed no differences regarding their age, body mass, body height and body mass index (P>0.05) (Table 1). Skeletal muscle mass was not different between the groups (P>0.05). Percentage of body fat was lowest in the 100-km master ultra-marathoners (P<0.05). Weekly running kilometers and weekly running hours were highest in the 100-km master ultra-marathoners (P<0.05). Running speed during training sessions was not different between the groups (P>0.05).

Association between age and anthropometry:

Age was moderately significant and negatively related

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to skeletal muscle mass for master half-marathoners (r= -0.31, P=0.002) and master marathoners (r= -0.38, P=0.0002). For master ultra-marathoners, age was strongly significant and negatively related to skeletal muscle mass (r=-0.53, P<0.0001). In master half-marathoners (r=0.22, P=0.03), master marathoners (r=0.24, P=0.02), and master ultra-marathoners (r=0.23, P=0.005), age was weakly significant and positively related to percentage of body fat. The coefficient of correlation between age and skeletal muscle mass decreased with increasing length of the running distance (Fig. 1).

For the correlation between age and percentage of body fat, the coefficient of correlation remained unchanged for all three running distances (Fig. 1).

Association of pre-race anthropometry with training:

Skeletal muscle mass showed no association with training variables (P>0.05). Percentage of body fat was moderately significant and negatively related to weekly running kilometers (r=-0.31, P=0.001) and running speed during training sessions (r=-0.33, P=0.0007) in master half-marathoners. In master marathoners, percentage of body fat was weakly significant and negatively related to weekly running kilometers (r=-0.26, P=0.01) and moderately significant and negatively to running speed during training sessions (r=-0.34, P=0.001). In master ultra-marathoners, percentage of body fat was moderately significant and negatively related to weekly running kilometers (r=-0.32, P<0.0001) and weakly significant and negatively to running speed during training sessions (r=-0.25, P=0.001).

Association of age and anthropometry with running times:

Age was weakly significant and positively (r=0.27, P=0.005) related to race time in master half-marathoners, and moderately significant in master marathoners (r=0.33, P=0.001) and master ultra-marathoners (r=0.37, P<0.0001) where the coefficients of correlation increased with increasing running distance. Skeletal muscle mass showed no relationship with race time (P>0.05). Percentage of body fat was

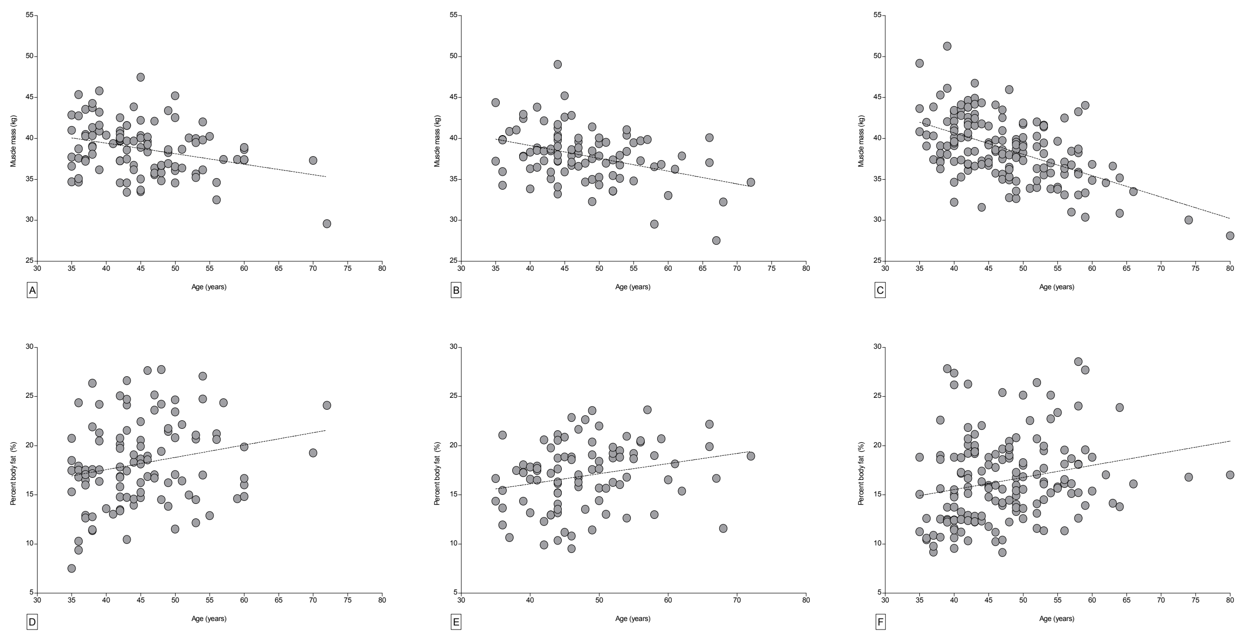

Fig. 1: The association of skeletal muscle mass with age for master half-marathoners (r= -0.31) (Panel A), for master marathoners (r= -0.38) (Panel B) and 100-km master ultra-marathoners (r= -0.53) (Panel C). With increasing length of the running performance, the coefficient of correlation became more negative. For percentage of body fat, the association with age

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for master half-marathoners (r=0.22) (Panel D), master marathoners (r=0.24) (Panel E) and 100-km master ultra-marathoners (r=0.23) (Panel F) showed the same coefficient of correlation

strongly significant and positively related to race times in master half-marathoners (r=0.45, P<0.0001), master marathoners (r=0.48, P<0.0001) and master ultra-marathoners (r=0.48, P<0.0001) where the coefficients of correlation also increased with increasing running distance.

Association of training with running times:

In master half-marathoners, weekly running hours were weakly significant and negatively related(r= -0.28, P=0.004), weekly running kilometers (r= -0.48, P<0.0001) and running speed during training sessions (r= -0.57, P<0.0001) however, were strongly significant and negatively related to race time. In master marathoners, weekly running hours were not related to race time (P>0.05). Weekly running kilometres were weakly significant and negatively (r= -0.25, P=0.01) and running speed during training was strongly significant and negatively related (r= -0.64, P<0.0001) related to race time. For master ultra-marathoners, weekly running hours were negligibly significant and negatively (r= -0.18, P=0.02), weekly running kilometres strongly significant and negatively (r= -0.48, P<0.0001) and running speed during training weakly significant and negatively (r= -0.28, P=0.0004) related to race times.

Multi-variate analyses:

In the multi-variate analysis (Table 2), age (P<0.0001), skeletal muscle mass (P=0.008), body fat (P=0.0001) and running speed during training (P<0.0001) were related to running times in master ultra-marathoners. For master half-marathoners and master marathoners, however, neither age nor skeletal muscle mass was related to running times (P>0.05). For both master half-marathoners and master marathoners, percentage of body fat (P=0.008 and P=0.004, respectively) and running speed during training (P<0.0001) were related to running times whereas in master half-marathoners, also weekly running kilometers (P=0.01) were associated with running times. When the age variable was removed from the multi-variate models (Table 3), body fat was related to half-marathon (P=0.0003), marathon (P<0.0001), and ultra-marathon (P<0.0001) running times.

In master half-marathoners (P<0.0001) and master marathoners (P<0.0001), speed during training was related to running times. In master ultra-marathoners,

Table 2: Associations between significant characteristics after bi-variate analysis and race time for the master half-marathoners, master marathoners and 100-km master ultra-marathoners using multiple linear regression analysis

Group		*β*	*SE*	*P* Value
Half-marathoners (*n*=103)	**Age**	0.3	0.2	0.1
	Skeletal muscle mass	-0.2	0.4	0.7
	Percentage of body fat	0.9	0.3	0.008
	Weekly running hours	0.1	1.1	0.9
	Weekly running kilometres	-0.3	0.1	0.01
	Speed in running training	-4.5	1.0	< 0.0001
Marathoners (*n*=91)	**Age**	0.6	0.3	0.06
	Skeletal muscle mass	1.2	0.8	0.1
	Percentage of body fat	2.2	0.7	0.004
	Weekly running hours	-0.5	1.8	0.8
	Weekly running kilometres	-0.05	0.2	0.7
	Speed in running training	-11.6	1.9	< 0.0001
100-km ultra-marathoners (*n*=155)	**Age**	6.4	1.2	< 0.0001
	Skeletal muscle mass	6.2	2.3	0.008
	Percentage of body fat	7.6	1.9	0.0001
	Weekly running hours	-2.1	1.9	0.3

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	Weekly running kilometres	-4.8	3.9	0.2
	Speed in running training	-1.5	0.3	< 0.0001

ß = regression coefficient; *SE* = standard error of the regression coefficient. The coefficient of determination (r^2) of the model was 0.47 for master half-marathoners, 0.55 for master marathoners, and 0.47 for master ultra-marathoners, respectively

Table 3: Associations between significant characteristics after bi-variate analysis and race time for the master half-marathoners, master marathoners and 100-km master ultra-marathoners using multiple linear regression analysis after removing the age variable

Group		*ß*	*SE*	*P* Value
Half-marathoners (*n*=103)	Skeletal muscle mass	-0.3	0.3	0.3
	Percentage of body fat	0.9	0.3	0.0003
	Weekly running hours	0.6	0.8	0.4
	Weekly running kilometres	-0.3	0.08	0.002
	Speed in running training	-4.3	0.8	< 0.0001
Marathoners (*n*=91)	Skeletal muscle mass	0.9	0.7	0.2
	Percentage of body fat	2.2	0.6	0.0008
	Weekly running hours	0.8	1.3	0.5
	Weekly running kilometres	-0.2	0.1	0.2
	Speed in running training	-11.9	1.7	< 0.0001
100-km ultra-marathoners (*n*=155)	Skeletal muscle mass	-0.7	2.1	0.8
	Percentage of body fat	10.5	2.0	< 0.0001
	Weekly running hours	0.05	2.0	0.9
	Weekly running kilometres	-1.6	0.4	< 0.0001
	Speed in running training	-3.0	4.2	0.5

ß = regression coefficient; *SE* = standard error of the regression coefficient. The coefficient of determination (r^2) of the model was 0.48 for master half-marathoners, 0.45 for master marathoners, and 0.36 for master ultra-marathoners, respectively

however, weekly running kilometers ($P<0.0001$) were related to ultra-marathon running times.

DISCUSSION

The main findings of this study were (i) age was significantly and negatively related to skeletal muscle mass and significantly and positively to percentage of body fat for master runners of all distances, (*ii*) skeletal muscle mass was not related to training characteristics whereas percentage of body fat was related to both volume and running speed during training in master runners of all distances, and (*iii*) percentage of body fat and training characteristics, not skeletal muscle mass, were related to running times for master runners of all distances.

Age, anthropometry and training:

Skeletal muscle mass was not different between the three groups. In all three groups of runners, skeletal muscle mass decreased with increasing age, as hypothesized. The association between skeletal muscle mass and age became more important with increasing length of a running distance. This was also backed up in the multi-variate analyses where both age and skeletal muscle mass were predictor variables for race time in the master ultra-marathoners, but neither in the master half-marathoners nor in the master marathoners. The age-related decrease in skeletal muscle mass can be partially prevented by regular physical training in master athletes [4,5,8,17,35]. Since neither age nor skeletal muscle mass were different between the three groups, we expected to find an association between training variables and skeletal muscle mass in the master ultra-marathoners since they showed differences in the predictor variables. Although training volume increased with increasing race distance, we found no associations between training variables and skeletal muscle mass in these three groups of runners.

In contrast to skeletal muscle mass, percent body was different between the three groups. Percentage of body fat was lowest in the ultra-marathoners, significantly different to both the half-marathoners and the marathoners. With increasing length of the running distance, percentage of body fat became lower in the

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subjects. The lower body fat in ultra-marathoners might be due to their training. For half-marathoners [38], marathoners [40] and 100-km ultra-marathoners [37], an association between body fat and training characteristics has been shown. However, correlation analysis does not prove cause and effect and low body fat in runners might also be due to genetics or diet. Also, percentage of body fat was predictive for both half-marathoners [38] and marathoners [40], but not for 100-km ultra-marathoners [37]. Most probably, training characteristics are more important for ultra-marathoners, since age, running speed during training and weekly running kilometers predicted 100-km race times [37], but not body fat. In all three groups of the present subjects, percentage of body fat increased with increasing age, as hypothesized. In contrast to skeletal muscle mass, we found significant associations between body fat and training variables in all three groups. Also for body fat, the age-related increase in fat mass can be partially prevented by regular physical training in master athletes [5]. Indeed, Legaz and Eston showed that intense training resulted in a significant increase in performance and decreases in sum of six skinfolds, abdominal, front thigh, and medial calf skinfolds [39].

Association of age, anthropometry and training with running times:

The three samples of master's level runners showed no differences regarding their age and anthropometry. Age was significantly related to race times in all three groups after bi-variate analyses, but only for the master ultra-marathoners after multi-variate analyses. Age seems to be predictive only for running distances longer than a marathon [36,37]. A recent study showed that 100-km ultra-marathon race time might be predicted by an equation using running speed during training, running volume and age [37]. For half-marathoners [38] and marathoners [40], however, age was not predictive for race time.

Based upon existing literature it was hypothesized that the decrease in skeletal muscle mass with increasing age would be associated with slower running times in master runners. Skeletal muscle mass was not related to half-marathon and marathon running times, but to ultra-marathon running times after multi-variate analysis. When the variable 'age' was excluded from the multi-variate model, only body fat was related to running times for all three groups. Therefore, skeletal muscle mass seemed not to affect running times in master runners, independent of the running distance. However, body fat was related to running times in master half-marathoners, master marathoners and master ultra-marathoners in contrast to skeletal muscle mass. The coefficient of correlation between body fat and race times increased from r = 0.45 for half-marathoners to r = 0.48 for marathoners and r = 0.49 for ultra-marathoners, respectively. It seemed that low body fat become more important with increasing length of a running distance. Body fat seems to be the most important anthropometric variable in endurance athletes as has already been shown for half-marathoners [38], marathoners [40] and triathletes [26-28].

An important finding was that volume and intensity in training showed differences regarding the length of the running distance. In master half-marathoners and master marathoners, speed during training was related to race times. In master ultra-marathoners, however, weekly running kilometers were related to ultra-marathon running times. Obviously, master athletes prepare specifically for the length of the running distance where ultra-marathoners invest more on volume compared to marathoners investing more on intensity. The same has been reported for long-distance triathletes. Triple Iron ultra-triathletes covering 11.4 km swimming, 540 km running and 126.6 km running relied more on training volume in cycling and running, whereas speed in cycling training was related to race time in Ironman triathletes competing over 3.8 km swimming, 180 km cycling and 42.195 km running [30]. Also when marathoners and 100-km ultra-marathoners were compared, marathoners rely more on speed in running during training whereas ultra-marathoners rely on volume in running training [41].

Limitations and implications for future research:

Skeletal muscle mass and body fat were estimated using an anthropometric equation. Both skeletal muscle mass and percentage of body fat might be more precisely determined using dual energy X-ray absorptiometry (DXA) and magnetic resonance imaging (MRI) [42]. The self-reporting of times and

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distances in training is a limitation since we have no way of establishing the reliability and precision of reporting. For future research, the reliability of training data might be enhanced by quantifying and validating self-reported training data with the use of global positioning system (GPS). Future studies need to investigate whether runners move to longer distances as they lose running speed with increasing age.

CONCLUSION

To summarize, body fat and training characteristics, not skeletal muscle mass, were associated with running times in master half-marathoners, master marathoners, and master ultra-marathoners. Master half-marathoners and master marathoners rely rather on high running speed during training whereas master ultra-marathoners rely on high running volume during training. The common opinion that skeletal muscle mass affects running performance in master runners needs to be questioned.

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