Physiological characteristics of male and female ultra-endurance runners

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This article follows on from the early research conducted at the University of Lincoln in 2007, when a group of 44 ultra-runners completed a questionnaire devised to collect information on the athlete's participation in ultra-racing, history of competition in single and multi-stage events, training schedules, perceived strengths and weaknesses of preparation for events, technical aids used in training and history of injury. A number of research questions were raised through analysis of the results of these questionnaires and this gave rise to the establishment of a comprehensive research programme, involving both laboratory and field data collection.

The first stage in this research programme, completed in late 2008, focussed on building a detailed physiological profile of the ultra-running community, from 'completers' to 'elite'. Physical characteristics of endurance athletes from a range of disciplines, including swimming, cycling, triathlon and running, has been reported in detail by various sources (Noakes *et al.,* 1990; Sleivert and Rowlands, 1996 and Billat *et al.,* 2001) and, more specifically, within ultra-endurance running in a more limited fashion. Yeung and Yeung (2006), for instance, compiled data on cardiopulmonary fitness, flexibility, muscular strength and endurance and body composition of participants in a 100km ultra-endurance team event, and Hoffman (2008) reported the anthropometric characteristics of competitors in the 2007 Western States Endurance Run, but many questions still remain about this particular athletic population.

With this issue in mind, then, around 100 runners were invited to participate in the study, through email correspondence, following advertisement of the study within the ultra-running community. Selection of the final sample group of 40 runners (30 males and 10 females) was based on the criteria that: a) they were engaged in regular training (>3 sessions per week); b) they had competed in ultra-distance races during the previous twelve months and c) they were available for laboratory testing.

Not surprisingly, the final group's ultra-endurance experience was highly varied, with the spectrum of participants covering 'beginners' (<5 ultra-races) through to 'veterans' (>30 ultra-races). In terms of ultra-running ability, both the male and female sub-groups were diverse in their composition, including several competitors who would frequently appear at the head of race results (top 10%). One male, for example, was part of the national UK ultra-running squad and currently holds a number of ultra-race records. These higher ability subjects would be expected to average around 10-12km·h^{-1} for an event, dependent on race terrain and distance. At the other end of the spectrum, there were a number of male and female participants whose primary aim was to complete each event they participated in and would be regarded as ‘back of the pack’ runners. The average speeds of these runners would be around 4-6km·h^{-1}, again dependent on race terrain and distance.

The runners had a number of physiological tests administered when they came to the labs at Lincoln. Firstly, anthropometric data was collected, including simple measures of mass, height, BMI and the sum of four skinfold sites, the latter in order to calculate percentage bodyfat.

Secondly, treadmill testing was then used to ascertain a variety of maximal and sub-maximal physiological characteristics. After a fingertip blood sample was taken, to determine resting blood lactate, and a 10-15 min warm-up administered, the first of the two treadmill tests was conducted. This stage of assessment was aimed at determining the physiological measures of running economy, lactate threshold and lactate turn-point, all deemed important variables in long-distance running. The lactate threshold is useful for athletes as it defines the transition between ‘easy’ and ‘steady’ running, and is an indicator of marathon speed, whereas the lactate turn-point indicates the transition between ‘steady’ and ‘tempo’ running, and is a useful predictor of 10mile to half marathon performance.

Once this test had been completed, the runners were given around 10 minutes to recover until they indicated they were ready to undertake the second and final running assessment, the aim of which was to assess peak aerobic capacity and maximum heart rate and lactate production. The runners were then given a 10 minute warm-down on the treadmill.

The anthropometric characteristics of the male and female athletes studied are presented in table 1. The range of ages (24-59 yrs) and the mean (39.4 yrs) reflects the diversity of the group. The male participants recorded means of 178.0 cm for height, 77.3 kg for mass and 24.3 kg·m^{-2} for BMI. The females recorded means of 161.3 cm for height, 58.0 kg for mass and 22.4 kg·m^{-2} for BMI. Similar values for both genders were observed in the body fat percentages (♂ mean 14.4%; ♀ mean 16.3%) and the sum of the skinfold measurements (♂ mean 31.5 mm; ♀ mean 39.2 mm), indicating a certain level of homogeneity existing with this group of ultra-endurance runners, when considering body composition and percentage fat levels.

Table 1. Anthropometric characteristics of male and female ultra-endurance athletes. Mean, ±s (range).

Factors	*All subjects (n=40)*	*Males (n=30)*	*Females (n=10)*
Age (years)	39.4 ±9.4 (24-59)	40.2 ±9.7 (24-59)	36.9 ±8.3 (28-49)
Mass (kg)	72.5 ±11.8 (50.7-95.8)	77.3 ±9.1 (55.6-95.8)	58.0*** ±4.9 (50.7-68.2)
Height (cm)	173.8 ±10.4 (148-191)	178.0 ±7.6 (156.5-191)	161.3*** ±7.3 (148-174)
BMI ($kg \cdot m^{-2}$)	23.9 ±2.1 (19.2 – 28.7)	24.3 ±1.9 (21.0 – 28.7)	22.4** ±2.2 (19.2 – 25.7)
Skinfold Total (Biceps) (mm)	4.5 ±1.7 (2 – 7.5)	4.2 ±1.6 (2 – 7.5)	5.4 ±1.7 (3 – 7.5)
Skinfold Total (Triceps) (mm)	10.6 ±4.0 (5.5 – 23)	9.2 ±2.8 (5.5 – 15.5)	14.9*** ±4.2 (10 – 23)
Skinfold Total (Subscapula) (mm)	10.6 ±3.7 (5.5 – 21)	10.6 ±3.6 (6 – 21)	10.6 ±4.1 (5.5 – 18)
Skinfold Total (Suprailliac) (mm)	7.8 ±2.8 (3 – 13.5)	7.6 ±2.8 (3 – 13)	8.4 ±3.1 (4.5 – 13.5)
Body Fat Totals (mm)	33.5 ±10.2 (17.5 – 56.0)	31.5 ±9.6 (17.5 – 56.0)	39.2 ±10.1 (24.5 – 51.5)
Body Fat (%)	14.8 ±3.9 (7.8-23.0)	14.4 ±3.9 (7.8-23.0)	16.3 ±3.8 (11.8-22.2)

Table 2 presents the cardiovascular and respiratory characteristics of the male and female subjects. Mean absolute and relative peak $\dot{V}O_2$ values for males were recorded as 4.1 $l \cdot min^{-1}$and 53.3 $ml \cdot kg^{-1} \cdot min^{-1}$ respectively and for females as 2.8 $l \cdot min^{-1}$ and 49.1 $ml \cdot kg^{-1} \cdot min^{-1}$ respectively. The range of values within this group (37.9-67.4 $ml \cdot kg^{-1} \cdot min^{-1}$) demonstrates the variety of aerobic capacities that exists within the sample and is another indicator of the diverse range of performance levels to be anticipated when examining race times. As expected for a group with a spread of ages, a large range of maximal heart rates were recorded from 148-203 $b \cdot min^{-1}$ (mean 182). Also showing a degree of diversity, and another indication of potential performance differentials, the calculations of velocity at peak $\dot{V}O_2$ ranged from 11.1-21.9 $km \cdot h^{-1}$ (mean 15.8). Running economy values were also diverse, with a range from 174-251 $ml \cdot kg^{-1} \cdot km^{-1}$ (mean 203). Finally resting lactate levels ranged from 0.8-3.4 $mmol \cdot l^{-1}$ (mean 1.5) and lactate levels at 3 minutes post peak testing ranged from 5.8-18.0 $mmol \cdot l^{-1}$ (mean 10.7).

Table 2. Cardiovascular and respiratory characteristics of male and female ultra-endurance athletes. Mean, ±s (range).

Oxygen consumption	*All subjects (n=40)*	*Males (n=30)*	*Females (n=10)*
Peak $\dot{V}O_2$ ($l \cdot min^{-1}$)	3.8 ±0.8 (2.06-5.14)	4.1 ±0.6 (2.91-5.14)	2.8*** ±0.4 (2.1-3.6)
Peak $\dot{V}O_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	52.2 ±7.0 (37.9-67.4)	53.3 ±6.9 (37.9-67.4)	49.1 ±6.8 (38.2-59.0)
Peak HR ($b \cdot min^{-1}$)	182 ±11.6 (148-203)	183 ±11.7 (148-203)	180 ±11.7 (159-203)
$v\dot{V}O_{2peak}$ ($km \cdot h^{-1}$)	15.8 ±2.0 (11.1-21.9)	16.2 ±1.8 (13.2-21.9)	14.7 ±2.1 (11.1-17.8)
Running economy ($ml \cdot kg^{-1} \cdot km^{-1}$)	203 ±18.7 (174-251)	202 ±19.0 (174-250)	208 ±18.2 (183-251)

Resting lactate level ($mmol \cdot l^{-1}$)	1.5 ±0.5 (0.8-3.4)	1.5 ±0.5 (0.8-3.4)	1.5 ±0.5 (0.9-2.6)
Post 3-minute lactate level ($mmol \cdot l^{-1}$)	10.7 ±2.6 (5.8-18.0)	11.1 ±2.9 (5.8-18.0)	9.5 ±0.9 (8-10.9)

The lactate threshold (LT) and associated values of the sample group are shown in Table 3. Mean speed at LT for males was recorded at 11.6 $km \cdot h^{-1}$ and for the females at 10.1 $km \cdot h^{-1}$. Heart rate (HR) at LT showed a diverse range between 112-181 $b \cdot min^{-1}$(mean 148 $b \cdot min^{-1}$) relating to a spread of % HR_{peak} values of 73-90% (mean 81%). The percentage of $\dot{V}O_{2peak}$ utilised at LT by the sample group also showed a varied range, from 59% up to 89% (mean 72.7%) continuing to endorse the heterogeneous nature of the subjects. Recorded lactate levels at LT ranged from 0.9-3.6 $mmol \cdot l^{-1}$ (mean 1.8).

Table 3. Lactate threshold profile of male and female ultra-endurance athletes. Mean, ±s (range).

Lactate threshold	*All subjects (n=40)*	*Males (n=30)*	*Females (n=10)*
Treadmill speed ($km \cdot h^{-1}$)	11.2 ±1.4 (8-14)	11.6 ±1.2 (10-14)	10.1 ±1.2 (8-12)
HR ($b \cdot min^{-1}$)	148 ±12.8 (112-181)	148 ±14.0 (112-181)	145 ±8.6 (136-163)
Lactate level ($mmol \cdot l^{-1}$)	1.8 ±0.6 (0.9-3.6)	1.9 ±0.5 (1.2-3.6)	1.7 ±0.7 (0.9-3.2)
HR (% peak)	81 ±4.5 (73-90)	81 ±4.5 (73-90)	81 ±4.5 (76-89)
$\dot{V}O_2$ (% peak)	72.7 ±7.9 (59-89)	73.1 ±6.7 (61-89)	71.4 ±10.9 (59-89)

Table 4 presents the lactate turn-point (LTP) and associated values of the sample group. Mean speed at LTP for the males subjects was recorded at 13.3 km·h^{-1} and for the females at 11.9 km·h^{-1}. Heart rate (HR) at LTP showed a range between 130-189 b·min^{-1}(mean 163 b·min^{-1}), relating to a spread of % HR_{peak} values of 83-94% (mean 89.7%). The percentage of $\dot{V}O_{2peak}$ utilised at LTP by the sample group also showed a range, from 70% up to 99% (mean 83.7%). Recorded lactate levels at LTP ranged from 2.1 to 4.3 mmol·l^{-1} (mean 3.2 mmol·l^{-1}).

Table 4. Lactate turn-point profile of male and female ultra-endurance athletes. Mean, ±s (range).

Lactate Turn-point	*All subjects (n=40)*	*Males (n=30)*	*Females (n=10)*
Treadmill speed (km·h^{-1})	12.9 ±1.5 (9-16)	13.3 ±1.3 (11-16)	11.9** ±1.4 (9-14)
HR (b·min^{-1})	163 ±10.8 (130-189)	163 ±11.3 (130-189)	164 ±9.7 (150-186)
Lactate level (mmol·l^{-1})	3.2 ±0.6 (2.1-4.3)	3.3 ±0.6 (2.1-4.3)	3.1 ±0.4 (2.3-3.6)
HR (% peak)	89.7 ±2.7 (83-94)	89.2 ±2.8 (83-94)	90.9 ±2.1 (88-94)
$\dot{V}O_2$ (% peak)	83.7 ±7.1 (70-99)	83.4 ±6.8 (70-99)	84.8 ±8.3 (73-99)

With the results of the lab testing finally compiled and analysed, the next stage of assessing the implications of this data, and its use for runners, coaches and sport scientists, has now begun. This database of information is of interest and importance in its own right, particularly to the scientific community, as the research on ultra-endurance athletes is sparse. Whilst we tend to know a great deal about the physical characteristics of elite level runners of middle to marathon distance, due to the quantity of studies using these populations, we know very little about the nature of the ultra-running community. The limited research that does exist in the area of ultra-running has often focused on small sample groups of elite athletes (Boileau *et al.,* 1982; Davies and Thompson, 1979a; Davies and Thompson, 1979b; Davies and Thompson, 1986; Wilmore and Brown, 1974) or on other endurance sports (O'Toole *et al.,* 1987) and is dated prior to the current growth in popularity of ultra-endurance racing. More recent studies on endurance and ultra-endurance runners (Noakes *et al.,* 1990; Billat *et al.,* 2001) provide a more appropriate base for comparison with this study, but these are still few and far between unfortunately.

Some recent research in this area has been conducted on larger and more heterogeneous samples of the ultra-running community (Hoffman, 2008; Yeung and Yeung, 2006), but these studies tend to be restricted in scope when the range of physical characteristics were considered. Hoffman (2008), for instance, reported only on the anthropometric characteristics of height, mass and BMI. Yeung and Yeung (2006) are also limited by the usage of field based tests, such as the sit and reach and the Queen's College Step tests, with resultant issues over the reliability and validity of such measures.

The sample group used in this study has anthropometric values similar to those reported by Hoffman (2008), in terms of mean age, mass and height, and also bear comparison with the group assessed by Yeung and Yeung (2006), in the areas of height and body fat percentage, but were heavier and older. In addition, this subject group were similar to the 'above-average running ability' ultra-marathon runners in the Noakes *et al.* (1990) study in terms of mass, but again they were older. Earlier research (Davies and Thompson, 1979a; Davies and Thompson, 1979b) also records the younger and lighter population characteristics at the elite level of performance than shown in this subject group. The anthropometric data is an indicator, therefore, of the varied level of performance to be expected with this sample of runners. The importance of a low percentage body fat for runners is demonstrated by the mean values for both males and females, which, in females in particular, are comparable to those recommended for optimal athletic performance (ACSM, 2000).

The diversity of cardio-vascular, respiratory and associated lactate profiles of this study's running group highlights the heterogeneous nature of the runners and is reflective of both the range of ages and hereditary characteristics within the group. The peak aerobic capacity values are a further endorsement of the variation existing within this sample of runners, with a large range of both absolute and relative values recorded. However, the means are below those reported in other ultra-running research, where mean values of 72.5 $ml \cdot kg^{-1} \cdot min^{-1}$ (males) and 58.2 $ml \cdot kg^{-1} \cdot min^{-1}$ (females) (Davies and Thompson, 1979a; Davies and Thompson, 1979b) and 64.5 $ml \cdot kg^{-1} \cdot min^{-1}$ (Noakes *et al.,* 1990) have been recorded for high level performers. Whilst a few of the athletes in this study were comparable to these means, the range of $\dot{V}O_{2peak}$ values again continues to reinforce the heterogeneous nature of this group.

Data on other variables such as running economy, lactate threshold and peak running velocity and their values within ultra-running subject groups is sparse and this study allows a substantial degree of information to be reported about this community, in order to begin development of such a database. The information from the one study which does exist (Noakes *et al.,* 1990) continues to reinforce the differences that exist between samples, where $v\dot{V}O_{2peak}$ (the velocity attained by the athlete at maximal oxygen uptake level) was recorded as a mean of 20.8 $km \cdot h^{-1}$, in contrast to 15.8 $km \cdot h^{-1}$ in our study group, and speed at lactate turn-point was 15.2 $km \cdot h^{-1}$ in comparison to 12.9 $km \cdot h^{-1}$. Unfortunately, no data is available anywhere in the scientific literature to indicate running economy and lactate threshold values of ultra-runners, but this does indicate the uniqueness of our study in presenting information across such a large range of physiological parameters.

Beyond straightforward comparisons of data, the study now needs to look at relationship of these physiological variables to race performance, as this is what will be of the greatest relevance to the ultra-running community. Noakes *et al.* (1990) draws out from his study an important conclusion related to performance indicators, by stating that the best laboratory-measured predictor of performance for ultra-runners in their study was the peak treadmill running speed ($v\dot{V}O_{2peak}$). The running speed at the lactate turn-point was also highlighted as being a good predictor. Both of these values were superior to other potential predictive factors, including $\dot{V}O_{2max}$ values. Also, peak post-exercise lactate levels, peak heart rates and running economy at 16 $km \cdot h^{-1}$ were noted as being without predictive value.

Data has been collected now at two races in the past year (Round Rotherham and Calderdale Hike) and the analysis of this information and its relationship to the laboratory measures will be the focus of the next articles. Firstly, we will be assessing whether any relationship exists between the physiological characteristics of runners (eg. peak treadmill running speed), obtained through the laboratory tests, and their race performance. Can we thus use certain data from the lab to predict race performance and therefore fine tune the testing process to examine only these relevant variables?

Secondly, it's of interest to see what level individuals are working at during races, in relation to these physiological characteristics. Is there commonality between runners, so does subject X, an ‘elite’ competitor, race in ultras at 70% of his/her $\dot{V}O_2$ max and is this matched by subject Y at the back of the pack, a person whose relative $\dot{V}O_2$ max values are inferior, or are they working at less than or more than this relative percentage?

Finally, the concept of an 'ultra-endurance threshold' (UET) has been mentioned previously by authors (Kreider, 1991) and is potentially linked to ultra-race performance, in the same way the lactate threshold has been shown by various studies to be correlated to marathon performance. This UET is regarded as a level which may be fixed and could be relative to a measurable entity, e.g. an individual's lactate threshold or certain percentage of HR/ $\dot{V}O_2$ max. If this does exist, and we can measure it in the lab, then this would be useful information for athletes and coaches. The data could be used to set an ‘optimal’ pace during an event, avoiding runners pushing too hard early on and ‘blowing up’ or, at the other end of the spectrum, running too conservatively and leaving too much in reserve at the end. It would also be a useful guide to pace setting for training, particularly on the key session of the long endurance run.

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