Heart rate responses of ultra-runners during competition and the existence of an ultra-endurance threshold

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As part of the ongoing ultra-running research programme being conducted at the University of Lincoln, this piece develops the themes introduced in recent articles and builds on the initial focus of the work, which involved creating a detailed physiological profile of the ultra-running community, from ‘completers’ to ‘elite’ was undertaken, with a sample group of 40 runners (30 males and 10 females) undertaking a number of physiological tests at the labs at Lincoln. This allowed a database of anthropometric, cardiovascular and respiratory characteristics to be established and provided the research team with an array of benchmark data that could be used to draw comparisons between runners and allow field measurements, collected at races, to be related to these underlying physiological characteristics. Undoubtedly this fieldwork is what will be of the greatest relevance to the ultra-running community, as it allows us to make recommendations for training and racing based on scientific evidence obtained at typical ultra-races in the UK and is extremely useful material for coaches and runners.

This article thus focuses on the data collected at two races in the past year and a half (Round Rotherham 2008 and Calderdale Hike 2009) and is based on the use of two groups who had already completed the tests in the laboratory and were available to compete at the selected events. The aim of the research was firstly to collate heart rate data during the races, along with sampling of blood for lactate and glucose at regular intervals along the course, and then secondly draw comparisons with the heart rate information and any possible links to the laboratory results obtained on each participant. The area of primary interest to the research team was to see what level individuals are working at during races, in relation to the data recorded in the lab, and to establish whether there were common themes arising between runners, particularly those who ran a successful race.

Also of interest was the examination of the concept of an 'ultra-endurance threshold' (UET), mentioned in previous articles and initially proposed by Kreider (1991), which is potentially linked to ultra-race performance. This UET has been proposed 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 maximum heart rate. If this does exist, and we can relate it from the field to a measurement from 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 related to the key endurance sessions.

During the races, each runner was fitted with a heart rate monitor to record heart rate responses during the entirety of the event. The monitors recorded heart rate at 15s intervals and, after the race was completed by the runner, the data was downloaded onto a computer for analysis. Blood samples were taken at various checkpoints on the courses and involved a small fingertip sample being taken and then measured immediately for levels of blood lactate and glucose. Each runner’s times and positions in the race were recorded at the end of the event. All of the participants in the races returned to the laboratory within a month of the race, in order to allow an up-to date assessment of their current physiological status.

The relevant data from the laboratory testing for the Round Rotherham participants is shown in figure 1 below. Raw anthropometric values of height, weight, age and resting blood lactate were taken before commencement of the treadmill testing. Measures of lactate threshold (defined as the first significant increase (>0.5mmol·l^{-1}) in blood lactate above baseline exercise values) and lactate turn point (defined as the running speed at which there is a distinct ‘sudden and sustained’ breakpoint in blood lactate) and their concomitant values of velocity, heart rate, lactate level and percentages of heart rate and $\dot{V}O_{2peak}$, were all calculated during the first part of the treadmill testing. Also running economy calculated as the oxygen cost of running at four sub-maximal speeds was established during this component of the testing. Peak oxygen uptake ($\dot{V}O_{2peak}$) values were calculated using the highest average 30 sec value of oxygen consumption data during the final stage of the second, maximal test. Velocity at peak oxygen uptake ($v\dot{V}O2_{peak}$) was determined by multiplying the peak $\dot{V}O_2$ value by 60 and dividing the result by the running economy value.

Figure 1. Physiological data on Round Rotherham participants, including important summative cardiovascular and respiratory values.

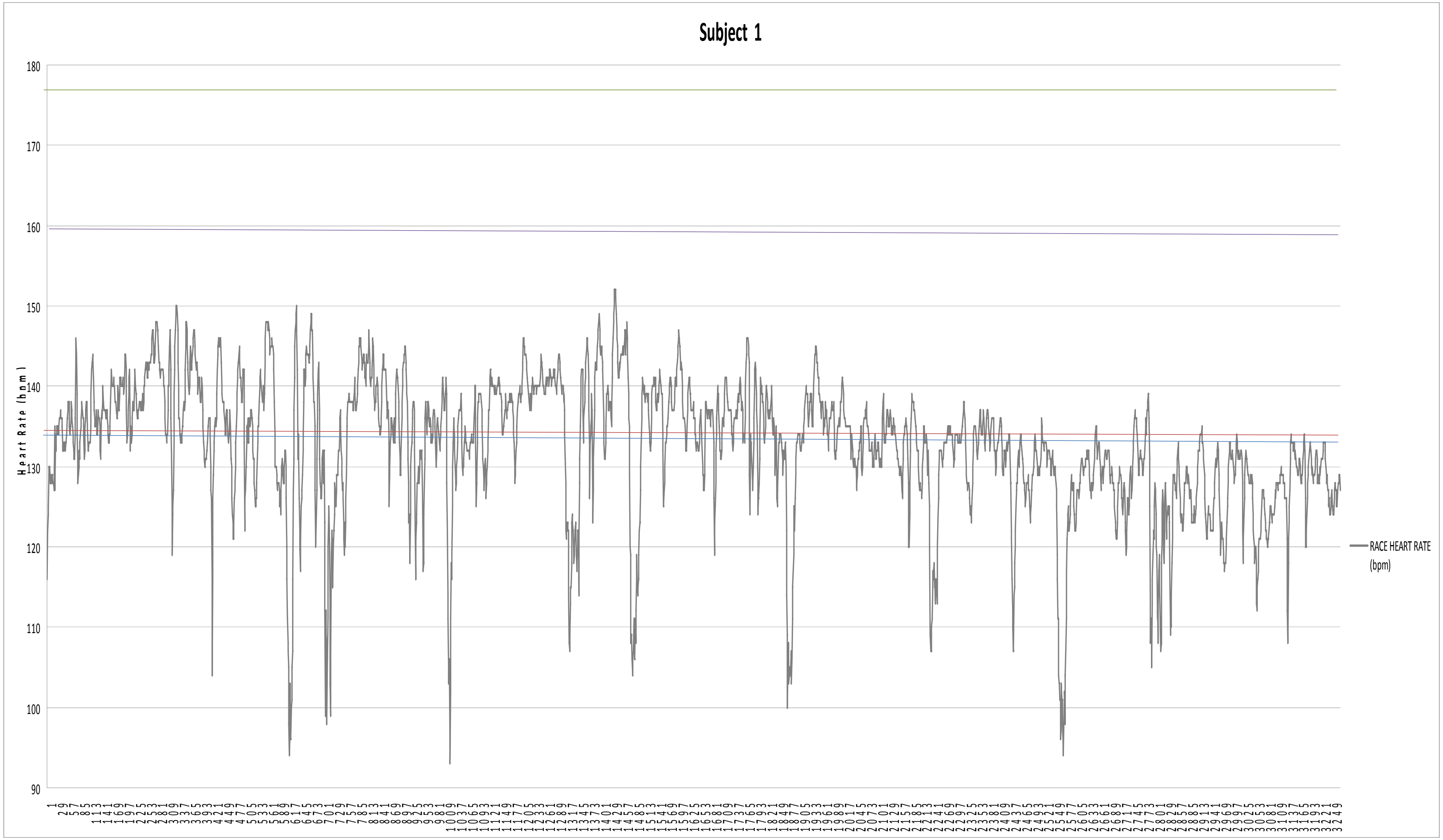
				Blood Lactates		Lactate Threshold	Lactate Turn Point			$\dot{V}O_{2peak}$		
Participant	Ht	Wt	Age	Rest	Max	Velocity - HR - Lactate - %HR max - %$\dot{V}O_{2peak}$	Velocity - HR - Lactate - %HR max - %$\dot{V}O_{2peak}$	Running Economy	HR max	l/min	ml/kg/min	v$\dot{V}O_{2peak}$
1	168	72.1	46	1.6	8.9	12.5km/h - 139bpm - 1.7mmol/l - 78% - 76%	14.5km/h - 159bpm - 2.3mmol/l - 90% - 92%	218ml/kg/min	177bpm	4.31	59.7	16.5
2	182.5	80.8	29	1.6	11.3	12km/h - 147bpm - 1.6mmol/l - 83% - 77%	14km/h - 162bpm - 3.6mmol/l - 91% - 88%	202ml/kg/km	178bpm	4.18	51.8	16
3	165.5	63.5	48	1.7	7.1	10km/h - 134bpm - 1.7mmol/l - 84% - 77%	11km/h - 150bpm - 2.9mmol/l - 91% - 87%	208ml/kg/km	160bpm	2.83	44.6	13
4	174	60.2	30	0.9	9.3	11km/h - 140bpm - 0.9mmol/l - 76% - 63%	13km/h - 162bpm - 2.3mmol/l - 88% - 77%	199ml/kg/km	185bpm	3.55	59	17.8
5	184	86.5	39	1	8	11km/h - 154bpm - 1.0mmol/l - 84% - 78%	13km/h - 171bpm - 2.8mmol/l - 93% - 87%	184ml/kg/km	186bpm	3.81	44.1	14.5
6	174	71.6	27	1.8	13.8	10km/h - 151bpm - 1.8mmol/l - 79% - 72%	12km/h - 168bpm - 3.2mmol/l - 88% - 82%	250ml/kg/km	191bpm	4.3	59.6	14.5
7	155.3	56.9	28	2.4	9.8	10km/h - 163bpm - 1.0mmol/l - 80% - 59%	12km/h - 186bpm - 2.4mmol/l - 92% - 73%	194ml/kg/min	203bpm	3.14	55.2	17
8	177	77.6	46	2.1	11.1	11km/h - 149bpm - 3.0mmol/l - 85% - 80%	12km/h - 159bpm - 3.9mmol/l - 90% - 92%	226ml/kg/km	176bpm	3.94	50.8	15.5
9	173	62.2	45	0.7	6.4	10km/h - 153bpm - 0.9mmol/l - 81% - 74%	12km/h - 172bpm - 2.3mmol/l - 91% - 83%	206ml/kg/km	189bpm	2.95	46.1	14.5
10	183	82.3	26	2.2	10.2	10km/h - 172bpm - 2.6mmol/l - 82% - 69%	11km/h - 182bpm - 3.0mmol/l - 87% - 74%	186ml/kg/min	209bpm	3.75	45.6	14.7

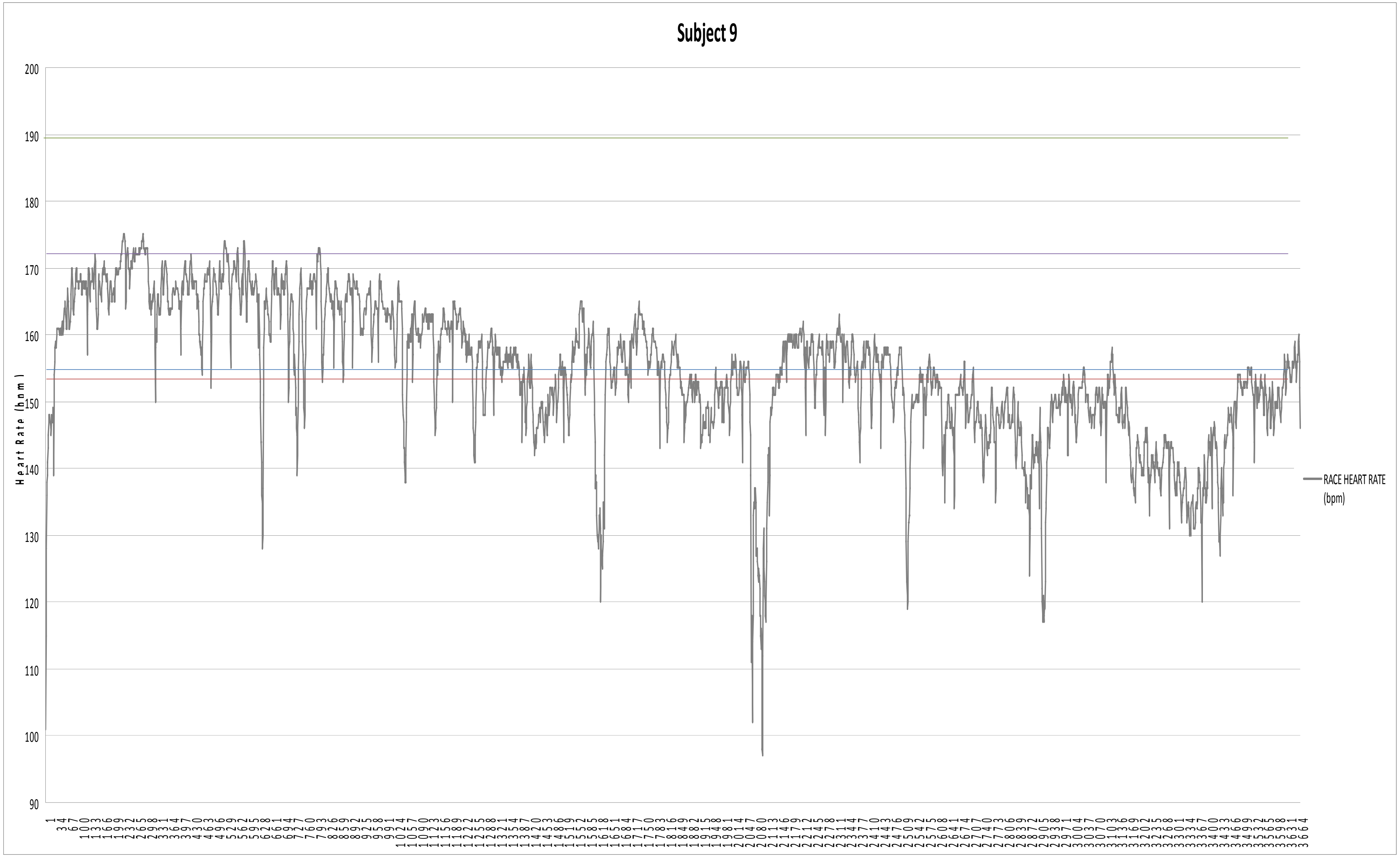
Of particular interest here are the values of the runners' lactate threshold (LT) and lactate turn point (LTP). The LT has been shown to relate to the transition between 'easy' and 'steady' running, and is an indicator of marathon speed, whereas the LTP indicates the transition between 'steady' and 'tempo' running and is a useful predictor of 10 mile to half marathon performance. Previous research has intimated that ultra-runners tend to operate, unsurprisingly, around the LT level, which allows them to maintain a steady aerobic output and is maximizing their efficiency as a performer. If a UET does indeed exist, then it is highly likely that it will be associated with this laboratory indicator. Certainly it would be anticipated that any runner working much above this level over the course of an ultra-marathon would be leaving themselves open to issues such as high fuel utilization and increased possibility of the onset of fatigue, through elevated production of lactic acid and an increasing reliance on anaerobic sources for energy. It is also expected that runners during our investigation would be operating below the LTP, as this level would be far too high to sustain for much beyond a half marathon.

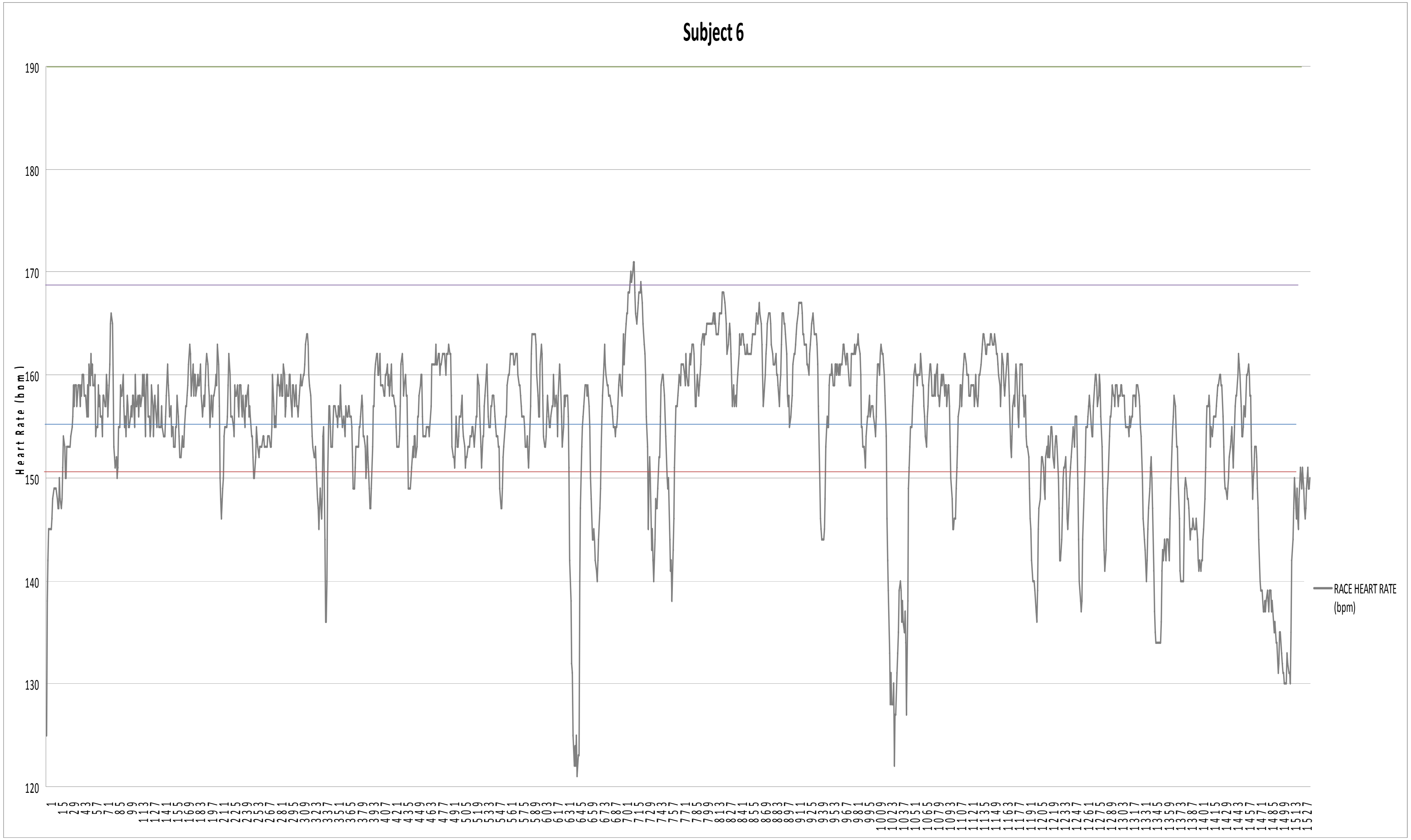
Examination of the heart rate data from the race then allowed for plotting of the various levels linked to the laboratory testing programme. Shown in figure 2 overleaf are traces from three of the runners, chosen as examples of different results obtained from the Round Rotherham race. Four lines are highlighted here, which are associated firstly with the heart rates obtained from the laboratory testing at maximum (green), LTP (purple) and LT (red). The final trace is an average of the heart rate over the entirety of the race (blue).

Participant 1's trace shows a range of recorded values between 93bpm and 152bpm, with the time spent at checkpoints associated with the lower limits recorded here. The majority of the race is spent between 120bpm and 140bpm. The general trend is downwards, which could be allied to a gradual slowing of pace, but also there is a tendency for values to be elevated at the start of a race by the psychological processes linked to increased anxiety and anticipation. Of key interest here, however, is the fact that the mean race heart rate is only 1bpm removed from the LT and this provides evidence that the UET for this runner is at or around this variable. Certainly the level maintained is well below LTP and the runner rarely comes within 10-15bpm of this value. Verbal feedback provided by the runner at the end of the race intimated that they felt that they had maintained a steady progress throughout and ended strongly. They also felt that their overall performance at this race had been close to their personal best, showing anecdotally that their pace management had been excellent throughout.

Figure 2. Heart rate traces recorded by three participants at the Round Rotherham race, with associated laboratory variables highlighted.




Subject 9
Heart Rate (bpm)
RACE HEART RATE (bpm)
200
190
180
170
160
150
140
130
120
110
100
90


Subject 6
Heart Rate (bpm)
190
180
170
160
150
140
130
120
RACE HEART RATE (bpm)

Participant 9's trace shows some similarities with that of participant 1, but one or two differences also exist. For instance, the heart rate is elevated for the first third of the race and this could be due to factors such as an elevated psychological arousal and/or running at a pace which is too quick to maintain throughout. Unlike the first runner, the LTP is surpassed on a few occasions and much of this part of the race is spent within 10bpm of this level. The majority of the race is spent between 140bpm and 160bpm. Crucially, the mean heart rate over the duration of the event is also within only 1bpm of the LT, giving further credence to the idea of the UET and its level being associated strongly with this laboratory measure. Again, this runner completed the course in a positive frame of mind and felt that their performance had been a strong one. Although the heart rate starts to drop towards the end, possibly as a result of fatigue, the runner manages to complete the course with an upward trend in heart rate, indicating an increased pace as the finish line neared.

Finally, the heart rate trace of participant 6 is shown and this demonstrates a number of issues. Of note is that the runner did not complete the course, finishing at the third checkpoint just after 24 miles. The main area of concern is that the mean race heart rate is around 5bpm above the LT and the runner spends much of the early part of the race between 5-10bpm above the LT. In the middle part of the run, the participant is often within 5-10bpm of the LTP and at one point spends a period of time at or around this level. This data set adds credence to the concept of pace setting at a heart rate associated with the LT and the runner may well have suffered from an early onset of fatigue due to operating at a level that was, at times, well above the LT.

The final set of data that is of interest from the Round Rotherham race is that of the blood lactate sampling, shown below in Figure 3. Runners 2, 6, 7 and 8 failed to complete the full 50 mile route and 'x' denotes a sampling error.

Figure 3. Blood lactate data obtained from all participants at the Round Rotherham race, with associated laboratory test values and checkpoint details.

	Laboratory values		Start	CP1 - 10.2miles	CP2 - 16.7miles	CP3 - 24.6miles	CP4 - 30.6miles	CP6 - 41miles	Finish - 50miles
	Rest/LT	LTP	Blood Lactate	Blood Lactate	Blood Lactate	Blood Lactate	Blood Lactate	Blood Lactate	Blood Lactate
Participant	*(mmol/l)*	*(mmol/l)*	*(mmol/l)*	*(mmol/l)*	*(mmol/l)*	*(mmol/l)*	*(mmol/l)*	*(mmol/l)*	*(mmol/l)*
1	1.6	2.3	2.1	1	1.1	0.9	1	1	0.7
2	1.6	3.6	1.3	1	1.6	1	1.3		
3	1.7	2.9	1.7	1.9	1.1	1.3	1.3	2.1	1
4	0.9	2.3	3.6	1.7	1.4	1.1	0.7	2.1	0.7
5	1	2.8	1.6	3.1	1.8	x	0.7	2.1	1.8
6	1.8	3.2	1.3	0.7	1.1	1.4			
7	2.4	2.4	1.1	x					
8	2.1	3.9	2.2	2	2.9	x	0.9		
9	0.7	2.3	2.1	1.4	1.3	1.2	1	2.3	1.1
10	2.2	3.0	1.3	x	1.7	1.2	1.3	x	1.4

This data concurs with much of that obtained through heart rates, in that the blood lactate levels obtained at the relevant checkpoints are allied closely with the laboratory resting/LT values and only on one occasion does the race level rise above the laboratory recorded value at LTP. Only at checkpoint 6 are values consistently recorded above LT, and this correlates with the location of the checkpoint at the top of an incline, but even then only one of these values touched the laboratory level recorded at LTP (participant 9). It would therefore appear from this data that much of the race is spent around baseline/LT levels and the majority of the energy provision for the runners is generated through aerobic mechanisms.

In summary, it would appear from this data collection exercise that there is evidence for the existence of a UET and this would seem to be linked into the LT level of the individual runner. Knowing this would be useful for the aspiring ultra-runner, both in terms of setting an appropriate pace for their long, steady training runs and also, more importantly, for their pace management during races. Assessing this optimal level of intensity of effort will be key to sustaining a pace that will ensure that an athlete does not ‘blow up’ before the finish and end up with a ‘dnf’ or a performance that is well below par nor do they run at a pace that is too slow and they feel that there was too much left in the tank at the end and they have underachieved.

References

Kreider, R. B. (1991). Physiological considerations of ultraendurance performance. *International Journal of Sport Nutrition*, 1(1), 3-27.