

**JEPonline**  
**Journal of Exercise Physiologyonline**

**Official Journal of The  
American Society of Exercise Physiologists (ASEP)**

**ISSN 1097-9751**

An International Electronic Journal

**Volume 6 Number 3 August 2003**

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**Sports Physiology**

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**ULTRA-ENDURANCE CYCLING: A FIELD STUDY OF HUMAN PERFORMANCE  
DURING A 12-HOUR MOUNTAIN BIKE RACE**

Jon Linderman<sup>1</sup>, Tim Demchak<sup>2</sup>, Julie Dallas<sup>3</sup>, Janet Buckworth<sup>3</sup>

<sup>1</sup>Department of Health and Sport Science, University of Dayton; <sup>2</sup>Athletic Training Department, Indiana State University, <sup>3</sup>School of Physical Activity and Education Services, The Ohio State University

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**ABSTRACT**

**ULTRA-ENDURANCE CYCLING: A FIELD STUDY OF HUMAN PERFORMANCE DURING A 12-HOUR MOUNTAIN BIKE RACE. Jon Linderman, Tim Demchak, Julie Dallas, Janet Buckworth**  
*JEPonline*. 2003;6(3):10-19. To investigate changes in physiological and psychological function during ultra-endurance events, 6 healthy cyclists (31.5±1.6 years) were studied during a 12-hour mountain bike race. Subjects covered 119-170 km, at average velocities of 11-14 km/hour. During the first two hours of the event heart rates averaged 155-157 beats/min, declined significantly during the third hour (142±14 beats/min; p<0.05), and was largely unchanged throughout the remaining nine hours of the race. Subjects consumed 1550-3300 Kcals during the event with an average of 662±76 g of carbohydrate. Although subjects consumed 4500-6400 mL of fluid during the race, hydration status, assessed from changes in body weight, indicated a dehydration indirectly quantified as a ~4% decrease in body weight pre- to post race (2.3±1.4 kg; p<0.05). Using the 10-point Borg Scale subjects rating of perceived exertion (RPE) increased hourly from 4.0±1.3 after the first hour of competition to 9.2±1.0 during the twelfth hour of competition (p<0.05). Profile of moods state (POMS) administered during the event revealed declines in vigor pre- to post-race (11.5±2.3 vs. 3.8±1.7; p<0.05), with concomitant increases in fatigue scores (5.3±2.8 vs. 19.3±0.5; p<0.05). Results of the present investigation suggest greater declines in mental than physiological function during prolonged off-road cycling competition.

Key Words: hydration, nutrition, psychobiology, POMS

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**INTRODUCTION**

Ultra-endurance events are generally considered to be continuous events lasting longer than 5-6 hours in duration. The popularity of these events including triathlons of Ironman™ distance (2.5 mile swim, 110 mile cycling, and 26.2 mile run), the coast-to-coast bike race known as RAAM (Race Across America), as well as 12-24 hour mountain bike races have increased in the later decades of the twentieth century. To date there have

been few studies focusing on sustained physical activity lasting more than 5 hours. During an ultra-endurance mountain bike race competitors traverse a designated off-road course ranging from 4-10 miles, attempting to complete as many laps as possible during the duration of the race (e.g. 12 hours). These events offer an ideal opportunity for studying participants engaged in a single mode of activity continuously. Further, because these events are staged on a closed course, investigators have frequent access to subjects to investigate the physiological and psychological effects of prolonged exercise.

Prolonged exercise will result in considerable metabolic heat production, and the evaporation of sweat is the main method of heat dissipation. Sweat rate increases in response to exercise (1,2), and increases further when exercise intensity is held constant and ambient temperature is increased (1,2). Thus, during prolonged exercise high ambient temperature increases the risk of dehydration. Sweat rate and subsequent dehydration are increased in hot humid environments, reflected by significant decreases in body weight. Further, dehydration decreases work tolerance,  $VO_2$  max, and stroke volume, while increasing the heart rate response relative to a cool environment.

Although individuals may complete a marathon without caloric supplementation, it is likely that an ultra-endurance athlete will consume thousands of calories during an event. It is well known that carbohydrate supplementation maintains blood glucose levels and delays both fatigue (3,4), and the perception of fatigue (5). However, most studies on carbohydrate supplementation have focused on activities no greater than 3-4 hours (6). Therefore, to date little is known about energy consumption during ultra endurance activities and the effect of energy depletion and replacement on blood glucose levels, mood states, and performance.

An athlete's sense of fatigue, depression, or vigor can influence performance (7). Many studies have reported decreases in performance on skills tests when subjects felt fatigued (7,8). However, most studies to date have looked at changes in mood pre- and post- activity, and have not assessed serial changes throughout a prolonged event. Central fatigue, rather than other causes of fatigue such as low energy availability is thought to cause cessation of exercise during prolonged exercise (>60 minutes) (9). In addition, because environmental conditions such as temperature, humidity, and illumination can affect mental state it would be of great interest to determine changes in mood throughout an ultra endurance event when environment is likely to change. Thus, the purpose of this study was to observe the physiological and psychological responses of athletes during a continuous 12-hour mountain bike race.

## **METHODS**

### **Subject Characteristics**

Twenty-two cyclists (20 male, 2 female) participated in the 1998 KENDA Nite Glo 12-hour mountain bike race in Chillicothe, Ohio. A total of 6 subjects (4 male, 2 female) volunteered to participate in the study. Beginning at midnight July 31<sup>st</sup>, subjects cycled on a closed course ~8km in length for 12 hours. This study was approved by the Ohio State University Institutional Review Board and all subjects signed an informed consent. The race sponsors provided medical support for all race participants and subjects provided their own bicycle for participation in the event. Subjects were provided with lighting systems on both their bikes and their helmets in order to compete in the dark (Nite Ride; San Diego, CA), and were provided with a two-way radio Motorola Walkabout<sup>TM</sup> affixed to their bicycle to facilitate communication between subjects and researchers.

### **Data Collection**

#### ***Environment and Performance***

Temperature, humidity, and barometric pressure were monitored pre-race and every hour throughout the race using a dry bulb thermometer, barometer, and sling psychrometer. The performance of the subjects was determined by total number of laps completed (distance) and velocity (distance/hour). Performance was corrected for time off the bike in the transition area when subjects rested, ate, or required work on their equipment. Heart rate was recorded each lap using an Acumen heart rate monitor (Acumen Inc.; Sterling, VA). Subjects relayed their heart rate to the investigators via radio at a pre-determined location along the racecourse.

### ***Nutrition and Hydration***

Each athlete completed a 48-hour diet recall the day of the race. Throughout the race food was provided to the subjects ad libitum. During the race subjects primarily consumed a maltodextrin gel containing 110 kcal/packet (GU; Sports Street Marketing; Berkeley, CA). In addition, subjects were provided free access to supplemental foods, with all intake of foods recorded by investigators. Total caloric consumption was assessed from food and fluids consumed. Subjects were also provided fluid ad libitum in the form of water or a 6% carbohydrate-electrolyte solution (Sports Street Marketing). Changes in hydration status were determined by changes in body weight pre- to post-race. Further, subject's hematocrit (10) and blood glucose concentrations (Lifescan, Johnson & Johnson) were determined pre- and post race from venipuncture.

### ***Psychological Parameters***

Changes in mood and psychological state were assessed using the Profile of Mood States (POMS), and rating of perceived exertion (RPE). An abbreviated version of the POMS was used to determine changes in six mood dimensions: tension-anxiety, depression-dejection, anger-hostility, vigor-activity, fatigue-inertia, and confusion-bewilderment (11). The abbreviated version of the POMS form consists of 30 adjectives, rated on a 5-point scale ranging from "not at all" to "extremely." The POMS was given 4 hours prior to the race and every 2 hours during the race via radio communication. During the race only the vigor and fatigue subscales were assessed. Borg's 10 point Likart scale was used to determine RPE every hour during the race via radio (12). The same individual administered the POMS & RPE throughout the race to help prevent possible verbal effects on the answers.

### **Statistical Analyses.**

Changes in body weight, blood glucose, hematocrit, and total mood disturbance were analyzed with a paired t-test, while changes in velocity, heart rate, fluid and caloric consumption, POMS, and RPE were analyzed using repeated measures ANOVA. When the test of within-subjects effects was significant tests of within subject contrasts were used to determine significance between time points. The level of significance determined a priori was  $p < 0.05$ .

## **RESULTS**

### **Environment**

Dry bulb temperature decreased from 15° C at midnight to 13.9° C at 7am, increasing with the rising sun to ~26° C at the conclusion of the event (Table 1). Humidity rose from 84% at midnight to 89% at 7am, falling to 69% by the conclusion of the event. Course conditions were likely affected by humidity with a wet or damp surface during the humid evening, drying with rising temperature and decreasing humidity during the morning hours following sunrise at ~7:00 am.

**Table 1. Effect of time on wet (Wb) and dry (Db) bulb temperatures, as well as relative humidity (%), measured one hour prior to the event (2300) and every hour through to the conclusion.**

	<i>Time of Day</i>													
	2300	2400	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200
<b>Db (°C)</b>	17.2	15	18.9	17.3	17.3	15.6	15	15.6	13.9	20.6	22.2	23.9	26.1	25.6
<b>Wb (°C)</b>	16.7	16.1	16.1	16.1	14.4	13.3	13.3	11.1	12.8	16.1	18.3	20	20	21.1
<b>Humidity (%)</b>	84	80	85	90	75	78	82	59	89	64	70	70	58	69

### **Performance**

Performance variables included total distance traveled (km) and average velocity (km/h). Total distance covered during the 12-hour event ranged from 119-170 km. Average distance covered was  $140 \pm 10$  km. During the first

7 hours of the race average velocity declined  $\sim 3$  km/h ( $14.2 \pm 0.6$  vs.  $11.1 \pm 0.8$  km/h) ( $p < 0.05$ ). Velocity increased to  $13.6 \pm 0.4$  km/h by 9 am ( $p < 0.05$ ), with no further increase throughout the event (Figure 1).

### Physiological Parameters

Heart rate (HR) declined throughout the entire race, decreasing an average of  $\sim 20$  beats/min by the 11th hour of the race (Figure 2). When compared to the first hour of the race HR had declined  $\sim 13$  bpm by the third hour ( $157 \pm 7$  vs.  $141 \pm 7$  beats/min) ( $p < 0.05$ ), and generally remained unchanged throughout the remainder of the event.

### Nutrition

Subjects consumed between 1500 and 3300 Kcal during the event, primarily from carbohydrate (CHO) (Table 2). Caloric consumption decreased over the course of the event (Figure 3). During the first hour of the event subjects consumed  $451 \pm 75$  Kcal, however, by the second hour caloric consumption had decreased to  $222 \pm 59$  Kcal ( $p < 0.05$ ). By the sixth hour of the race caloric consumption had decreased further to  $151 \pm 81$  Kcal ( $p < 0.05$ ). During the last hour of the event subjects consumed just  $25 \pm 22$  Kcal ( $p < 0.05$ ). Total CHO consumption averaged  $662 \pm 76$  g over the course of the event, and CHO consumption averaged  $0.9 \pm 0.1$  g/min. Post-race blood glucose levels ( $101.8 \pm 7.9$  mg/dL) did not reflect hypoglycemia and was not different from pre-race blood glucose ( $100.7 \pm 6.7$  mg/dL) (Table 3).

### Hydration

Subjects consumed between 4500 and 6400 mL of fluid during the course of the event (Table 2). Fluid consumption was highly variable throughout the event (Figure 4) averaging  $460 \pm 26$  mL/hour. During the first hour fluid consumption averaged  $748 \pm 211$  mL, but fell to just  $295 \pm 74$  mL by the fifth hour of the event ( $p < 0.05$ ). Subjects were significantly dehydrated at the end of the race as evidenced by loss of body weight (Table 3). Body weight decreased an average of  $2.3 \pm 1.4$  kg, or  $\sim 4\%$ , from pre- to post-race ( $71.2 \pm 3.9$  vs.  $68.7 \pm 3.3$  kg) ( $p < 0.05$ ). Changes in hematocrit did not reflect dehydration.

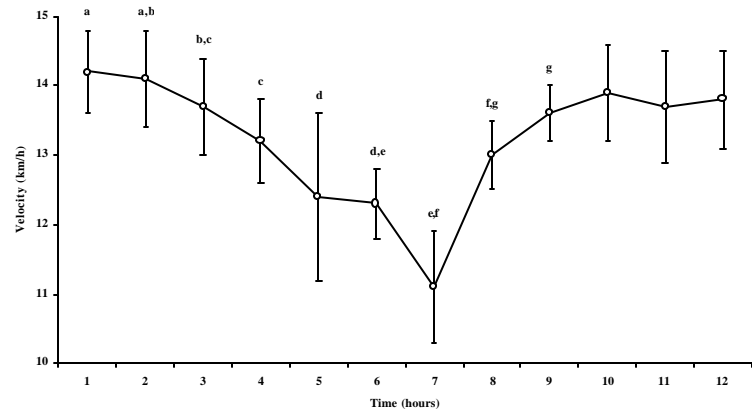


Figure 1. Velocity (km/hr) during a continuous 12-hour ultra-endurance off-road cycling event. Values are means  $\pm$  SE. Time points with like symbols significantly different from each other ( $p < 0.05$ ).

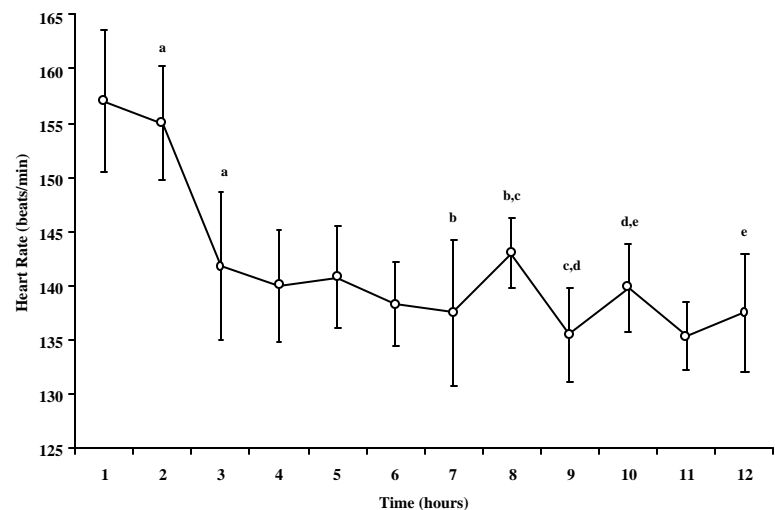


Figure 2. Heart rate vs. time over the course of a continuous 12-hour ultra-endurance off-road cycling event. See Figure 1 for explanation of symbols.

### Psychology

Psychological measurements revealed significant changes in rating of perceived exertion (RPE) (Figure 5) as well as the fatigue and vigor subscales of the Profile of Mood States (POMS) (Figure 6). After two hours of racing, RPE increased from  $4.0 \pm 0.5$  to  $5.2 \pm 0.5$  ( $p < 0.05$ ). Between the fifth and eleventh hours of racing RPE continued to increase from  $5.5 \pm 0.4$  to  $18.8 \pm 0.3$  ( $p < 0.05$ ). Similarly, the POMS subscale rating for fatigue increase from  $6 \pm 1.6$  at 2 hours to  $14 \pm 2.4$  at 6 hours ( $p < 0.05$ ), and by the end of the event had risen further to  $19.3 \pm 0.5$  ( $p < 0.05$ ). Vigor fell throughout the event from  $11.5 \pm 2.3$  to  $1.8 \pm 0.7$  by the twelfth hour ( $p < 0.05$ ).

**Table 2. Total fluid, energy consumption, and composition of energy consumed by each subject during a 12-hour mountain bike race.**

Subject	Total Fluid	Total Energy	Energy Composition		
	(mL)	(Kcals)	% Fat	%CHO	%Protein
1	5361	3037	11	87	2
2	5032	2493	2	95	4
3	6370	3319	0	100	0
4	5817	3093	0	100	0
5	4898	1458	0	100	0
6	3090	3090	1	97	1
<b>Mean±SD</b>	<b>5095±1122</b>	<b>2748±688</b>	<b>2±5</b>	<b>96±5</b>	<b>1±2</b>

**Table 3. Changes in body weight (kg), hemotocrit (%), and venous blood glucose (mg/dL) measured prior to and immediately following 12 hours of mountain bike racing.**

Subject	Bodyweight		Hematocrit		Glucose	
	Pre-	Post-	Pre-	Post-	Pre-	Post-
1	72.8	71.8	46	42	117	75
2	80.9	76.4	43.5	44.5	80	107
3	75.9	70.9	46.9	43	90	104
4	76.4	72.7	46.5	44.5	96	108
5	58.6	56.4	41.5	38.5	117	90
6	62.7	63.7	40	42	104	127
<b>Mean±SD</b>	<b>71.2±9.6</b>	<b>68.7±8.1*</b>	<b>44.1±3.2</b>	<b>42.4±2.4</b>	<b>100.7±16.1</b>	<b>101.8±19.3</b>

\*significant difference ( $p < 0.05$ )

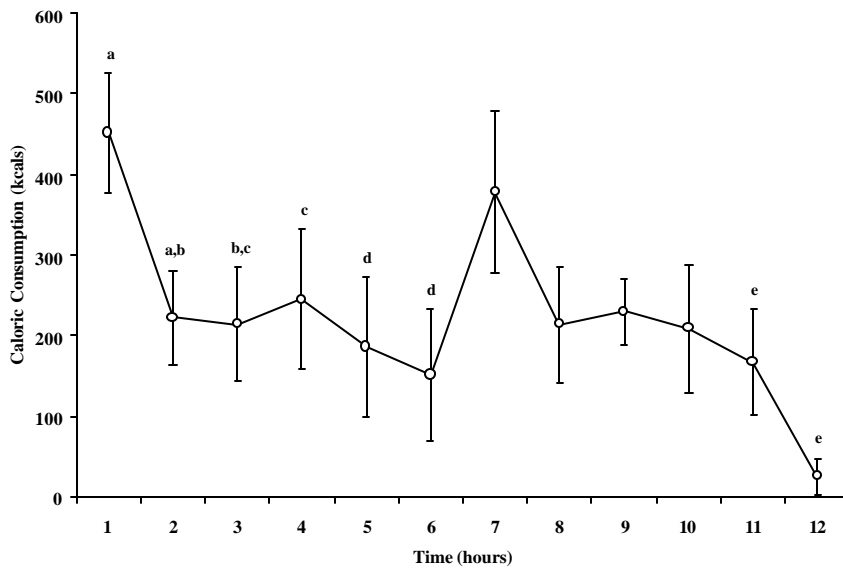


Figure 3. Caloric and fluid consumption vs. time over the course of a continuous 12-hour ultra-endurance off-road cycling event. See Figure 1 for explanation of symbols

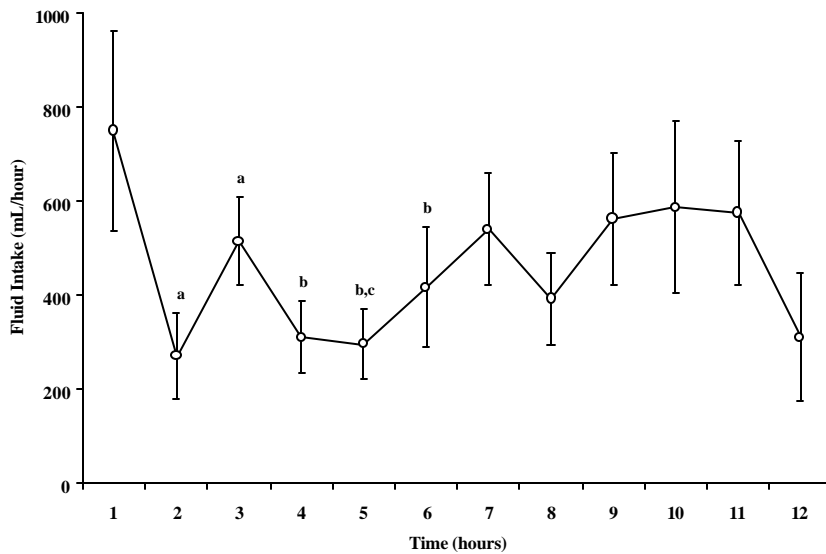


Figure 4. Fluid intake vs. time over the course of a continuous 12-hour ultra-endurance off-road cycling event. See Figure 1 for explanation of symbols.

## DISCUSSION

The purpose of this study was to characterize select physiological and psychological variables in the field during an ultra-endurance cycling race. This event offered an ideal opportunity for studying participants engaged in a single mode of continuous activity. To our knowledge, this is the first study to investigate performance criteria, estimate total caloric and fluid consumption, and characterize changes in physiological and psychological function during an ultra-endurance competition.

Total distance covered during the 12-hour event ranged from 119-170 km. This range of distance traveled is consistent with a sample size of only six competitors, who were heterogeneous in ability and gender. Because changes in body mass were minimal, we contend that the subject's velocity was therefore associated with their power output. Velocity declined significantly during the first 7 hours of the event ( $14.2 \pm 0.6$  vs.  $11.1 \pm 0.8$  km/hour;  $p < 0.05$ ), and then increased to  $13.6 \pm 0.4$  km/h during the eighth and ninth hours of the event ( $p < 0.05$ ), with no further increase during the final three hours (Figure 1). Because investigators could neither control environment nor the condition of the course, it is unclear how velocity and thus power output were increased during the later 5 hours of the event.

Increased illumination could have improved the efficiency with which subjects completed the course. In addition, as humidity fell following sunrise, the course became dryer which likely decreased rolling resistance. Interestingly, however, changes in velocity were not associated with increased myocardial demand as determined from heart rate.

It was anticipated that if subject velocity was representative of power output, then HR would change in a similar pattern as velocity, and also increase in response to both metabolic heat production, thermal stress of the environment, and dehydration. Throughout the first three hours of the event subject's heart rates (HR) were

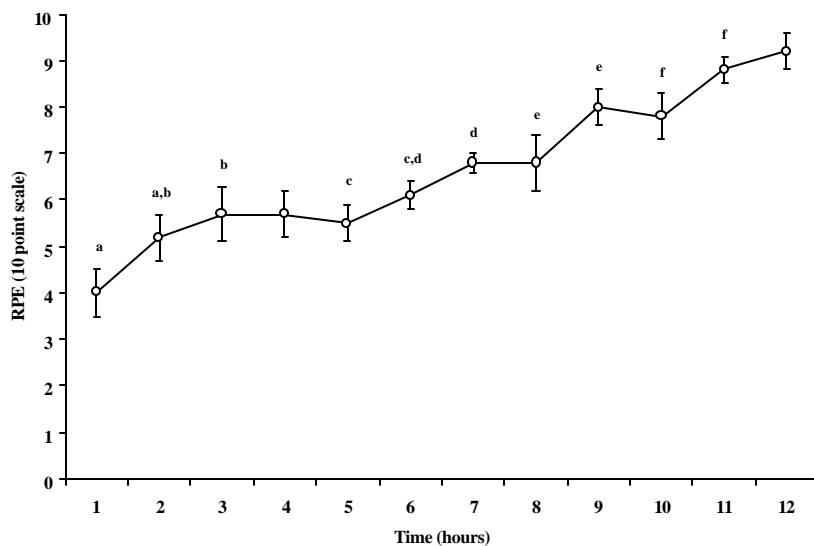


Figure 5. Rate of perceived exertion (RPE) vs time over the course of a continuous 12-hour ultra-endurance off-road cycling event. See Figure 1 for explanation of symbols.

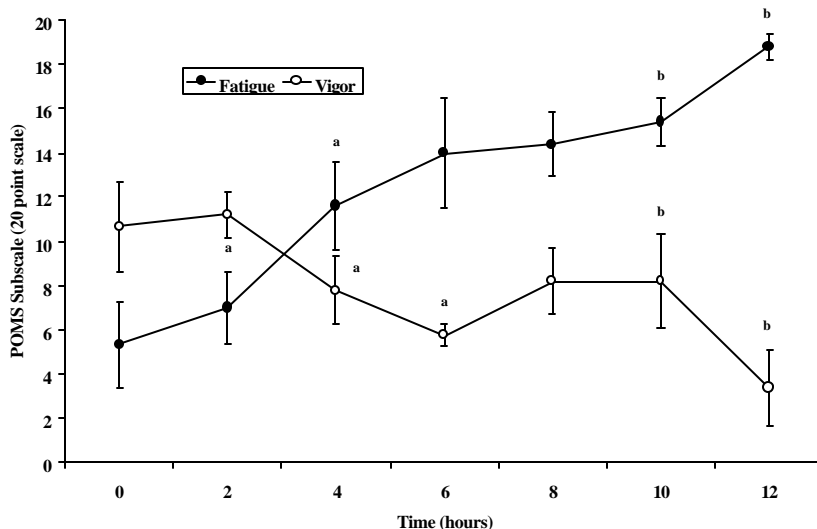


Figure 6. Changes in POMS fatigue and vigor subscales time over the course of a continuous 12-hour ultra-endurance off-road cycling event.

quite variable, but as with velocity (Figure 1) decreased significantly (Figure 2). It seems probable that the decline in heart rate early in the event was associated with decreased race velocity. However, heart rate remained relatively stable following the 3<sup>rd</sup> hour of the event. Considering the large metabolic heat production likely associated with the energy requirement necessary to compete in this event, the rising temperatures following sunrise (Table 1), and the increased velocity following sunrise (Figure 1), HR would be expected to rise. One limitation of the study was that HR was only sampled once per hour. More frequent HR sampling may have provided a clearer understanding of the field relationship between HR and work. In addition, the investigators could not control other factors such as changing course conditions and illumination, which may have altered the effort required to complete the course at a given distance. It is also unclear why HR response did not increase in response to dehydration.

Sawka and Pandolf reported that dehydration, indirectly assessed from a 4% decrease in body weight, led to decreases in exercise performance and maximal work capacity ( $VO_2\max$ ) of 27% and 48%, respectively. It is also known that modest dehydration will lead to an increased HR at the same exercise

intensity to compensate for a decrease in stroke volume. In the present study subjects were exposed to a fairly wide range of ambient temperatures, humidity, and radiant heat (Table 1). With ambient temperatures in the mid 20's after sunrise core temperature would be expected to rise during the race. With humidity at ~70% evaporative heat loss would also be impaired. Subjects consumed an average of  $460 \pm 26$  mL/hour, well below the 600 mL/hour recommended by the American College of Sports Medicine. Thus, it was not unexpected to find that subjects were dehydrated following the event (Table 3). In the present study subjects lost nearly 4% of their bodyweight pre- to post-race, and thus, we would expect a decrease in their exercise performance. Given this level of dehydration and the increased performance by subjects following sunrise, we conclude that course conditions must have improved substantially for subjects to improve performance as they dehydrated. Further, we conclude that in spite of access to water at all times the subjects either did not or could not drink sufficiently to maintain pace with water losses due to sweating. In addition to unrestricted access to fluid subjects were given free access to supplemental energy needed to complete the event.

During 12 hours of continuous racing an individual will require thousands of calories to provide energy for the working muscles. Therefore, energy availability is extremely important to endurance athletes in order to maintain power output and performance. Carbohydrate supplementation every 20-30 minutes during exercise helps to maintain blood glucose levels and delay physical fatigue (3,4,13,14,15). Research has also found that consumption of carbohydrates could lead to a lower perception of fatigue (5). During prolonged sporting activities such as field hockey, consumption of carbohydrate drinks during practice led to a lower feeling of fatigue as compared to players that consumed a placebo drink (8). However, most studies on carbohydrate supplementation have focused on activities no greater than 3-4 hours (6).

The range of total caloric intake was quite large, 1550-3300 Kcals. In addition, with the exception of a spike around sunrise, caloric consumption declined after the first hour of exercise. Subjects primarily chose to consume a maltodextrin gel throughout the event, which is a popular CHO supplement with endurance athletes. Subjects consumed an average of  $662 \pm 76$  g of CHO during the event. Interestingly, the rate of CHO  $0.9 \pm 0.1$  g/min, is fairly close to maximal oxidation rates for exogenous CHO of 1-1.2 g/min (16). Recently, Couture et al. reported that subjects exercising at  $\sim 70\%$  of  $VO_{2max}$  for 2 hours derived  $\sim 60\%$  of their energy from CHO and that oxidation of a glucose solution (3.5g/kg bodyweight) increased throughout the exercise bout to 1.25 g/min by the end of the second hour (16). In the present study subjects exercised at  $\sim 75\%$  of their age predicted heart rate following the third hour of the event. This level of intensity would require significant use of endogenous and exogenous CHO and would necessitate CHO supplementation. Therefore, unlike the large fluid deficit leading to dehydration, subjects appeared to be more closely match CHO supplementation with use. However, some subjects reported feelings of nausea, cramping, or bloating during the event. These observations may be associated with poor blood flow to the gut due to redistribution of blood flow to working skeletal muscle and to the skin for thermoregulation. These gastrointestinal problems may have been associated with the large deterioration in psychological state reported by the subject's a whole.

In the laboratory Borg's 10 point rating of perceived exertion scale (RPE) increases with increased exercise intensity during a progressive maximal exercise test (12). However, in the present study we observed a progressive linear increase in RPE from  $\sim 4$  to nearly 9 by the end of the event. Interestingly, the increase in RPE over time was apparently independent of exercise intensity. For example RPE increased  $\sim 2$  points in by the end of the third hour while subject velocity decreased significantly. RPE continued to increase hourly during the event as velocity first remained constant and then increased. It is possible that during prolonged endurance activity that the RPE scale is more reflective of psychological state than perception of exercise intensity.

An athlete's sense of fatigue, depression, or vigor, can influence performance (7). Many studies have reported decreases in performance on skill tests when subjects felt fatigued (7,8). However most studies to date have looked at changes in mood pre- and post- activity, or following training (17), and have not assessed changes throughout a prolonged event. To our knowledge the present study is the first to measure serial changes in mood throughout a 12-hour ultra endurance event using the fatigue and vigor subscales of the Profile of Mood States (POMS) (Figure 6).

The results of this study indicate that like RPE, the subject's assessment of their fatigue using POMS increased throughout the event. Using a twenty point scale, fatigue averaged  $\sim 5$  prior to the start of the event. This rather high baseline was perhaps influenced by the athlete's lack of sleep, since the event began at midnight. Fatigue continued to increase throughout the event, nearly topping out the scale at  $18.8 \pm 0.3$  by the end of the event. Similarly vigor fell throughout the event. However, because vigor may have been influenced by the subject's performance relative to other competitors, the decline in vigor did not mirror the rise in fatigue. Many factors likely affected the marked deterioration in mental state observed in the present study. Physiological factors

such as increased core temperature and glycogen depletion are known to affect perceptions of fatigue (3,5). In addition, subjects reported gastrointestinal discomfort, which likely affected mood or perceptions of effort. Further, subjects experienced at least some sleep deprivation competing from midnight to noon, and were required to exercise in darkness for half of the event.

Illumination has been shown to significantly effect performance and feelings of fatigue. Maas et al. (18) reported less perceptual fatigue during a performance test and better visual acuity in sunlight than white light, however self-reported feeling of fatigue were not different between groups. Light has been shown to increase vigor and cognitive performance and decrease the sense of fatigue in people suffering from depression (19). Although not reflected in the group mean, some subjects reported a euphoric feeling at sunrise and indicated a temporary increase in vigor at that time.

## CONCLUSIONS

The factors affecting performance in ultra-endurance events are likely as varied as the motivations for competing in prolonged endurance events. We observed that subjects were unable to maintain proper hydration or consistent caloric supplementation. In spite of dehydration and reported declining mood state, subjects performance at the end of the event, as measured by velocity, was on par with their performance in the early hours of the competition. However, the overall decline in psychological state that was not associated with dramatic declines in performance, suggest that the mental aspects of ultra-endurance sports participation may be more challenging than the physiological challenges. Future studies would be improved by characterizing the physical work capacity of the subjects in the laboratory prior to the event in order to assess relative exercise stress during competition. Further, increased use of telemetry for collecting heart rate data, skin and core body temperature, as well as more frequent measures of blood borne substrates with portable analyzers would improve our understanding of the physiological stresses inherent to athletes competing in ultra-endurance events.

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**Address for correspondence:** Jon K. Linderman, Ph.D., FACSM, Department of Health and Sport Science, University of Dayton, 300 College Park, Dayton, OH 45469-1210; Phone: (937) 229-4207; FAX: (937) 229-4245, Email: [jonlinderman@udayton.edu](mailto:jonlinderman@udayton.edu)

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