Physiological and psychological measurements of dogsled drivers during the 1049 mile Iditarod Trail Sled Dog Race.

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PHYSIOLOGICAL AND PSYCHOLOGICAL MEASUREMENTS OF DOGSLED DRIVERS
DURING THE 1049 MILE IDITAROD TRAIL SLED DOG RACE

by

Carla E. Cox

B.S., Loma Linda University, 1973
M.S., Colorado State University, 1975

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for the degree of Doctor of Philosophy
The University of Montana
2004

Approved by:

Co-Chairperson

Co-Chairperson

Dean, Graduate School

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Driving a team of dogs requires physical and mental strength and endurance to help the team negotiate rough terrain, to be alert to dangers on the trail and to monitor the fitness of the team. Prolonged physical activities in the cold have been related to elevated energy expenditure. In addition, a considerable amount of evidence has demonstrated the need for adequate hydration during athletic performance. This study examines the physical fitness of the musher prior to the start of the race. During the event the energy requirements, level of hydration, self-ratings of physical fatigue and changes in the level of attentiveness were assessed.

Prior to the start of the race, a standard step test was utilized to predict VO$_{2\text{peak}}$. In addition, mushers were monitored at seven checkpoints along the trail from Anchorage to Nome, Alaska during the 14-day event. Doubly labeled water was used to assess energy expenditure. Food records were obtained to determine the distribution and quantity of macronutrients consumed. To obtain information on physiological and psychological changes that occurred during the event, a variety of measurements were obtained at five checkpoints along the trail. These included resting and exercise heart rate, urine samples, self-ratings of fatigue and the Benton Controlled Oral Word Association test.

The data demonstrated that dog sled drivers had an estimated VO$_{2\text{peak}}$ above average. Total energy expenditure (TEE) during the event averaged 20.8 MJ-day$^{-1}$ (4972 kcal-day$^{-1}$) from Anchorage to Nome for our male subject and 11.8±1.7 MJ-day$^{-1}$ (2808±397 kcal-day$^{-1}$) for our female subjects during the race. Food records demonstrated an average intake below recommended levels for carbohydrates and adequate in protein for endurance athletes. The majority of mushers showed signs of dehydration during the event based on common urinary markers. Mushers demonstrated an increased level of fatigue (self rated) during the event. Measurements of cognitive performance did not change significantly during the race.
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Finally, I would like to thank my husband Roger, for encouraging me to pursue my dream “later in life” at the expense of time together canoeing and fishing for the elusive trout.
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INTRODUCTION

Sports performance is based on a wide variety of variables including genetic and environmental factors, which include nutrition, hydration, mental focus and fitness. The completion of the 1,049 mile (symbolic distance) Iditarod sled dog race is no different. Although the dogs are an important component of the team, and have been the focus of most of the research on dog sled racing (Hill, 1998; Hinchcliff, Reinhart, Burr, Schreier, & Swenson, 1997; Kronfield, 1973; Proper Nutrition a concern, 1996), the sled driver is also important. Driving a team of dogs (mushing) requires physical and mental strength and endurance. The driver must be alert to dangers on the trail, such as open water, and be physically able to help the team through steep and icy terrain. Few researchers have attempted to assess the physiological and psychological needs of the sled driver, or to investigate the affects fitness may have on the overall changes in physiology that occur during endurance dog sled racing. In addition, the role of sleep deprivation in decision making during endurance dog sled racing has not been researched. The focus of this study is to determine baseline data on the energy and fluid needs of mushers during endurance type dog sled racing. Additionally this study will address whether the accumulated sleep deprivation during the event causes deficits in attention. Because fitness may influence utilization of nutrients and ability to cope with sleep deprivation, data on the level of fitness of the musher prior to the start of the Iditarod start will also be gathered.

The Iditarod starts in Anchorage, Alaska the first Saturday in March. It is a continuous race, traversing some of Alaska’s most brutal country, ending 9-14 days and
over 1000 miles later in Nome, Alaska. During the race, physical strength is required to negotiate rough terrain. One of the most adventurous and nerve-wracking sections of trail is the Happy River Gorge (between Finger Lake and Rainy Pass, see map page 36). The team follows a steep and undulating trail. Sleds are rolled and trees hit (Sherwonit, 1991). In this section, physical strength is required to control the team. Heading up Rainy Pass, the musher needs physical endurance to aid the team on the steep climb. On the Yukon River, where the scenery remains relatively flat and unchanging for over 150 miles, mental discipline may be required to stay alert.

Adequate kilocalories (kcal) are essential to maintain the energy necessary for manipulating the sled, running with the team, and for sustaining mental vigilance. In addition, the distribution of macronutrients is important. Multiple studies have demonstrated the need for increased carbohydrate consumption during exercise in the cold (Rosenbloom, 2000, Vallerand & Jacobs, 1989) and for endurance activities (Rosenbloom, 2000; McArdle, Katch & Katch, 2000; Houtkooper, 1992). Carbohydrate administration during sustained activity has also been shown to improve mental vigilance (Liberman, Falco & Slade, 2002). This research is in contrast to the misconception of many mushers that fats are the preferred source of fuel (Cox, Gallea & Ruby, in press; Runyan, 2002).

A considerable amount of data support the need for adequate hydration during athletic performance (Rehrer, 2001; Murray, 1992). Freezing water bottles, the difficulty of urinating while wearing multiple layers of clothes, therefore voluntary restriction of water intake, and the challenge of accessing insulated water bottles on the sled make staying hydrated on the trail problematic. Dehydration can lead to decreased plasma

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volume, increased heart rate and decreased stroke volume (Heaps, Gonzalez-Alonso & Coyle, 1994; Hamilton, M., Gonzalez-Alonso, Montain & Coyle, 1991) and decrease performance. Cognitive processing time has also been linked to dehydration (Anislie, et al, 2002; Cian, Barraud, Melin & Rapehl, 2001). Changes in hematocrit and hemoglobin have been utilized to detect changes in hydration with mixed results (Shirreffs, S., 2000). During a recent case study, hematocrit rose from 37.5% to 38.5% during the two week Iditarod event (Cox, Ruby, Gaskill, & Uhlig, in press), indicating dehydration. Popkin et al (1980) also described blood changes of mushers during the Iditarod that indicate dehydration.

In addition to elevated energy needs and the challenges of maintaining hydration, endurance dog sled drivers are often faced with chronic fatigue. When entering a checkpoint, the first priority of the driver is the care of the dogs. Before the driver attends to personal needs, the dogs are fed, injuries and sore feet are attended to, straw is spread out and the dogs are encouraged to sleep. After tending to the dogs, the driver must dry clothes, heat and ingest personal food and prepare gear for departure. The driver is lucky to get 1-2 hours of sleep in a 5.5 hour rest stop. A common schedule for a dog sled driver is to run 6 hours and “rest” 5.5 hours (C. Banse, personal communication, October 12, 2002). Sleep deprivation has been related to state instability (Doran, Van Dongen, & Dinges, 2001) and cognitive dysfunction (Kim, et al, 2001). Sleep deprivation resulting in poor decision making during the Iditarod could ultimately result in injury or death to the musher or dogs.

Fitness is linked to performance in most athletes. In dog sledding, the underlying belief of mushers is that the physical fitness of the dog is the key, and the role of his or
her own fitness needs is minimal. In spite of these beliefs about musher fitness, dog sled driving is a physical sport, requiring physical strength and endurance. In addition, fitness appears to delay the onset of fatigue due to sleep deprivation (Duarte, et al. 2002), which is of considerable importance to the musher.

If the basic physiological and fitness requirements of the sled driver could be determined, recommendations could be developed that have the potential to enhance the driver's competitiveness and the likelihood of completing the race while decreasing the risk of injury or death to the dogs and musher.

**Statement of problems:**

Few data have been collected on the physiological needs or the state of cognition of the dog sled driver during an endurance sled dog race. In order to make basic recommendations for this group of athletes, baseline data must be collected. Initial concerns include energy balance and hydration. In addition, collecting a priori musher fitness data could indicate whether the musher needs a separate training regimen, or if training the team also physically trains the musher.

Due to the continuous nature of the Iditarod sled dog race, fatigue is a problem for all mushers. The harsh environmental conditions encountered during the race (snowstorms, thin ice, narrow passages, route finding) make critical thinking imperative to the safety and performance of the team. Collecting baseline data on attentiveness level during the race will help to establish the amount of mental impairment occurring to mushers on the trail.
Selection of the dogs is of paramount importance in the Iditarod endurance sled dog race, however, the physical and mental ability of the driver also contributes to the safe and timely completion of the race. The musher should start the journey physically fit, maintain adequate energy and hydration during the race, and sustain a high level of mental alertness if the dogs and musher are to safely arrive in Nome.

Research Questions:

1. What are the average energy requirements of the musher in a sled dog endurance event?

2. Does the dog driver consume adequate kcals to maintain body weight?

3. Does the dog driver consume enough carbohydrate to match the standards set by the American Dietetic Association and the American College of Sports Medicine for endurance sports?

4. Does the musher stay hydrated during the race?

5. What are the projected fluid needs of the musher?

6. Does cognitive function deteriorate during the race and what are the affects of pre race fitness, hydration, carbohydrate ingestion, and energy balance on cognitive function?

7. Does the musher experience physical fatigue that could affect performance and is fatigue related to pre race aerobic fitness, hydration, carbohydrate ingestion or energy balance?
Limitations:

There are many factors other than food, hydration, sleep and aerobic fitness that affect the performance of the musher and the team. Musher strength, intelligence, experience and the quality of the equipment all play substantial roles. In addition, weather and trail conditions along with the strength of the dog team can impact the energy and fluid needs of the musher. A minimum of twenty-four mushers will be recruited for the study on a volunteer basis. The first twenty-four volunteers will be the subjects. More males than females are expected to volunteer representing the ratio actually doing the race. Due to the arduous nature and length of the race, not all mushers will complete the race resulting in some incomplete data sets.

Delimitations:

Subjects in the study include mushers who are either professional or recreational distance mushers. To be eligible for the Iditarod, they must have previously completed a minimum of a 200 and a 300 mile mid-distance sled dog race prior to the Iditarod. The information gained from this study would apply to mushers in endurance races and may not be transferable to mushers training for and participating in sprint and mid distance races. Due to the variations in environmental conditions, certain parameters (e.g., fluid and kcalories) may differ from year to year.
Definition of Terms:

Scientific

Cognitive function: Mental control which includes the ability to concentrate and to process relevant cues (Williams (Ed.), 2001).

Fat free mass: Body mass devoid of all extractable fat (McArdle, Katch & Katch, 2000).

Water turnover: The rate which body water is turned over. If body composition and water content remain constant, water intake equals water loss (Leiper, Ptisalidis & Maughan, 2001).

Urine osmolality: The osmotic concentration of the fluid. It is expressed as mOsmol/kg water (Iowa Clinic, n.d.).

Urine specific gravity: A test that measures the concentration of particles in the urine (Iowa Clinic, 2002).

Maximal oxygen consumption (VO2max): The maximum rate at which an individual can consume oxygen. It is an important determinant of physical work capacity (Brooks, Fahey, White & Baldwin, 2000).

Ventilatory Threshold (VT): The point at which pulmonary ventilation increases disproportionately with oxygen uptake during graded exercise (McArdle, Katch & Katch, 2000).

Illusion: An appearance or feeling that misleads because it is not real (Barnhart and Barnhart, (Ed.), 1989).

Hallucination: The condition of seeing, hearing, tasting, smelling or feeling things that exist only in a person’s imagination (Barnhart and Barnhart, (Ed.), 1989).
Terms related to driving a dog sled team:

**Sleddogs:** “Alaskan huskies” are a dog bred specifically for pulling a sled. They are bred for intelligence, speed, durable feet, the ability to stay warm in cold temperatures and love of pulling the sled.

**Musher:** Another term for the dog sled driver. This is the person who is in charge of the dogs and the sled.

**Rookie:** An entrant running the Iditarod for the first time. However, they are individuals who have successfully completed previous races or they could not qualify to run the Iditarod.

**Veteran:** Sled driver who has completed at least one Iditarod.

**Pumping:** A method of mushing where one leg remains on the runner, while the remaining leg is used to help propel the sled forward by pushing off the snow.

**Running:** The dog sled driver gets off the sled, and while holding onto the handle bar of the sled, runs next to the sled which results in their own body weight being removed from the sled.

**Pushing:** The musher helps the team by pushing the sled and running behind it. This can occur while negotiating steep terrain or with a team of fatigued dogs.

**Significance of the Study:**

There is limited information on the physical and psychological responses of the dog sled drivers during endurance events such as the Iditarod or Yukon Quest, another long distance sled dog race. By assessing a group of dog sled drivers, using an interdisciplinary approach, recommendations based on scientific study can be made that
would enhance the quality of the mushing experience, help maximize performance, and decrease the chance of poor choices leading to musher or dog injury or death.

II. Review of the Literature:

**Introduction to the Iditarod: the setting**

The Iditarod is an internationally known endurance sled dog race. The race begins in Anchorage, Alaska, with a ceremonial start on the first Saturday of March and finishes with the arrival of the final musher into Nome, usually within 14 days. The race covers between 1050 and 1150 miles, depending on the year and weather. Drivers begin the race with a maximum of 16 dogs, and must complete the race with a minimum of 5. There are 22 checkpoints after leaving Knik (day 2 and the true beginning of the race into the wilderness), not including the finish at Nome. The race begins at sea level and includes river crossings, a pass of 3,160 feet elevation (Rainy Pass, mile 224), 150 miles on the frozen Yukon River, and 250 miles along or across the Bering Sea (depending on the conditions of the ice). There is no road access for approximately 1000 miles of the race. The weather can be a significant factor in the race, often dipping below -30°F with fierce winds. Snow conditions change from year to year and day to day. The course conditions can be deep snow, ice, rock or bare ground during years of low snow.

The sled dog is a remarkable athlete with a strong instinct to run and pull. When well trained, a team can average up to fourteen miles per hour for hundreds of miles. The force of the dogs pulling in concert is remarkable. At the beginning of a race, it is difficult to slow or stop the team. During the first day of the Iditarod, a second sled is attached to the first, and a second musher accompanies the driver to help control the
team. The second day begins the true start of the race, when the driver and team leave Knik beginning a lone journey for the next 1000 miles.

Dog drivers must provide all the care for their team. This includes feeding, watering and general veterinary care. Prior to the race, all food for the dogs and musher is sent ahead to the checkpoints. Before feeding, the dog food must be heated in boiling water in a cooker specifically designed for cold weather mushing. Straw for dog bedding is provided at some checkpoints, which the musher can obtain, carry over to the team and spread out for the weary dogs. Mushers almost always sleep outside with their dogs during the race.

Although the dogs provide much of the work power of the team, the musher also contributes. Energy is expended negotiating rough terrain, steering the sled around sharp turns, avoiding obstacles, and pumping and pushing the sled on hills and when the dogs are tiring.

**Energy needs:**

Recommendations to meet kcal needs of the athlete are documented for a wide variety of sports (Economios, Bortz, S & Nelson, 1993; Position of the American Dietetic Association, 2000; Rosenbloom, (Ed.), 2000). The increased energy expenditure with increasing duration and frequency of exercise has been well studied. Previous studies have also documented the increased kcal cost of physical work in cold environments (Taylor, et al, 1994; Campbell, 1982). Much of the increased cost of work in cold environments is due to the difficulty moving with heavy clothing, rather than the increased needs of thermogenesis. Energy expenditure while wearing heavy clothing
results in kcal expenditure 5-15% higher than when subjects wear only light clothing (Gray, Cosmolazio & Kark, 1951; Tietlebaum & Goldman, 1972; Brotherhood, 1973).

Mushers are faced with both increased activity and exposure to cold, however, there is no research documenting the kcal needs of the dog driver during endurance races. A book entitled “The Iditarod Arctic Sports Medicine/Human Performance Guide” was published in 1989 (Turner, (Ed.), 1989). The nutrition recommendations appear to be based on intuition and basic nutrition knowledge of the author, rather than based on scientific studies into the nutrient needs of the dog sled driver. This applies to the information distributed during the 1987 Arctic Sports Medicine Conference as well (Pichon & Turner, 1987). There was reference to a survey that was sent to 90 mushers who had competed in the Iditarod for the previous five years, investigating their food intake during racing. The rate of return on the survey was 17.7%. No actual information was published on the questions asked or the responses received in reference to quantities of foods consumed. The recommendation for kcals was extremely high (up to 8000 kcals/day). Due to the limited response rate and the lag time since the respondents had completed the Iditarod, the recommendation is suspect. Other research on athletes in cold weather environments has revealed much lower kcal expenditures. For example, the Iditasport, a self propelled cross country ski race across much of the same terrain, revealed an energy intake of 4170 kcals/day for women and 7110 kcals/day for men (Case, Evans, Tibbets, Case, & Miller, 1995). In a similar environment to the Iditarod, skiers on a transpolar ski trek averaged an intake of 4000-5000 kcals per day (Shepard, 1991). In the later two examples, it would be expected that their kcal needs would be even higher than the musher, due to the fact that they are self propelled and not being
aided by a team of dogs. Kcal intake of polar explorers with dog teams at the turn of the century, using loaded sleds and driving on untracked terrain, demonstrated an intake of approximately 5500 kcals per day to maintain body weight (Feeney, 1998). Self propelled expeditioners in the Antarctic revealed an average intake of 3565 kcals per day (Taylor, et al., 1994). The results of these studies would all imply that the predicted 8000 kcals per day is an overestimate.

There has been a considerable amount of research directed at the nutrition needs of the endurance athlete (Houtkooper, 1992; Singh, Pelletier & Deuster, 1994; Applegate, 1989; Rontoyannis, Skoulis, & Pavlou, 1989). Indeed, the dog sled driver may easily fit into this category. During the Iditarod, the musher frequently contributes to the effort of the whole team. Because it is a continuous race, participants are often physically active for 20 or more hours per day for up to two weeks. In addition to the high level of daily activity, kcal expenditure is increased in the cold. Examples of ultra endurance athletes in cold environments indicate a high kcal output. In a study of 13 participants in a Canadian/Soviet transpolar ski trek, the average kcal energy expenditure per day (based on an average of 12 miles per day over 91 days) was 4000-5000 kcals per day (Shepard, 1991).

Collecting intake and energy balance data:

Energy expenditure has been documented via collection, measurement and analysis of expired air; doubly-labeled water; measured food records; food wastage; dietary recall; dietary history and food frequency questionnaires. Food records have been used for decades to determine the intake of population groups. However, self reported
intakes have historically resulted in underreporting of kcal intake. This has been specifically shown in females (Johansson, Solvoll, Bjorneboe & Drevon, 1998; Martin, Su, Jones, Lockwood, Tritchler & Boyd, 1996) and in obese individuals (Kroke, Klipstein-Grobusch & Boeing, 1998; Heitmann, Lissner & Osler, 2000; Johansson, et al., 1998; Hoidrup, et al., 2002). Barnard, Tapsell, Davies, Brenninger & Storlien (2002) reported less accurate (underestimated) food intake in highly active individuals, and those with highly variable dietary intakes. Underreporting has also been documented in athletes when compared with doubly labeled water measurements (Burke, 2001). Black, et al. (1991) in an analysis of 37 published studies, showed underreporting of dietary history to be 25% (vs. diet recall of 88%). Underreporting was also documented in soldiers during a 10-day field exercise in the Canadian Arctic, when compared to energy expenditure using doubly labeled water assessment (Jones, Jacobs, Morris & Ducharme, 1993).

Researchers have attempted to assess the kcal intake of sled dog drivers by questionnaire. Mushers who had competed in the previous 5 Iditarod dog sled races were retrospectively asked their food choices (Turner, (Ed.), 1989). This would likely result in significant errors, especially considering that prospective daily food logs result in large reporting errors. Iditasport participants were asked to recall their food intake immediately after they had completed their event (Case et al., 1995). These data are also likely to result in inaccurate estimates of kcal intake due to lack of weighing food prior to the race, not recording food wastage and not keeping records during the event.

More accurate methods of dietary assessment have been described. Weighed records have demonstrated accuracy (Bingham, et al., 1995). However, weighed records
have also had skeptical results. Some researchers have demonstrated recorded intakes of 82% of actual energy expenditure compared to doubly labeled water analysis. Subjects in a dietary trial in Ireland, in the upper third of energy intakes, demonstrated an almost perfect ratio of self reported intakes to expected energy needs assessed using doubly labeled water (1.01 for men and .96 for women) (Livingstone, et al., 1990). A group of 23 Marines during a strenuous eleven-day cold weather field exercise were asked to record their dietary intake. Kcal estimates did not differ significantly from doubly labeled water estimates (Hoyt, et al., 1991).

Although doubly labeled water is thought to be the gold standard for measurement of energy expenditure, it is not without drawbacks, being very expensive, and difficult to obtain currently (B. Ruby, personal communication, May, 2002). In addition, there are a number of adjustments and assumptions that must be made which can potentially create measurement errors (Schoeller, Taylor & Shay, 1995). Due to the complex logistics of the Iditarod, the cost of the labeled water, and possible errors increased by the unpredictable nature of the Iditarod, the use of doubly-labeled water as a method of measurement is impractical.

Another method of assessing energy intake is to assess the amount of food wastage. This method involves the recording of food sent on the trail, along with food not used. Plate waste studies require meticulous monitoring of intake and waste and are too cumbersome and unreasonable for use in a setting such as the Iditarod, where subjects may not be in human contact for long periods at a time.

Food records appear to be the most reasonable approach to evaluate food intake during the Iditarod, but must be done with care to minimize inaccuracy. Accuracy should
be improved by being particular about the population used (non-obese individuals with little pressure to underreport), and by using a simplified system to record intake, minimizing opportunity for error. Another advantage of using food records is that they can be collected with minimal cost and the data provides the researcher with the ability to assess macronutrient intake as well.

In 2001 (Cox et al., in press), a case study was carried out on a musher in the Iditarod. The musher sent a list of prepackaged, weighed food items to the researcher. Food items were then listed on a check off sheet with the name of the checkpoint to which they were sent. This method minimized writing and decreased recording error by cueing as to foods available at the checkpoint, as well as providing a selection of having eaten none, ¼, ½, ⅜, or all of the packaged food (figure 1).

**Distribution of Macronutrients:**

A benefit to food records is the ability to obtain information on the contribution of macronutrients to the diet. Historically, fat has been used in the far north as a concentrated form of kcals. Fat was thought to be the fuel of choice in the severe cold (Timmons, Araujo & Thomas, 1985). The majority of the dog sled drivers in the 2002 Iditarod believed it was the best fuel of choice for the musher during the dog sled race (Cox et al., 2002). There is evidence that carbohydrates (CHO) may instead be the optimal macronutrient to enhance performance in severe cold. Exposure to cold during rest shifts substrate utilization from mainly lipids at thermal neutrality to a greater reliance on carbohydrates (Vallerand & Jacobs, 1989, 1992; Vallerand, Zamecnik & Jacobs, 1995). Glycogen depletion can also be accelerated with cold exposure (Pitsiladis
Maughan, 1999). Doubt (1991) reported strong evidence that adequate amounts of carbohydrate are necessary in cold environment. Diminished fat utilization during exposure to cold temperatures has been demonstrated during cycling (Layden, Patterson & Nimmo, 2002). Cold induced vasoconstriction may be partially responsible for the decrease in lipid mobilization (Rosenbloom, (Ed.), 2000). As personal testament, after Steger’s expedition to the north pole, Steger (1987) believed in retrospect, a higher percentage of carbohydrates may have been beneficial, helping to prevent some of the lethargy and cramping they experienced.

Seven to thirteen grams of carbohydrate per kilogram body weight per day (g/kg bw/day) depending on energy expenditure are recommended for endurance athletes (Rosenbloom, (Ed.), 2000; Houtkooper, 1992; Singh, Pelletier, & Deuster, 1994). This does not account for exposure to the cold, which may increase carbohydrate needs even further (Doubt, 1991; Weller, 1998). To add to the list of benefits of carbohydrate ingestion, carbohydrate administration during a sustained activity has been shown to improve vigilance (Lieberman, Falco & Slade, 2002).

**Hydration:**

Hydration is vital to the athlete. A water deficit of as little as 2-3% of total body water impairs exercise performance (Armstrong, Costill, & Fink, 1985; Nielsen, et al., 1981). Dehydration can result in elevated heart rate and decreased stroke volume (Gonzalez-Alonzo, 2000), fatigue (Maughan, 1992), and decreased performance (Murray, 1995). Dehydration also shortens the time to the onset of fatigue (Armstrong, 2000).
Keeping well hydrated is especially difficult during activities in the severe cold. Water freezes and must be thawed prior to ingestion. While driving a dog team, urinating in the cold while holding onto the sled is a cumbersome task. Mushers may try to limit the need for urination by withholding fluid, a serious concern with cold weather athletes. Cold weather also exacerbates dehydration due to cold-induced diuresis and increased respiratory water loss (Murray, 1995).

Research has demonstrated, dog sled drivers in the Iditarod have an increased hematocrit over the two week period (Cox, et al., 2002; Popkin et al., 1980) indicating probable dehydration.

**Measurements for hydration and water turnover:**

Several methods have been utilized for determining hydration status in the field. Shirreffs and Maughan (1998) measured the osmolality of the first morning void in athletes. The field measurement was used on 29 athletes to determine their hydration status for feedback. The findings suggested that urine osmolality was an effective tool to determine daily fluctuations in hydration status. This is a relatively simple test, non-invasive, and can be used in a remote setting.

Using a measurement of hemoglobin and hematocrit, Dill and Costill (1974) calculated the percentage change in volumes of blood, plasma and red cells to determine dehydration in a group of six males before and after running. This method, although valid, has the disadvantage of being more invasive and difficult to use in a remote setting where ready access to a laboratory is not available.
Armstrong (1998), in a study of 9 highly trained athletes, demonstrated that urine osmolality and urine specific gravity were valid indices of hydration status. The dehydration protocol in the Armstrong study was 3.7% of body mass. In a study of 12 subjects dehydrated to 1%, 3% and 5% of body mass, urine osmolality and urine specific gravity were shown to be a sensitive marker of dehydration, but the urine markers demonstrated a lag time behind plasma osmolality during acute dehydration (Popowski et al., 2001). In a study of over 650 samples in an isolated setting, urea nitrogen-to-creatinine ratio appeared to be a sensitive index of imminent hypohydration. In this study, osmolality did not appear to be a valid measurement of hydration as there was no significant difference in urine osmolality between subjects having a urine specific gravity greater than or less than 1.03 (Francesconi et al., 1987).

In addition to weight changes, urine specific gravity and osmolality, and blood parameters, a method using deuterium oxide ($^2$H$_2$O) to determine total body water has been utilized in a variety of population groups (Leiper, Carnie, & Maugham, 1996; Ruby, Schoeller, Sharkey, Burks, & Tysk, 2002). Water turnover can be calculated from the change in deuterium dilution. Timing and multiple mathematical corrections make this method more difficult in the field setting. Differences between measurements from deuterium and densitometry related to the amount of total body water were noted when urine was collected prior to a period of 10 hours for equilibrium (van Marken Lichtenbelt, Westerterp, & Wouters, 1994).

Though valid for short duration activities, measurement of weight loss alone is not an accurate measurement of dehydration due to changes in loss of fat and lean body mass during the two-week event. Determination of changes in lean body mass using
Skinfold measurements can be used to determine changes in body composition. Skinfold measurements accurately reflect body fat in non-obese women (Heyward, et al, 1992). Fogelholm & Lichtenbelt (1997) noted a relative underestimate of body fat using the Jackson and Pollack equation when compared to underwater weighing. This would not, however, have an influence on the change in body fat from one point of time to another within the same individual. In 1993, a decrease in body weight and fat mass during the Iditarod Sled Dog Race was noted (Case et al, 1995). Using bioelectrical impedance, Chapman, Tibbetts, Case, Evans & Mills (1992), demonstrated a decrease in total body fat of 2.5% during the Iditarod.

Fatigue:

Systematic sleep deprivation has been linked to emotional, behavioral, physiological and cognitive performance deficits in humans (Duerte et al., 2002). Fatigue is common on the Iditarod trail, and stories of hallucinations due to severe fatigue have been reported (Paulson, 1994; Freedman, 1992; Balzar, 1999). In a study on the biobehavioral changes in the Iditarod (Stillner, Popkin & Pierce, 1981), two racers reported visual hallucinations; three reported illusions.

A study on house officers (Hawkins, Vichick, Silsby, Kruzhich & Butler, 1985) revealed significant deficits in primary mental tasks in the acutely sleep deprived. In a review of the literature, Himashree, Banerjee & Silvamurthy (2002) discussed the detrimental effects of sleep deprivation on psychological performance, which includes lapsing, cognitive slowing, memory impairment and a decrease in vigilance and sustained attention. When tasks are monotonous and low in cognitive demand, individuals that are
sleep-deprived take longer to respond to stimuli, relative to their rested counterparts (Wilkinson study, as cited in McCarthy & Waters, 1995, Wilkinson, 1968). Lapsing (brief periods of unresponsiveness) may be partially responsible for decrements in performance with sleep deprivation (Williams, Lubin, & Goodnow, as cited in McCarthy & Waters, 1995). Deficits in motor performance, memory, receptive and expressive speech, and complex verbal arithmetic functions have also been reported after sleep deprivation (Kim, et al., 2001). Thermoregulation is also affected by sleep deprivation, and has been noted to result in decreases in both hand and core temperatures (Ax, & Luby, as cited in VanHelder & Radomski, 1989).

Dog drivers in the Iditarod, often run throughout the night. They frequently run a schedule resulting in a maximum of four hours of sleep per night. One musher claimed to have slept nineteen hours in thirteen days of racing (Freedman, 1992). In 1979, front runners were reported to have slept three hours or less per night (Stillner, Popkin & Pierce, 1981). This may not only have an impact on the musher's physical performance, but could put them at risk for lack attentiveness resulting in poor decision making with serious consequences. It is unlikely that mushers will change their strategy to include more sleep during the race, however, it may be possible to focus more attention on brief periods of quality rest. There has been some literature to support the concept that physical fitness may help to minimize fatigue during episodes of sleep deprivation (Duarte et al., 2002).
Testing measures for cognitive function:

A wide variety of tests have been utilized to determine changes in cognitive function during sleep deprivation (Wimmer, Hoffmann, Bonato & Moffitt, 1992). Many take over 30 minutes to complete (Wimmer, 1992), which make them difficult to administer in a continuous style race. Some require computer hook-ups (Bohnen, & Gaillard, 1994; Wimmer, 1992) that are impossible to use in the very remote setting of Alaska's interior where cold temperatures prevent the use of battery driven laptop computers and electricity is unavailable. The limited dexterity of cold fingers precludes using paper tests as mushers arrive at checkpoints. Therefore, an easy to administer oral test that can be given quickly should be used to assess changes in cognitive function during the Iditarod. The Controlled Verbal Fluency Task (CVFT) (Bechtold, Benton & Fogel study, as cited in Ruff, 1996; Borkowski et al., 1967) and the Benton Controlled Oral Word Association (COWA) tests (Bechtoldt, 1962) have been previously validated, orally administered, and take only 3 minutes.

The purpose of the COWA and FAS tests are to evaluate the spontaneous production of words. No specific material is required (Spreen & Strauss, 1998). There are three letters in the sequence, and the subject is allowed 1 minute to think of as many words as possible that start with a specified letter. The final score is the sum of the acceptable words produced during the three trials. The test is able to detect changes in word association fluency (Sumerall, Timmons, James, Ewing & Oehlert, 1997). Generally used to detect the affects of dementia in a patient with disorders such as Korsakoff's syndrome and Huntington's Disease, impaired performance on verbal fluency tasks, such as the COWA, have been associated with a variety of left-hemisphere
impairment (Demarkis & Harrison, 1997). Word fluency tests also demonstrate how well subjects organize their thinking (Mitrushina, M., Boone, K., & D'Elia, L., 1999). The focus for the testing will be changes in the number of words produced over time, rather than a comparison between subjects.

It appears that improved physical fitness should be a significant benefit for the dog sled driver due to its positive impact on muscle glycogen stores, fuel utilization, strength, endurance (Plowman & Smith, 1997) and for its contribution to prevent fatigue in the sleep deprived state (Duarte et al., 2002). Chronic exertional fatigue in conjunction with sleep loss and negative energy balance can result in cold intolerance (Young & Castellani, 2001). The increased susceptibility to hypothermia is important to recognize, especially when an individual is in the extreme isolated conditions of the Iditarod.

**Determination of Aerobic Fitness:**

There are a wide variety of tests to determine levels of fitness. The most accepted is a maximal oxygen test performed in a laboratory. It includes the continuous measurement of oxygen consumption during treadmill walking using a metabolic cart. This determines oxygen consumption at peak effort ($V_O^{2\text{max}}$) and ventilatory threshold (VT) (Petrella, Koval, Cunningham & Paterson, 2001). This direct measure of fitness requires extensive and generally non-portable equipment along with a technician trained in the use of the cart (Francis, 1987). Direct measurement of $V_O^{2\text{max}}$ also requires the subject to exercise to maximal volitional exhaustion, requiring significant motivation on the part of the subject (Francis, 1987). This direct method of measure is impractical.
when testing multiple individuals in a short period of time or in a remote setting, both requirements of the current project.

Sevens and Sykes (1996) compared three tests used to measure aerobic fitness; Astrand cycle protocol, Chester Step Test, and the Bleep test. The Astrand cycle protocol used a calibrated cycle ergometer and a heart rate monitor. Cadence remained constant with changes in watts every minute until a heart rate of approximately 130 beats per minute was reached. This level of activity was maintained for three minutes, and then a heart rate was obtained. Heart rate and workload were used to predict aerobic capacity. The Chester Step Test used a twelve-inch bench. The subject was asked to step on and off the bench. The pace was started at fifteen steps per minute and increased every two minutes by five steps per minute. The test was continuous until the subject’s heart rate reached 80% of maximum (determined by 220-age x .80). Aerobic capacity was determined from a chart that had been derived from a prediction equation. The Bleep Test was a shuttle type test. Subjects were asked to run back and forth between cones, and to run for as long as possible. There was no significant difference between the mean scores of all three tests. In addition, there was no gender difference. These three tests appear to be interchangeable. All three are valid and reliable tests for estimating aerobic capacity (Sevens, 1996).

The Three Minute Step Test has been used for mass testing (ACSM’s Guidelines for Exercise Testing and Prescription, 1995) using prediction equations based on heart rate and standardized step height. This method is quick to administer and easily adapted to the field setting (Francis, 1987). The test should initially last 3-4 minutes, long enough to adjust the individual’s respiration and circulation to that workload. This self-paced test
is safe and simple and reliably predicts VO$_{2\text{max}}$ (Petrella et al., 2001). A wide variety of step test measurements have been adapted for use with specific population groups (Tuxworth & Shahnawaz, 1977; Katch. 1983; Siconolfi, Garber, Lasater & Carleton, 1985). The major changes in the testing include step height, cadence, frequency and duration. The step test utilized by the YMCA is conducted with a 12-inch high bench, with a stepping rate of 24 steps per minute for three minutes (American College of Sports Medicine, (5th Ed.), 1995). Heart rate is counted for 1 minute, starting within 5 seconds of the completion of the exercise. Normative tables are published to determine fitness level (Golding, Myers & Sinning (Eds.), 1982).

Tests used to determine aerobic fitness should be training specific (American College of Sports Medicine 2nd Ed., 1993). However, there are no specific ergometers or protocols available for dog sled drivers. The step test is validated and has been used on a wide variety of population groups to determine aerobic fitness.

To subjectively assess the intensity of the exercise for the individual, the Borg scale of rating of perceived exertion (RPE) was developed (Borg, 1982). However, in recent years, an easier rating scale has been utilized with a revised scale of 0-10. A rating of 10 usually corresponds with maximal level of exercise (Heyward, 1991). This appears to be more easily understood by the subject and provides more valid information to the researcher (American College of Sports Medicine, (5th Ed.), 1995). It can also be used to determine ventilatory threshold (VT) and the rate of lactate accumulation (American College of Sports Medicine, (5th Ed.), 1995). A regression equation is applied to the heart rate and RPE data to determine VO$_{2\text{max}}$ and VT, respectively. The step test is presently being researched at the Human Performance Laboratory at the University of 24
Montana as an accurate and easy method to predict $V_T$ in the field setting (S. Gaskill, personal communication, November 1, 2002).

**Determination of physical fatigue:**

It may be possible to monitor physical fatigue using a repeated step test. The Stamina Index Test (SIT) was developed to monitor health and training status in Nordic and Biathlon skiers (Hill, Motl, Estle & Gaskill, 1997). This was used to determine overtraining, but may be a practical approach to monitoring physical fatigue as well (S. Gaskill, personal interview, November 1, 2002). To aid in the determination of fatigue, mushers will also be asked to rate their feeling of fatigue using a 1-5 point scale, the most fatigued rated at five.

**III. Methods:**

**Subjects:**

Subjects: Approval will be obtained from the IRB of the University of Montana. 25-30 subjects will be recruited on a volunteer basis by face to face contact, e-mail, letter and/or phone. Names and addresses of the mushers will be obtained from the Iditarod secretary, Anchorage, Alaska. Iditarod race sign up dates are June 29 – Dec. 2, 2002.

**Procedures:**

In order to determine kcalorie intake and the contribution of macronutrients during the race, a food record will be obtained from the subjects. At least 4 weeks prior to the start of the Iditarod, a list of foods that are packed for the trail will be sent to the researcher using a specified format that will include recipes, portion sizes and labels.
Instructions on the format will be sent to the musher a minimum of 2 months prior to the race. This list will then be converted to a check off list for the musher to be used during the Iditarod. Each food item will be listed under each checkpoint. Full, ⅔, ½ and ¼ serving size will be available as a check off for the musher. There will also be an area for the musher to write additional foods that may be eaten at a check-point, such as chili or soda pop (Table 1).

This individualized food record will be given to each musher 1-2 days prior to the Iditarod start. A sample will be sent to the musher with initial directions for completing the food drop list, and will be again explained on distribution. The food records will be collected at the end of the race in Nome and analyzed using the Food Processor® Version 7.3 Program (ESHA Research, Salem, Oregon, USA). To aid in the determination of nutrients ingested per kilogram (kg) body weight, a weight will be taken at the beginning of the Iditarod using a calibrated digital scale. A collapsible but rigid measuring rod will be used prior to the beginning of the race to record accurate heights of all subjects. One researcher will measure the height of all subjects for consistency.

To determine the level of hydration prior to and during the Iditarod sled dog race, the driver will be asked to supply the researchers with a urine sample at the start of the race, in Anchorage, the mandatory 24 hour layover, the mandatory 8 hour in White Mountain (77 miles from the finish) and at the finish in Nome. This will be analyzed for specific gravity and osmolality. Urine samples will be collected in 5 ml cryogenic vials, and stored for the duration of the experimental period. Urine specific gravity (Uₗₛ) will be determined using a hand held refractometer (Atago Uricon-NE, Farmingdale, NY). A drop of distilled water will be placed on the face of the prism prior to sample series
analyses. Using distilled water as the standard, the instrument will be adjusted to 1.000. Each void sample will be analyzed in duplicate. Urine osmolality (U_o) will be determined by freezing point depression (Precision Systems mOsmette Model 5004). Samples will be analyzed in duplicate for all collection time points. Before any sample is analyzed, the osmometer will be calibrated against standards of known osmolality (100, 500 mOsmol– CON-TROL, Natick, MA).

In addition, a weight will be measured on a calibrated digital scale prior to the beginning of the race, as soon as possible but at least within 1 hour of the arrival at the checkpoints at the mandatory 24-hour layover, the 8 hour layover in White Mountain, in Nome, and within 24 hours of completion of the event.

Six of the subjects will be recruited to determine water turnover rates using $^{2}$H$_{2}$O. In addition, two individuals will be recruited as controls. On the evening before retiring for bed, the six subjects will be provided with an oral dose of $^{2}$H$_{2}$O (99% ape, approximately 2 grams – Cambridge Isotope Laboratories, Andover, MA) diluted in 35 ml of distilled water after collection of a background sample. The subjects will be asked to rinse the container of $^{2}$H$_{2}$O with 20 ml of tap water three times and to ingest the contents. Subjects will be asked to refrain from eating and drinking until first void urine samples are collected in the morning. Following the first void, weight will be determined in capiline® long underwear and stocking feet using a calibrated digital scale. The subject will be asked to collect all overnight voids. The second void will be collected within sixty minutes. All samples will be collected, labeled and stored in 5 ml cryogenic vials. Urine samples will again be collected at the mandatory 24 hour and 8 hour rest stops, and at the completion of the race in Nome. Due to the nature of the continuous
format of the race, samples cannot be collected at a specific time during the day, but will be collected within one hour of arrival at the checkpoint. All samples will be transferred immediately to cryogenic vials and frozen. Samples will remain frozen until analyzed. Total body water will be calculated from the change in isotopic enrichment (background vs. the second void urine) using equation 1 (Ruby et al., 2002). Skinfold measurements will be used to determine any changes in lean body mass (LBM) over the duration of the race. Measurements will be collected prior to the beginning of the race in Anchorage and at the completion of the race in Nome. Site selection will be determined using the equations of Jackson and Pollock (1978, 1980). The same researcher will complete all skinfold measurements.

Physical fatigue (stamina) will be measured using a repeated step test. Subjects will be asked to perform a one-minute step test using an 8 inch step with a cadence of 88 at each of the specified mandatory layovers, and at the completion of the race in Nome. The results will be compared to the results of the initial step test. In addition, fatigue during the race will be determined using a 5-point rating scale. Each subject will be verbally asked to rate his or her level of fatigue prior to the start of the Iditarod (Anchorage), at the beginning of the mandatory 24-hour and 8-hour rests and on arrival in Nome. Five will be designated as the most fatigued to one the least fatigued.

To assess changes in attentiveness, the Controlled Verbal Fluency Test (CVFT), will be given to the driver prior to the start of the Iditarod. Within one hour of arrival at the 8 and 24-hour mandatory layovers, the Controlled Oral Word Association (COWA) test will be administered. The verbal fluency test will be administered by the primary researcher or one of the trained research assistants. A portable tape recorder will keep
track of all the words provided by the subject within the allotted time period. For the
quickness of administration, as well as the ability of the test to determine changes in
attentiveness and organization of thinking over the course of the endurance race, the
COWA and FAS tests were selected.

To assess the level of fitness of the musher, a step test will be administered prior
to the start of the race. The subject will be asked to sit for three minutes. A one minute
step test will then be initiated using an 8 inch step with a cadence rhythm of 88 (22
cycles)/min. This will be followed by a one minute step test using an 8 inch step with a
cadence of 120 (39 cycles)/min. Immediately after each test, a heart rate (determined
stethoscope) and rate of perceived exertion (RPE) will be recorded. The subject will be
asked to sit immediately after the initial heart rate. A heart rate will be measured after 30
seconds (count for 10 seconds) and 60 seconds of sitting. A second step test will follow
immediately after the 60 second rest using a 10 inch step, with a cadence of 120 (30
cycles)/minute. Heart rate and RPE will again be measured. Using a prediction equation
adapted by Gaskill (personal communication, October 30, 2002), an estimated VT and
VO$_2$$_{max}$ will be determined to evaluate the subject’s level of fitness prior to the start of
the Iditarod, and to determine exertional fatigue during the Iditarod with repeated
measures.

In summary, on March 1, prior to the start of the Iditarod sled dog race the
Controlled Verbal Fluency Task (CVFT) will be administered (Figure 1). The subjects
will be asked to rate their level of fatigue using a 5-point scale. The subjects will be
asked to complete 3-one minute step tests, including measurements of heart rate and
RPE. The subjects will be weighed and measured in long underwear and stocking feet.
In addition, a urine sample will be obtained. Six of the subjects will be recruited to participate in a determination of total body water using $^2\text{H}_2\text{O}$. Skinfold measurements will also be obtained on this select group of participants. During the race, the Controlled Oral Word Association (COWA) test, fatigue measurement scale, one minute step test, weight and urine sample will be obtained within one hour of the start of the mandatory 24 hour layover (the 3 most common sites will be staffed by a researcher; McGrath-mile 413, Takotna-mile 436, and Iditarod-mile 564), within one hour of the start of the mandatory 8 hour layover in White Mountain (mile 1084), on arrival in Nome (Finish) and 24 hours later. Mushers will take care of the dogs first, but will be available for the sampling within the first hour of arrival at the checkpoint. The subjects will be asked not to consume food or beverage during that hour. Every effort will be made to collect the data as close to arrival at the checkpoint as possible (Figure 1).

Three field researchers (assistants) will be needed during the data collection phase. Three in Anchorage (total = 3), one at each of the 24 hour checkpoint (total = 3), 1 in White Mountain and 2 in Nome (total = 3). Three digital scales will be calibrated prior to the Iditarod, and compared to one another for accuracy. Three identical steps will be designed which are 8 inches in height, 8 inches deep and 24 inches in width. In Anchorage, each mandatory checkpoint and Nome, the researcher or research assistant will collect on each subject a weight in long underwear and stocking feet and a urine sample within one hour of arrival at the pre-determined checkpoints. In addition, the subject will be asked to perform a one-minute step test, take one of three verbal tests and rate their level of fatigue.
Statistical procedure:

Descriptive data will be expressed as mean +/- SD for the measures of estimated
VO_{2max}, total dietary intake (kcal/kg/day), CHO intake (g/kg/day) and water turnover
(rH20 L/day).

A one way repeated measures ANOVA will be used to analyze changes in body
weight, hydration (osmolality and specific gravity), cognitive function, fatigue, heart rate
and fat free mass during the Iditarod.

Univariate correlation will be used to determine the relationship between all
variables. These include the relationship between rH20, energy intake, total energy
expenditure, CHO intake (g/kg/day), estimated VO_{2max}, estimated VT, Δ osmolality, Δ
specific gravity, Δ body weight, cognitive function and fatigue.

Stepwise regression will be applied to determine the variables of hydration,
energy balance, CHO intake (g/kg/day), estimated VO_{2peak}, estimated VT, fatigue
cognitive function and time to race completion.

The level of significance for all statistical evaluations is set at α .05.
Table 1: Food Checklist Example

**Skwentna**

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<thead>
<tr>
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<tbody>
<tr>
<td>Lasagna</td>
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<td>Mashed potatoes</td>
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<td>Snickers</td>
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<td>Jerky</td>
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<tr>
<td>Lemonade</td>
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<tr>
<td>Other</td>
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Lemonade: ☐ 1 quart ☐ 3 cups ☐ 2 cups ☐ 1 cup

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### Figure 1 – Timeline for data collection

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<tbody>
<tr>
<td>ABCD</td>
<td>E</td>
<td>F</td>
<td>G</td>
<td>H</td>
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</table>

- **A** - 1-2 days prior to the start of the Iditarod
- **B** - Morning of the ceremonial start
- **C** - Evening prior to the race start
- **D** - Morning prior to the race start
- **E** - At the 24 hour check point (Takotna, McGrath, Iditarod)  
- **F** - At the 8 hour (White Mountain)  
- **G** - Within 1 hour of the arrival in Nome  
- **H** - 24-36 hours after arrival in Nome

Provided with food check list: **A**

- Cognitive Function test: **A, E, F**
- Sleep deprivation rating scale: **A, E, F**
- One minute step test: **A, C, E, F, G**
- Weight: **A, E, F, G, H**
- Height: **A**
- Skinfold measurements: **A, G, H** (deuterium subjects only)
- Urine collection: **D, E, F, G** (deuterium subjects only), **E, F, G** (all other)
- Collection of food records: **G or H**
- Deuterium administration: **C**
- Caliper measurements: **A, G**
Equation 1. Calculation of total body water from the change in isotopic enrichment

\[
\text{TBW (kg)} = \frac{d \cdot \text{APE} \cdot 18.01}{\text{MW} \cdot 100 \cdot R_{\text{std}} \cdot \Delta\delta^2} \Bigg/ 1.0141
\]

- \( d \) = isotopic dose in grams
- \( \text{MW} \) = the molecular weight of \(^2\text{H}_2\text{O}\) (20.00)
- \( \text{APE} \) = atom percent excess of \(^2\text{H}_2\text{O}\) stock solution (99.99)
- \( 18.01 \) = molecular weight of unlabeled water
- \( R_{\text{std}} \) = isotopic difference noted in the standard (0.00015576)
- \( \Delta\delta^2 \) = change in enrichment from background (relative to SMOW to second void)
- \( 1.041 \) = assumed isotope dilution space for \(^2\text{H}_2\text{O}\)
References


Barnard, J., Tapsell, L., Davies, P., Brenninger, V. & Storlien, L. (2002). Relationship of high energy expenditure and variation in dietary intake with reporting accuracy
on 7 day food records and diet histories in a group of health adult volunteers.


Chapter 1. Case Study of Training, Fitness, and Nourishment of a Dog Driver during the Iditarod 1049 mile Dog Sled Race.

The purpose of the present case study was threefold: 1. To estimate intake and expenditure of a dog driver (musher) while participating in the Iditarod; 2. To determine the hydration status of the musher at the completion of the event; 3. To evaluate training related changes in aerobic capacity and body composition of a long distance dog sled driver in preparation for and following completion of a 1049 mile (1692 km) sled dog race. Actual energy intake during the Iditarod Sled Dog Race was estimated at 8,921 kilojoules (kJ) per day. Nutrient intake expressed as percentage kJ of total energy (14 %, 44 %, and 42% for protein, carbohydrates and fat respectively). Weight loss of .72 kg of body weight indicated an energy deficit of 1819 kJ per day during the race. Total energy needs per day were calculated to be 10,740 kJ/day. An increase in hematocrit and hemoglobin during the race may indicate dehydration during the event. There was an improvement in aerobic fitness during on snow training as determined by ventilatory threshold and VO2peak data. Fat free mass was maintained during training (46.4 kg) with a concomitant decrease in fat (2.4 kg). Fat free mass was also maintained during the 12 day race.
Introduction:

In preparation for the 1049 mile (1692 km) Iditarod sled dog race, dog sled drivers (mushers) often train their dogs for over 2419 km from September through March. Before snowfall, the dogs are trained by pulling a four wheeled all terrain vehicle (ATV). The work of the musher at this point includes carrying the dogs from their circle (where they are tied) to the main line, harnessing the dogs and hooking them into the main line. In addition to harnessing and hooking up the dog team, the musher often helps the team by pumping (pushing with one leg, while maintaining balance on the sled) and running. Besides the physical work of training the dogsled team, buckets of food and water are carried to the dogs throughout the year, a significant task because there are often more than seventy dogs per kennel.

As elite sled dogs reach their maximum potential through specialized breeding programs, excellent feeding regimens and scientifically designed canine physical training programs, the importance of the fitness and nutrition of the driver may emerge as the critical component to winning dog sled races. Well trained drivers who are able to maintain their fat free mass, weight and hydration during the event could maximize their ability to assist the dog team and improve team performance.

The Iditarod sled dog race begins in Anchorage the first weekend of March each year and runs through mountainous sections of remote Alaska and finishes on a coastal section of the Bering Sea. The race is continuous, except for two mandatory 8 hour and one 24 hour rests. Mushers generally complete the
race in nine to fourteen days. Food for the dogs and drivers is shipped ahead to
check-points along the trail. The mushers do not receive any outside assistance,
and must care for their dogs needs as well as their own. During the race, the
musher helps the team negotiate rough trails, which includes many hills,
hummocks, and potholes. Often the trail is heavily rutted as well. Jumping off the
sled to miss a tree, running up the hills to decrease the load the dogs must pull,
pushing and hanging onto the sled require both aerobic fitness and strength.
Mushers have been known to break trail with snowshoes and to require crampons
to negotiate icy area. In addition, there are the daily tasks of watering, feeding
and general caring for the dogs, which increase the day to day energy expenditure
of the competitor. Physical work for eighteen hours per day is not unusual. In
addition, heavy clothing is required to combat the environmental extremes of
Interior Alaska, (temperatures often reach -45°C) contributing to the total energy
expenditure of the musher. The drivers usually maintain a rigorous schedule,
with little time for rest. Many times mushers will run through the night and rest
during the day if the weather is too warm for the dogs.

Although there are multiple articles written on the energy expenditure of
the sled dog, (7, 8, 12, 17) there is an absence of information on the fitness level
and energy expenditure of the dog sled driver during training and participation in
a long distance event. Previous estimates of energy expenditure during mushing
have been derived from retrospective food journals of arctic explorers who used
sled dogs, often with heavy loads, negotiating difficult, ungroomed terrain. (4, 5,
10, 20). This information is of interest, but has minimal application to the energy
needs of the musher using state of the art sleds, lighter loads while often covering
distance of more than 161 km per day. To our knowledge, no one has attempted
to gather energy intake data on mushers in an endurance event, and to establish
the level of hydration of the musher at the completion of the event. In addition,
the fitness level of the driver has not been researched.

In 1993, Case (1), demonstrated a decrease in body weight and fat during
the Iditarod Sled Dog Race among ten participants. Using bioelectrical
impedence, Chapman (2) demonstrated a decrease in total body fat during the
Iditarod Sled Dog Race in four female and thirteen male mushers of middle age.
Additional research has evaluated the psychological stress encountered by the
endurance musher (19). Racers displayed slowing of psychomotor activity,
impairment of recent memory and temporal disorientation. A reduction in total
blood cholesterol and serum protein values and an increase in muscle enzymes
(creatine phosphokinase, serum glutamic-oxalacetic transaminase and lactic
dehydrogenase) have also been described during extended sled dog racing. (15)

The purpose of the present case study was threefold: 1. To estimate
energy intake and expenditure of a musher while participating in the Iditarod; 2.
To determine the hydration status of the musher at the completion of the event; 3.
To evaluate training related changes in aerobic capacity and body composition of
a long distance musher in preparation for and following completion of a 1049
mile (1692 km) sled dog race.
Methodology:

This study was approved by the Institutional Review Board (IRB) of the University of Montana. One 49 year old female musher was recruited for the case study. The subject has completed a wide variety of distance sled dog races, including being a previous participant in the Iditarod. Prior to fall training, she had been involved in a weight-training program. She is an active individual, but did not participate in a planned aerobic exercise program prior to or during sled dog training. An approved consent form was completed and signed by the participant prior to beginning testing. The subject began on-snow sled training with dogs at the beginning of December, 2000.

Food intake data were recorded using a simplified food journal. Due to the exhaustive nature of the race, ease of recording food intake was essential. Most of the food was prepackaged and shipped to the race checkpoints more than a month ahead of time. This pre-packaging of the food provided the opportunity to record food intake by means of a check off list, which would allow the subject to determine if ¼, ½, ¾, or all of the packaged food items had been consumed (Figure 1). Some check points provide an option of home-cooked meals for the mushers. Items that were eaten in addition to the packaged items were recorded in the back of the log book. The dietary record was analyzed using the Food Processor® Version 7.3 Program (ESHA Research, Salem, Oregon, USA).

Calculation of total body expenditure was accomplished using the total energy intake data (above), averaged over the 12 days of the race. This
information was combined with the weight loss data (weight loss sustained after 48 hours, allowing for re-hydration) to determine total energy needs per day.

A blood sample was analyzed for hematocrit and hemoglobin at a state certified laboratory prior to on-snow training to aid in the determination of hydration status. The same data were collected at the end of the training period, prior to leaving for the Iditarod Sled Dog Race. Within one hour of completing the Iditarod an additional sample was also obtained (Figure 2). The hematocrit and hemoglobin were determined using a Coulter Max M. The hemoglobin was determined photometrically. The hematocrit was calculated (measured red blood cell count x mean corpuscular volume/10).

Anthropometric and measures of aerobic capacity were completed at the Human Performance Laboratory at the University of Montana in mid December, mid February, and at the end of March. Additional weights and anthropometric measurements were determined at the completion of the race in Nome, with the subject’s weight being measured at the Norton Sound Hospital. Height and weight were measured with the subject dressed in Capilene® long underwear. All weight determinations were made on calibrated balance beam scales. Measurements were made prior to training, at the end of training, immediately, 24 and 48 hours after the event. Body fat was estimated using skinfold calipers (Lange) and hydrostatic weighing. Skinfold measurements were taken on the right side of the body and done by the same researcher at every visit. Measurements were taken on three sites; thigh, suprailium and triceps. The Jackson and Pollack (1980) formula was used to determine body density (9). Percent body fat was calculated using the age-gender
specific formulas suggested by Heyward and Stolarczyk (1996) equation (6). Two hydrostatic measurements were taken prior to the actual test to familiarize the subject with the underwater technique. Three weights were averaged to determine body density using the Lohman formula (13). Residual volume was determined using the Goldman and Becklace formula (14). Caliper measurements were taken prior to on snow training, prior to leaving for the Iditarod Sled Dog Race, immediately after the completion of the event and upon return home, eleven days after the event (Figure 2). Hydrostatic measurements were taken prior to on-snow training and eleven days after the completion of the race (Figure 2).

To determine oxygen consumption at peak effort ($VO_2$ peak) and ventilatory threshold ($VO_2$VT), the subject was exercised on the treadmill using the Balke protocol. Oxygen consumption was measured continuously during treadmill walking using a Parvo Medics metabolic cart (Salt Lake City, Utah). The metabolic cart was calibrated before each test with known concentrations of $O_2$ (15.2%) and $CO_2$ (5.17%). Expired gases were averaged and recorded every 15 seconds. $VO_2$Peak was determined by noting the maximum $O_2$ uptake at the point at which the subject felt as though the maximum workload had been reached. The ventilatory threshold (VT) was determined by the first break where a transition in the relationship between $VCO_2$ and $VO_2$ occurred. VT was selected independently by two separate investigators. Ratings of perceived exertion (RPE) were determined by asking the subject perceived level of effort on a 20 point scale at each incremental raise of the treadmill. The subject was measured at her three visits to the laboratory: prior to on-snow training, prior to
leaving for the event, and after returning home (eleven days after the race) (Figure 2).

Results:

Energy intake was calculated at 8,921 kilojoules (kJ) per day. Nutrient intake expressed as percentage kJ of total energy was estimated at 14 %, 44 % and 42 % for protein, carbohydrates and fat respectively. Energy deficit based on a sustained weight loss of .72 kg for 48 hours after the event was estimated at 23,285 kJ during the 12.8 day race, for an average deficit of 1819 kJ/day.

Table 1 shows energy intake and macro nutrient consumption data. Weight loss during the Iditarod sled dog race was 3 kg from the start of the race to immediately after completing the event (Table 2). Two days were allowed for rehydration. Weight immediately after the race was 54.0 kg. A total of 2.3 kg was regained within 24 hours and weight was stable for 48 hours. Although direct measurement of hydration was not tested, the subject gained 4% of her body weight within 24 hours after the end of the race. Blood chemistry data are shown in Table 3. Hematocrit rose from 37.5% to 38.5%.

Fitness data are shown in Table 4. VO_{2\text{peak}} increased during the on snow training by 20.6% (40.7 ml/kg/min to 49.1 ml/kg/min). VO_{2VT} improved 15% with a concurrent increase in grade of 1% during on snow training. On return from the race, VO_{2\text{peak}} had almost returned to pre-training levels, however was still elevated over baseline (42.37 ml/kg/min). VO_{2VT} returned to pre-training
levels within eleven days of completing the Iditarod. Of note, the subject started on snow training in good condition (40.7 ml/kg/min).

Skinfold measurement results indicated fat free mass was maintained during training (46.4 kg), with a concomitant decrease in fat (2.4 kg). During the race, fat free mass was maintained based on skinfold measures collected immediately post race.

Discussion:

Energy intake was determined using a check-off system. That system could be used in other events in which prepackaged foods are used, for example, mountain climbing expeditions. The total kJ needs were calculated to be 10,740 kJ per day, based on total intake and accounting for weight loss sustained 48 hours after the event. Resting metabolic rate for the subject’s height, weight and age using the Harris Benedict Equation was estimated, with an additional 10% for thermic effect of food and 70% for extreme activity resulting in an estimated total energy need of 9962 kJ per day. However, our determinations estimated by energy balance data on the subject revealed an even higher energy requirement of 10,740 kJ/day for the subject. This illustrates the high energy demands of this sport. The subject’s carbohydrate intake was low (4.1 g/kg/day). Considering the extended physical activity required of the musher, a higher carbohydrate intake is suggested to maintain muscle and liver glycogen and overall performance, similar to athletes in other sports requiring physical endurance (16).
Based on pre-race and post-race hematocrit and hemoglobin, plasma volume decreased by 2.3% (Table 3). This would support the weight gain concept of dehydration noted at the completion of the event when the subject gained 2.3 kg within 24 hours.

During training, the subject performed all the tasks of caring for her dog team including training, feeding, watering, and hooking up the team and putting them back in the dog yard when the training session was completed. All of these physical activities probably contributed to the level of fitness prior to on-snow training. The increase in fitness resulting from on-snow training may be related to the pumping and running with the sled, which occurs with on-snow training versus training with a four wheeled ATV in the fall. As the on-snow training season progressed, training increased in both intensity and duration. The results of this study indicated an increase in $VO_{2\text{peak}}$ and $VO_{2\text{VT}}$ (Table 4). The large increase is difficult to explain. The subject does have asthma, and although consistency was used throughout in the use of her medication, it is possible that the environmental condition and the use of the inhaler may have influenced the results.

These data agree with the work of Chapman (2) who illustrated, through bioelectrical impedance (BIA), maintenance of lean body mass and loss of fat during the same race in 1990. Lean body mass was maintained during the duration of the training and event, with a decrease in total body weight. However, the accuracy of BIA is compromised if the hydration status of the subject changes (11).
Hydration is difficult to maintain with exercise in the cold environment. Fluid must be kept in insulated containers such as a thermos or insulated cover. This makes access to fluid more difficult. While running the team, both hands are never free to unscrew lids and unzip insulated covers, because one hand must always be on the sled. In addition, it is very challenging to urinate in the cold environment and while running the sled, so the incentive is to minimize this somewhat complicated task. Levels of hydration were not checked throughout the race, but significant weight gain (4%) was noted within 24 hours of the end of the race and remained stable, indicating adequate rehydration. Water loss of as little as 2% of body weight is known to affect performance (18), so maintenance of body fluids should be a high priority and could have possibly improved our subject’s performance.

It is apparent that physical training, adequate dietary intake and fluid balance contribute to the optimal performance of the musher. If the dog sled driver is using a handler to accomplish much of the training, an individualized exercise training schedule should be considered for the musher. In addition, adequate intake of kilojoules with special emphasis on carbohydrates and hydration during an endurance race may enhance the overall performance of the whole team. Further studies using doubly labeled water to accurately quantify total energy expenditure are required to determine the unique dietary needs of this group of athletes.
References


Acknowledgments: A huge thank you to the subject for her willingness to be prodded, poked and run on the treadmill to exhaustion. Thank you to the Western Montana Clinic, Missoula, Montana and the Norton Sound Hospital Laboratory, Nome, Alaska for their donation and help in analyzing the blood data. Thank you to Dustin Slivka, graduate student in Health and Human performance at the University of Montana, for his help with the metabolic cart.
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<th>¼</th>
<th>½</th>
<th>¾</th>
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<tr>
<td>Skwentna</td>
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<tr>
<td>Spaghetti</td>
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<tr>
<td>Pizza</td>
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<tr>
<td>Creamed carrots</td>
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<tr>
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<tr>
<td>Horrible bar</td>
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<tr>
<td>Cupcake</td>
<td></td>
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</tbody>
</table>

Figure 1 – Food record provided to subject to coincide with the food drop off at the checkpoint. Simplicity was the focus. The food was pre-packaged by the subject and mailed to the checkpoint ahead of time by the Iditarod race committee.
<table>
<thead>
<tr>
<th></th>
<th>Mid December</th>
<th>Mid February</th>
<th>Mid March</th>
<th>End of March</th>
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<tbody>
<tr>
<td>(pre-on snow training)</td>
<td>(prior to leaving for the race)</td>
<td>(Immediately before and after the race)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>A, B, C, D, E</td>
<td>A, B, D, E</td>
<td>A, B, D</td>
<td>B, C, D, E</td>
</tr>
</tbody>
</table>

Figure 2  Time Line for Data Collection

A – Blood sampling (CBC, lipid, thyroid)
B – Body weight
C – Body composition, hydrostatic
D – Body composition, skinfold calipers
E – VO2 and Ventilatory Threshold
Table 1 – Average Energy and Nutrient Intake during the 12.8 days Iditarod Dog Sled Race

<table>
<thead>
<tr>
<th>Macronutrient Intake</th>
<th>Protein</th>
<th>Carbohydrate</th>
<th>Fat</th>
</tr>
</thead>
<tbody>
<tr>
<td>g.d⁻¹</td>
<td>74.5</td>
<td>235.6</td>
<td>98.2</td>
</tr>
<tr>
<td>g.kg⁻¹bw.d⁻¹</td>
<td>1.3</td>
<td>4.1</td>
<td>1.7</td>
</tr>
<tr>
<td>% total</td>
<td>14</td>
<td>44</td>
<td>42</td>
</tr>
</tbody>
</table>

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Table 2 – Weight Changes During Training and Racing

<table>
<thead>
<tr>
<th></th>
<th>Pre on-snow training (Mid December)</th>
<th>Prior to leaving for the race (Mid February)</th>
<th>Immediately after the race (Mid March)</th>
<th>24 hours after the race (Mid March)</th>
<th>10 days after the race (End of March)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body weight (kg)</td>
<td>59.5</td>
<td>57.0</td>
<td>54.0</td>
<td>56.3</td>
<td>57.6</td>
</tr>
</tbody>
</table>
Table 3 – Hemoglobin and Hematocrit values

<table>
<thead>
<tr>
<th></th>
<th>Pre on-snow training (Mid December)</th>
<th>Prior to leaving for the race (Mid February)</th>
<th>10 days after the race (End of March)</th>
<th>Normal laboratory values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hemoglobin (g/dl)</td>
<td>12.8</td>
<td>13.1</td>
<td>13.2</td>
<td>12 to 16</td>
</tr>
<tr>
<td>Hematocrit (%)</td>
<td>37.5</td>
<td>37.5</td>
<td>38.5</td>
<td>36 to 48</td>
</tr>
</tbody>
</table>
Table 4 – Changes in Maximal and Submaximal Aerobic Fitness  
(a) VO2peak,  
(b) Ventilatory Threshold

<table>
<thead>
<tr>
<th></th>
<th>Prior to Training on Snow</th>
<th>Prior leaving for the Iditarod</th>
<th>10 days after returning</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) VO₂ Peak</td>
<td>40.7</td>
<td>49.1</td>
<td>42.4</td>
</tr>
<tr>
<td>(ml/kg/min)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(b) VO₂VT</td>
<td>34.5</td>
<td>40.5</td>
<td>35.1</td>
</tr>
<tr>
<td>(ml/kg/min)</td>
<td></td>
<td></td>
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</table>
Chapter 2. Hydration status of Sled Drivers during the Iditarod Trail (1049 Mile) Sled Dog Race

Abstract. Physical activities in the cold have been related to significant levels of dehydration due to elevated energy expenditure and therefore enhanced respiratory water loss and difficulty accessing fluids. The application of urinary markers for hydration status has not yet been applied to dogsled drivers during an endurance event.

PURPOSE: to determine changes in commonplace urinary markers of hydration maintained by the drivers (mushers) during the Iditarod dogsled race across Alaska.

METHODS: Sixteen mushers were recruited for the study, 13 completed the entire race. Body weight was obtained prior to and at the end of the race. At five different checkpoints along the 1049-mile trail (symbolic distance), urine was collected. Water turnover was measured in 5 mushers from rates of deuterium ($^2$H$_2$O) elimination ($r$H$_2$O). Urine osmolality ($U_{osm}$) was determined using freezing point depression. Urine specific gravity ($U_{sg}$) was determined using a hand held refractometer. RESULTS: Out of the 13 subjects that completed the race, four of the mushers had a $U_{sg} \geq 1.03$ (mean 1.020±0.009). Ten had a urine osmolality $\geq 900$ mOsm/L during the race, with an average $U_{osm}$ of 868±277 during the duration of the event. There was an average drop in weight from the beginning to the end of the Iditarod of 0.70±1.63 kg. Water turnover demonstrated that $r$H$_2$O averaged 2.85±1.18 kg·day$^{-1}$ (range 2.03 – 4.60). CONCLUSION: These data demonstrate that the majority of mushers studied showed signs of dehydration based on common urinary markers during the long distance dogsled race.
Introduction

The Iditarod Trail Sled Dog Race starts in Anchorage, Alaska the first Saturday in March. It is a continuous race, traversing some of Alaska’s most brutal back country, requiring nine to fourteen days to complete the over 1000 miles to Nome, Alaska. Although the dogs provide most of the forward momentum for the team, the musher also contributes to the race. Energy is expended by the musher to negotiate rough terrain, steer the sled around sharp turns, avoid obstacles, as well as to pump (push with one foot while standing with one foot on the runner) and push the sled while running uphill and when the dogs are showing signs of fatigue. Because the Iditarod is a continuous race, the participants are often physically active for twenty or more hours per day for up to two weeks. In addition to the physical demands, the weather can be a significant factor in the race. Temperatures are often below -22°C, matched with extremely low humidity and fierce winds on the coastal section of the trail.

Hydration is vital to all endurance athletes. A water deficit, of as little as 2-3% of total body water, has been shown to impair exercise performance (Armstrong, Soto et al. 1998). Dehydration can result in elevated heart rate and decreased stroke volume (Gonzalez-Alonso, Mora-Rodriguez et al. 2000), fatigue (Maughan 1992) and decreased performance (Murray 1995). Dehydration also shortens the time to the onset of fatigue (Armstrong 2000).

Maintaining normal hydration is especially difficult in the severe cold. Water freezes and must be thawed prior to ingestion. Sled dog racing creates an additional challenge as urinating while holding onto the sled is a cumbersome task; encouraging
some mushers to limit the need to urinate by restricting fluid intake. Cold weather also exacerbates dehydration due to cold-induced diuresis and respiratory water loss in conditions of low humidity (Murray 1995).

Several methods have been utilized for determining hydration status in the field. A simple, non-invasive test is the measurement of urine osmolality and specific gravity requiring only the collection of urine samples. Popkin (Popkin, Stillner et al. 1980) measured the osmolality of the first morning void in athletes. The field measurement was used on 29 athletes to determine their hydration status. The findings suggested that urine osmolality was an effective tool to determine daily fluctuations in hydration status. Armstrong (Armstrong, Soto et al. 1998) found similar results in a group of nine highly trained athletes. An additional field measure of hydration status is the use of hemoglobin and hematocrit measurements. Dill (Dill and Costill 1974) calculated the percentage change in volumes of blood, plasma and red cells to determine dehydration in a group of six males before and after running. Prior research has shown that dog sled drivers in the Iditarod have an increase in their hematocrit over the duration of the race (Cox, Gaskill et al. 2003) (Popkin, Stillner et al. 1980) suggesting signs of dehydration. This method, although valid, has the disadvantage of being more invasive and difficult to use in a remote setting, such as the roadless route of the Iditarod Trail Sled Dog Race, where ready access to a laboratory is not available.

The purpose of our study was to determine changes in commonplace urinary markers of hydration and to assess rates of water turnover in the drivers (mushers) during the Iditarod dogsled race across Alaska. Markers of cognition, changes in heart rate, and the self-assessment of fatigue were also measured.
Methods:

Subject population. Sixteen subjects were recruited on a volunteer basis through individual meetings with racers, e-mail requests to race participants, letter and/or phone. All participants provided written informed consent before participating in this study, which was approved by the Institutional Review Board of the University of Montana.

Testing schedule. To determine the level of hydration prior to and during the Iditarod sled dog race, urine samples were obtained at the start of the race in Anchorage, at three checkpoints along the trail at Ruby (mile 328), Unalakleet (mile 860), White Mountain (mile 1044) and at the finish in Nome. In addition, body weight was obtained using a calibrated digital scale prior to the beginning of the race and immediately after the completion of the race in Nome. Drivers were weighed dressed in Capilene® long underwear and socks under both testing conditions. Prior to the start, and at each of the above checkpoints, a resting heart rate, bench step test, exercise and recovery heart rate, rating of perceived exertion (RPE) using a 20-point scale, a fatigue rating scale and a cognitive test were administered. In addition, a urine sample was collected immediately upon the arrival of the musher at each checkpoint facility. All mushers were asked to abstain from drinking or eating anything at the checkpoint prior to providing the urine sample. Five of the 16 initial subjects were provided with an oral dose of $^2$H$_2$O (99% ape Cambridge Isotope Laboratories, Andover, MA) based on 1.43 g (range 1.35-1.52) kg$^{-1}$ after the collection of a background urine sample (between 2200 and 2300 the night prior to the race start). After consumption of the original dose mixture, the dose vial was rinsed three times with tap water to ensure complete isotopic delivery. Subjects were asked to refrain from eating or drinking until first void urine samples were collected. All

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overnight urine was collected. First and second morning voids were collected between 0430 and 0705. The five subjects were weighed immediately after first morning void in Capilene® long underwear and socks as mentioned above.

**Hydration markers.** Urine samples were analyzed for urine specific gravity ($U_{sg}$) and osmolality ($U_{osm}$). The samples were collected in sterile covered and sealed urine containers and within 24-hours the samples were transferred, in duplicate, into 5 ml cryogenic vials for later analysis. Urine specific gravity was determined in duplicate using a calibrated hand-held refractometer (Atago Uricon-NE, Framingdale, NY). $U_{osm}$ was determined by freezing point depression (Precision Systems mOsmette Model 5004) after the instrument was calibrated using 100, 500 mOsmol standards (CON-TROL, Natick, MA). Water turnover was calculated from the initial enrichment following the dose of $^2$H$_2$O and the change in enrichment from the initial sample to the completion of the race in Nome, nine to fourteen days later.

**Isotopic analysis and water turnover.** The Stable Isotope Laboratory at the University of Wisconsin, Madison, WI, conducted isotopic analysis of all urine samples. Briefly, deuterium analysis was performed by chromium reduction according to Schoeller (Schoeller, Colligan et al. 2000) using a dual inlet isotope ratio mass spectrometer (Delta Plus Mass Spectrometer, Finnigan MAT, San Jose, CA, USA). Enriched and depleted controls were analyzed at the start and end of each batch, and these secondary standards used to calculate the “per mille” abundance versus Standard Mean Ocean Water (SMOW) for each urine sample. All analyses were performed in duplicate, and all specimens from the same participant were analyzed in the same batch. Results were corrected for any memory from the previous chromium reduction process. If duplicates
differed by more than 5 per mil, duplicate analyses were repeated. Total body water (TBW) was determined as previously described (Trabusi, Troiano et al. 2003)

**Physical fatigue.** The heart rate response was measured at each checkpoint using a standardized bench step exercise test. Subjects were asked to perform a one-minute step test using a 19.2 cm step, following the beat of a metronome (88 counts/minute). Heart rates were collected prior to the step test (after one minute of seated rest), at the end of one minute of stepping and at 30 and 60 seconds post-exercise during seated recovery. Each subject was asked to determine perceived level of effort using a 20-point scale and was verbally asked to rate the level of their fatigue on arrival at the checkpoint by responding to a 5-point rating scale (1 = least fatigued, 5 = most fatigued).

**Cognitive function.** To assess changes in attentiveness, the Controlled Oral Word Association (COWA) test was administered to the subject by the primary researcher or one of the trained research assistants. The subject was given one minute to list all the words that started with an assigned letter; this was repeated for 2 additional letters. Three letter sequences (FAS, CFL and PRW) were selected based on their tests of validity and reliability as previously determined (Spreen and Strauss 1998). FAS and CFL were used twice over the five check-points.

**Data Analysis:**

Descriptive data are reported as means±sd. The dependent variables of hydration status (urine markers), cognitive function, perceived rating of fatigue, and heart rate response to the step test were analyzed using an analysis of variance (ANOVA). Pearson correlation coefficients were used to determine correlations between and the

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variables of hydration; cognitive function, ratings of fatigue, and heart rate before and after the step test.

**Results:**

Thirteen out of the original 16 research subjects completed the race. Complete data sets were obtained from 10 drivers. Data were obtained for an additional three drivers through the Unalakleet checkpoint (860 miles into the race). Of the final three, one dropped out of the race, one completed the race after the researchers had left Nome, and a third was unavailable due to race circumstances. Two racers of the original sixteen dropped out early in the race, one due to problems with their dog team, another with a broken ankle.

Dehydration was determined using the criteria of $U_{\text{osm}} \geq 900$ mOsm$\cdot$L$^{-1}$ recommended by (Shirreffs and Maughan 1998) and $U_{\text{eg}} \geq 1.030$ (Francesconi, Hubbard et al. 1987). Of the subjects who completed the race through Unalakleet, ten (77%) were dehydrated at some point during the race using the criteria of Shirreffs and Maughan. Using the Francesconi criteria for $U_{\text{eg}}$, four (31%) were dehydrated at some point during the race. The National Collegiate Athletic Association recommends the use of $U_{\text{eg}} 1.020$ to determine the upper level of euhydration (Popowski, Oppliger et al. 2001), using this criteria, all but one musher (92%) were mildly dehydrated at some point during the event (Table 1).

When finish place is considered, the top two finishers in our subject population had an average urine osmolality value of $504$ mOsm$\cdot$L$^{-1}$ and $619$ mOsm$\cdot$L$^{-1}$ compared to the two mushers in the back of the subject pool who had an average $U_{\text{osm}}$ of 1415.
mOsm·L⁻¹ and 998 mOsm·L⁻¹. One of later mushers dropped out of the race in Shaktoolik, approximately 940 miles into the race. When comparing drivers who completed the race in 10 days or less compared to those that took 12 days or more, the subjects who completed the race in the front 1/3 of the pack had an average U_{osm} of 759 mOsm·L⁻¹ compared to those in the back 1/3 of the pack who had an average U_{osm} of 971 mOsm·L⁻¹.

Five of the subjects were female drivers. Females had an average U_{osm} of 802±276 mOsm·L⁻¹ compared to the male (eight subjects) average of 909±287 mOsm·L⁻¹ (Table 2). Eight of the mushers were veterans of the Iditarod, having completed the race at least once prior to 2003; the remaining five were rookies. When comparing veterans to rookies (having never completed an Iditarod), veterans averaged 830±204 mOsm·L⁻¹ compared to the rookies with a U_{osm} of 952±426 mOsm·L⁻¹ (Table 2).

A one way repeated measures ANOVA demonstrated a significant (p< 0.05) change in hydration status from Anchorage to Nome with the greatest change occurring between Anchorage and Ruby (Table 1) (the first monitored checkpoint, 328 miles into the race).

Resting heart rate increased significantly over the course of the race (p< 0.05)(Figure 1). However, exercise heart rate and recovery heart rate during and after the standardized step test did not change significantly over the course of the race. There was a significant (< 0.05) relationship between the rating of perceived exertion during the step test at the various checkpoints of the race (Figure 2), and the overall fatigue rating scale (Figure 3).
Pearson correlation coefficient \(r=0.97\) demonstrated a positive relationship between average resting heart rate and degree of dehydration \((p < 0.05)\). The Fatigue Rating Scale was positively correlated \(r=0.87\) to the resting heart rate over the course of the race \((p < 0.05)\). The relationship between the fatigue rating scale and the level of dehydration \(r=0.74\) averaged at each checkpoint was not significant. There was not a significant relationship between the cognition test index and markers of hydration or fatigue.

Eleven of the subjects completing the race were weighed in Nome at the completion of the race. The average change in body weight was a loss of \(0.70\pm1.63\) kg during the race, with a range of \(-3.1\) kg to \(+1.7\) kg over the course of the race.

Water turnover \((rH_2O)\) mean was \(2.9\pm1.2\) kg·d\(^{-1}\) from Ruby to Nome, and \(2.7\pm0.9\) kg·d\(^{-1}\) over the entire race. This corresponded to \(43.5\pm7.1\) ml·kg·d\(^{-1}\) and \(42.3\pm5.4\) ml·kg·d\(^{-1}\) from Ruby to Nome and over the entire race, respectively (Table 3).

**Discussion:**

During the 2003 Iditarod dog sled race, 77% of the mushers involved in the present investigation experienced subtle to pronounced dehydration at some time during the event using the criteria of \(U_{\text{o}}s_m\geq900\) mOsm·L\(^{-1}\). The greatest change in osmolality was between Anchorage and the Ruby checkpoint (mile 328). The early race dehydration may have been the result of a last minute, unanticipated course change. During the 2003 event, the route was changed from the normal start in Anchorage due to lack of snow on the original portion of the trail, to a new route that originated in Fairbanks and joined the usual trail in Ruby. This change required that mushers follow a new route, arriving in
Ruby after approximately 115 miles from the previous checkpoint where water was available. Rather than having access to water available every 40-90 miles, mushers camped on the trail and had to heat their own water for their dogs and themselves. This is time consuming and difficult when fatigued, and may have contributed to the marked change in hydration during this early segment of the race. Between Unalakleet and White Mountain, hydration markers declined (Table 1). During the Unalakleet to White Mountain portion of the race, there were multiple checkpoints where mushers could obtain fluids, and the longest duration between checkpoints was 58 miles.

In general, dogsled drivers who sustained higher average speeds were better hydrated than those who were slower. Rating of fatigue may be related to the level of dehydration, which could make finishing the race more challenging than when well hydrated. Levels of hydration may also be related to the mushers experience with the race. The less experienced dogsled drivers tended to be slower than those who were more experienced and generally demonstrated a higher prevalence of dehydration compared to the veteran mushers.

The data would have been even more dramatic between the front and the back of the pack with the exception of two mushers. One musher in the very competitive group was dehydrated during the entire race (average $U_{osm} 1049 \pm 48 \text{mOsm} \cdot \text{L}^{-1}$; range 1001-1101 mOsm·L$^{-1}$). Complaints of severe fatigue were noted at each checkpoint, and the average rating of fatigue was 4.5±.6(range 4-5). In contrast, a musher that took over 12 days to complete the event was well hydrated throughout the race with an average $U_{osm} 360 \pm 199$ mOsm·L$^{-1}$ (range 165-656 mOsm·L$^{-1}$) with an average on the fatigue rating scale of 2.4±.5(range 2-3).
Dehydration can lead to decreased plasma volume, increased heart rate and decreased stroke volume (Heaps, Gonzalez-Alonso et al. 1994). This was demonstrated in our study as well, with a significant positive relationship between dehydration and increased heart rate at rest and during the standardized bench stepping exercise.

Mushers may benefit by maintaining adequate hydration during the Iditarod Trail Sled Dog Race both in terms of competitiveness and reducing their rating of perceived exertion. Our data demonstrated an increased rating of perceived exertion during the entire duration of the race. (Rintamaki, Makinen et al. 1995) demonstrated lower efficiency, higher physical strain and earlier exhaustion in dehydrated individuals during exercise in the cold. The change in perceived exertion in our study may have been related to dehydration, or to the fatigue associated with a continuous race of over 9-14 days in severe cold.

Although there were trends in levels of hydration and markers of fatigue between subsets of our population group, these were not statistically significant. The lack of significance may have been a consequence of our relatively small sample size.

Understanding the relationship between increased dehydration and increased distances between checkpoints may encourage drivers to become innovative in designing systems to maintain hydration. Choosing foods for the trail such as soups and stews that contain high volumes of fluid, adapting personal hydration devices that are modified for the sled and checking hydration through urine color monitoring (Armstrong 2000), may all be advantageous for the musher.

Increased cognitive processing time has been linked to dehydration (Ainslie, Campbell et al. 2002) (Cian, Barraud et al. 2001). The non significant relationship
between the urinary hydration markers and cognitive performance in this study may have been due to the choice of the test for determining changes in cognitive function. With long hours on the trail, and the resourcefulness of the musher, the COWA test could lend itself to strategies that might enhance the results of subsequent tests.

Average water turnover was 43.16±5.4 ml·kg⁻¹·d⁻¹ from Ruby to Nome. This was similar to that seen for cyclist (47 ml·kg⁻¹·d⁻¹)(Leiper, Pitsiladis et al. 2001), but lower in comparison to trekking (78.7±17.5 ml·kg⁻¹·d⁻¹) (Fusch, Gfroerer et al. 1998), climbing at high altitude (73±20 ml·kg⁻¹·d⁻¹ ascent; 83±17 ml·kg⁻¹·d⁻¹ descent) (Fusch, Gfroerer et al. 1996) and wildland fire suppression (94.8±20.1 ml·kg⁻¹·d⁻¹) (Ruby, Schoeller et al. 2003). This is likely related to the limited access to liquids without having to melt snow. In addition, due to the length and continuous nature of the race, chronic fatigue could have played a role by not taking the added time to melt snow for drinking.

Future research should focus on methods to decrease the rate of dehydration in mushers, as well as on alternative tests for measuring cognitive performance during extended activities. Overall, these data suggest that performance during endurance dog sled driving is related to hydration.
Table 1. Urine osmolality and specific gravity at each checkpoint expressed as individual
data and means±sd

<table>
<thead>
<tr>
<th>Urine Specific Gravity</th>
<th>Musher</th>
<th>Anchorage</th>
<th>Ruby</th>
<th>Unalakleet</th>
<th>White Mtn.</th>
<th>Nome</th>
<th>Average on the trail</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.025</td>
<td>1.006</td>
<td>1.021</td>
<td>1.013</td>
<td>1.016</td>
<td>1.014</td>
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<td>1.025</td>
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<td>13</td>
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<td>1.032</td>
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</table>

| Mean ±sd               | 1.014  | 1.025     | 1.024| 1.020      | 1.022      | 1.023|
|                        | 0.007  | 0.009     | 0.007| 0.009      | 0.006      | 0.007|

<table>
<thead>
<tr>
<th>Urine Osmolality mOsm·L⁻¹</th>
<th>Musher</th>
<th>Anchorage</th>
<th>Ruby</th>
<th>Unalakleet</th>
<th>White Mtn.</th>
<th>Nome</th>
<th>Average on the trail</th>
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<td>1025</td>
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<tr>
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<td>1691</td>
<td>1139</td>
<td></td>
<td></td>
<td>1415</td>
<td></td>
</tr>
</tbody>
</table>

| Mean ±sd                 | 451    | 923       | 893  | 748        | 813        | 868  |
|                         | 251    | 376       | 266  | 332        | 218        | 277  |
Table 2. Urine osmolality (mOsm·L⁻¹) and specific gravity for population subsets over the entire course. Data are presented as means±sd.

<table>
<thead>
<tr>
<th></th>
<th>Females</th>
<th>Males</th>
<th>Rookies</th>
<th>Veterans</th>
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<tbody>
<tr>
<td><strong>Osmolality</strong></td>
<td>802</td>
<td>909</td>
<td>952</td>
<td>830</td>
</tr>
<tr>
<td>(mOsm·L⁻¹)</td>
<td>±276</td>
<td>±287</td>
<td>±426</td>
<td>±204</td>
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<tr>
<td><strong>Specific Gravity</strong></td>
<td>1.022</td>
<td>1.023</td>
<td>1.026</td>
<td>1.022</td>
</tr>
<tr>
<td></td>
<td>±0.007</td>
<td>±0.006</td>
<td>±0.010</td>
<td>±0.005</td>
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</tbody>
</table>
Table 3. Water turnover (rH₂O) during the different checkpoints of the race. Data are expressed as individual data and mean±sd

<table>
<thead>
<tr>
<th>Subject #</th>
<th>Start – Ruby kg·d⁻¹</th>
<th>Ruby – Trail #2 (48 hours outside of Ruby) kg·d⁻¹</th>
<th>Ruby – Unalakleet kg·d⁻¹</th>
<th>Ruby – Nome kg·d⁻¹</th>
<th>Ruby – Nome ml·kg⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>2.35</td>
<td>2.39</td>
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</tr>
<tr>
<td>5</td>
<td>2.73</td>
<td>2.56</td>
<td>2.18</td>
<td>na</td>
<td>34.11*</td>
</tr>
<tr>
<td>Mean</td>
<td>2.69</td>
<td>2.80</td>
<td>2.64</td>
<td>2.85**</td>
<td>43.16**</td>
</tr>
<tr>
<td>±sd</td>
<td>0.83</td>
<td>0.90</td>
<td>0.98</td>
<td>1.18</td>
<td>7.12</td>
</tr>
</tbody>
</table>

*data for the Ruby – Unalakleet portion of the trail (532 miles)
** does not include subject #5
Figure 1. Changes in resting heart rate during the race ($p < 0.05$). Data expressed as means±sd.
Figure 2. Change in exercise RPE during the standardized bench stepping exercise at the different checkpoints throughout the race (p<0.05). Data are expressed as means±sd.
Figure 3. Changes in fatigue rating scale during the race (p<0.05). Data are expressed as means±sd.
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Chapter 3. Determination of Total Energy Expenditure of Dog Sled Drivers during the Iditarod trail (1049 mile) sled dog race

Abstract. PURPOSE: The purpose of this study was threefold: (a) to assess the total energy expenditure (TEE) of the musher, (b) to determine the distribution of macronutrients ingested during the race and (c) to estimate the fitness level of the dogsled driver (musher) prior to the race. METHODS: Five mushers from the Iditarod sled dog race were recruited as research subjects to receive doubly labeled water, with three agreeing to monitor food intake. Four out of the five subjects completed the entire race. Pre-race estimate of aerobic fitness (VO2peak) using a multi-stage bench stepping protocol were also determined. RESULTS: Doubly labeled water data demonstrated an average TEE of 20.8 MJ·d·1 (4972 kcal·d·1) from Anchorage to Nome for our male subject, with an average of 11.8±1.7 MJ·d·1 (2808±397 kcal·d·1) for the female subjects during the race. Food records suggested an average distribution of macronutrients of 1.5±0.4, 3.9±0.4 and 1.7±0.9 g·kg·1 for protein, carbohydrates and fats, respectively. Estimated VO2peak was 66.2 ml·kg·1·min·1 and 50.0±8.4 ml·kg·1·min·1 for the male (n=1) and female subjects (n = 4), respectively. CONCLUSION: These data demonstrate that dogsled drivers with an above average estimated VO2peak maintain a consistent high daily total energy expenditure (TEE) throughout all phases of the race.
Introduction:

Each year the Iditarod starts in Anchorage, Alaska the first Saturday in March. It is a continuous race (9-14 days), traversing some of Alaska’s most brutal backcountry, finishing over 1000 miles later in Nome, Alaska. Previous research using the doubly labeled water methodology has demonstrated an average TEE of 47.1±5.9 MJ·day⁻¹ (11214±1405 kcal·day⁻¹) of sled dogs (14) in a mid distance race (490 km). These data demonstrate that the dogs contribute dramatically to the forward momentum of the team. However, it is important to note these data were collected during a shorter race than the Iditarod (1692 km). These data also downplay the importance of the fitness level and overall TEE of the musher while driving the dog team over multiple days on the trail.

Driving a team of dogs requires physical strength, endurance and quick decision making so as to maintain speed while frequently navigating dangerous trails and terrain. The driver must be physically able and skilled to help the team through steep and icy conditions and be able to negotiate sharp turns using a series of verbal commands. In addition, the driver may need to physically help the team when heavy snow has fallen and the trail has been obliterated. Past research has clearly demonstrated that the level of aerobic fitness is linked to endurance performance in most athletes. In addition, aerobic fitness appears to delay the onset of fatigue due to sleep deprivation (9) which is of considerable importance to the musher in a continuous 9-14 day event.

Options for the measurement and estimate of TEE have included measurement and analysis of expired air; doubly-labeled water; measured food records; food wastage; dietary recall; dietary history and food frequency questionnaires. However, during
extended activity in the field environment with limited access to the subjects, only a few approaches are appropriate. Although food records have been used for decades to determine the intake of population groups, and prediction of energy expenditure when changes in weight are also accounted for, self reported intakes have historically resulted in underreporting of total energy intake (4, 19, 23). In an analysis of 37 published studies, Black (5) showed underreporting of dietary history to be 25% (vs. dietary recall of 88%). Underreporting was also documented in soldiers during a 10-day field exercise in the Canadian Arctic, when TEI was compared to TEE using doubly labeled water (20).

Energy expenditure of humans during continuous activity in extreme environments using the doubly labeled water method (DLW) has been documented in a variety of settings. TEE of adult male Marines assessed during an 11-day cold weather exercise demonstrated an average expenditure of 20.7±0.8 MJ·day⁻¹ (4919±190 kcal·day⁻¹) (16). In a contrasting, but equally extreme environment, our laboratory has demonstrated TEE during arduous wildfire suppression of 23.0±1.5 MJ·day⁻¹ (5476±357 kcal·day⁻¹) (28). Although the TEE has been measured during a variety of other field oriented tasks including competitive cycling (39), space flight (21), and mountaineering (38), the Iditarod dog sled race provides a unique opportunity to study the rate of human energy expenditure during extended exercise with the added challenges of sleep deprivation, extreme cold, and the management of a large team of dogs.

Adequate total energy intake (TEI) is also essential to maintaining the energy necessary for manipulating the sled, running with the team, and for sustaining mental vigilance during this extended cold weather race. In addition, the distribution of macronutrients is important. The extreme cold provides logistical problems for the
musher’s diet because most food items are completely frozen and must be thawed or partially thawed prior to ingestion. Easy access to food and water is often limited by the location of checkpoints. Multiple studies have demonstrated the importance of carbohydrate consumption during exercise in the cold (27, 36) and for endurance activities (15, 24, 27). Carbohydrate administration during sustained activity has also been shown to improve mental vigilance (22). Past research supporting the importance of dietary carbohydrate is in contrast to the misconception held by many mushers that fats are the preferred source of fuel (7, 29). It is presumed that this misconception and resulting food choices have been developed from historic food availability for indigenous peoples in the far north. And perhaps also in part is due to the dietary requirement of fat for the dogs during endurance activity.

Previous research has surveyed mushers who had competed in the five previous Iditarod sled dog races. Subjects were asked retrospectively about their food choices (34). However, it is likely that this approach results in significant errors, especially considering that daily food logs recorded during the time of food consumption result in large reporting errors. In 2001 (8) our laboratory conducted a single-subject nutritional case study on a female musher during the Iditarod. Detailed food records were collected throughout the entire race, and TEE was estimated at 10.73 MJ·day\(^{-1}\) (2557 kcal·day\(^{-1}\)) based on energy intake data along with pre-race and post-race body weight measurements. The benefits of the doubly labeled water (DLW) method in this particular field environment are that it 1) provides a non invasive approach to the measurement of TEE and 2) has been demonstrated to be an accurate method across a range of environmental extremes (16, 28). The purpose of this study was to determine the TEE of
the musher, to determine the TEI and distribution of macronutrients and to estimate the fitness level of the dog sled driver prior to the race.

Methods:

Subjects

Fourteen subjects completed the Iditarod musher study, which is reported elsewhere. Five of the subjects were also recruited for this portion of the study. All subjects were recruited on a volunteer basis through individual meetings with racers, e-mail requests to race participants, letter and/or by phone. All participants provided written informed consent before participating in this study, which was approved by The University of Montana Institutional Review Board.

Energy Expenditure Analysis

Total energy expenditure was determined using doubly labeled water. Five subjects were recruited to ingest an oral dose of $^2\text{H}_2\text{O}$ (99% ape Cambridge Isotope Laboratories, Andover, MA) mixed with $\text{H}_2^{18}\text{O}$ (10% ape Cambridge Isotope Laboratories, Andover, MA). The oral dose of each tracer was ingested immediately after the collection of a background urine sample (between 2200 and 2300). Each subject was provided with an oral dose of $1.44\pm.08$ g·kg$^{-1}$ for both $^{18}\text{O}$ and $^2\text{H}$ labeled water. After consumption of the original dose mixture, the dose vial was rinsed three times with tap water to ensure complete isotopic delivery. Subjects were asked to refrain from eating or drinking until the first void urine samples were collected the following morning. All overnight urine was collected. First and second morning voids were collected.
between 0430 and 0705. The five subjects were weighed immediately after first morning void in Capilene® long underwear and socks. To compensate for any noted shift in the background enrichment, an individual who did not receive the DLW, but was from the same geographic area, was used as a control.

Urine samples were collected in sterile covered and sealed urine containers. Within 24 hours, the samples were transferred, in duplicate, into 5 ml cryogenic vials for storage and later analysis. Urine was collected at the start of the race in Anchorage (as above), at three checkpoints along the trail at Ruby (mile 328), Unalakleet (mile 860), White Mountain (mile 1044) and at the finish in Nome (mile 1121).

The Nutritional Sciences Laboratory at the University of Wisconsin, Madison, WI, conducted isotopic analysis of all urine samples. Briefly, each urine sample was mixed with ca. 200 mg of dry carbon black and filtered through a 0.45 micron filter to remove particulates and much of the organic material. Two 1 mL samples of each specimen were placed in 2 mL sealed, glass vials. Deuterium analysis was performed by reducing 0.8 µL of cleaned fluid over chromium at 850° C (12) which produces pure H2 gas that is introduced to a Finnigan MAT Delta Plus isotope ratio mass spectrometer (30). Deuterium abundance was measured against a working standard using a standard dual inlet, Faraday Cup, differential gas isotope ratio procedure. Enriched and depleted controls were analyzed at the start and end of each batch, and these secondary standards were used to calculate the “per mille” abundance versus Standard Mean Ocean water for each urine sample. All analysis was performed in duplicate and all specimens from the same participant analyzed during the same batch. Results were corrected for any memory from the previous chromium reduction process. If duplicates differed by more than 5
parts per mil, duplicate analyses were repeated. Isotope dilution space was calculated as described by Coward and Cole (6).

TEE was adjusted for time between checkpoints (Anchorage to Ruby, Ruby to Trail #2, Unalakleet to Nome). Energy expenditure per day for each segment was determined and summed to determine total energy expenditure between Anchorage to Nome.

*Macronutrient Analysis*

Food intake was systematically recorded by three of the mushers in the study. Waterproof supplies (Rite in the rain pens and booklets®) were distributed for use to decrease the chance of missing records due to damaged or smudged paper from the wet conditions. Subjects were instructed on the importance of accuracy in estimating portion sizes of ingested food and keeping an accurate account of all food eaten throughout the race. The dietary records were analyzed using the Food Processor® Version 7.3 Program (ESHA Research, Salem, Oregon, USA).

*Estimation of VO2peak*

To estimate the pre-race VO2peak of the mushers, a multi-stage step test (1) was used. Resting heart rate was obtained after three minutes of sitting. Subjects were then asked to perform a one-minute step test using a 19.2 cm step, following the beat of a metronome (88 counts·minute⁻¹); after a one minute rest, the subject stepped for one additional minute on the 19.2 cm step at 120 counts·minute⁻¹. After one minute of rest, the subject was asked to repeat the stepping procedure on a 25.4 cm step at 120
Heart rates were obtained following each workload. A prediction equation based on the linear heart-rate to workload relationship and estimated maximal heart rate (220-age) was used to estimate VO\textsubscript{2peak} (11, 25).

**Skinfold Measurements**

Body composition data were obtained prior to the start of the race. Height was determined using a tape measure fixed to a wall, and subjects were weighed in their underwear on a calibrated Seca digital scale (Hanover, MD) prior to the start of the race in Anchorage and at the completion of the race in Nome. Body fat was estimated using skinfold calipers (Lange, Santa Cruz, CA). Skinfold measurements were taken on the right side of the body and done by the same researcher. Measurements were taken on three sites in rotational order: chest, abdomen and thigh for male subjects; tricep, suprailliac and thigh for female subjects. Multiple measures were repeated in a rotational order until at least two values were obtained within 0.5 mm. Body density was calculated using the gender specific equations established by Jackson and Pollack (17, 18). Body density was converted to percent body fat using the age gender specific formulas suggested by Heyward and Stolarczyk (13).

Descriptive data are reported as mean±sd. TEE across the various checkpoints were compared using a one-way ANOVA with repeated measures.
Results:

Of the five DLW subjects that started the race, 4 (80%) completed the entire course. We were able to obtain data through Unalakleet (mile 860) on the fifth subject. Of the five subjects (Table 1), 3 were veterans and 2 were rookies.

There was a last minute reorganization of the race course due to lack of snow which resulted in mushers spending one day driving their dog trucks from Anchorage to Fairbanks after the isotope was consumed. Because of this alternation, the TEE data from Ruby to Nome is more reflective of the mushing aspect of the race, eliminating the driving day. TEE from Ruby to Nome was 22.6 MJ·day⁻¹ (5406 kcal·day⁻¹) and 12.3±1.7 MJ·day⁻¹ (2925±399 kcal·day⁻¹) for the male and female subjects, respectively. Specific segment analyses demonstrate slight variations in TEE along the trail (Table 2). However, there were no significant differences in TEE among the various segments of the race (p=0.10).

Food record data (n=3) suggested an average TEI of 10.3±4.0 MJ·day⁻¹ (2078±735 kcal·day⁻¹). Macronutrient breakdown included a protein intake of 1.5±0.4g·kg·day⁻¹, carbohydrate intake of 3.7±0.3g·kg·day⁻¹, and fat intake of 1.8±1.1g·kg·day⁻¹ from Anchorage to Nome (Table 3).

Estimated VO₂peak was 66.2 and 50.0±8.4 ml·minute⁻¹ for the male (n=1) and female subjects (n=4), respectively, was used to determine aerobic fitness. Percent body fat was 16.5% and 19.4±5.4% for the male (1) and female (5) subjects. Two out of the five subjects (40%) stated that they participated in an exercise program (Nordic track or dance) on a regular basis outside of the normal tasks required of driving and caring for a dog sled team.
Discussion:

Previous recommendations of 33.6 MJ·day⁻¹ (8000 kcal·day⁻¹) have been made for mushers participating in the Iditarod (26). In contrast, our data demonstrate a much lower rate of TEE, more closely related to individuals participating in a transpolar ski trek (average 16.8-21.0 MJ·day⁻¹ (4000 - 5,000 kcal·day⁻¹)) (32). Historical retrospective studies on arctic explorers using dog teams, suggest an intake of approximately 23.1 MJ·day⁻¹ (5500 kcal·day⁻¹) (10), which is in close agreement to our current data. Only one of our study subjects was a male with an average TEE over the entire race of 20.8 MJ·day⁻¹ (4972 kcal·day⁻¹). He did not keep a food record during the race. Our average female TEE (n=3) was 11.8±1.7 MJ·day⁻¹ (2808±397 kcal·day⁻¹), which was above the TEI (10.3±4.0 MJ·day⁻¹ (2078±735 kcal·day⁻¹)) calculated from food records completed by these subjects. The overall average TEE for the females was more similar to our previous case study estimate in a female based on TEI and changes in body weight (10.7 MJ·day⁻¹ (2557 kcal·day⁻¹)) across the race (8).

Due to a last minute course change resulting from a lack of snow on the initial segment of the course from Knik to Ruby, mushers were required to drive by truck from Anchorage to Fairbanks to an alternate start, delaying the start of the race by one day. Due to this logistical change, isotopic elimination and the resultant calculations for TEE were separated from the other segments of the race (Table 2). Calculating energy expenditure between checkpoints, the male subject demonstrated a continued increase in the MJ (kcaTs) expended as the race progressed. This may have been due to a decrease in the size of his dog team throughout the race (16 to 10 dogs) as well as the fatigue of the
dogs, and his need to further assist his team. In addition, the final section of the trail contains hills that may also require the additional physical contribution of the musher, aiding the team by pushing the sled and pumping on the runners. Although there are inconsistencies among the group of four female subjects, the overall average energy expenditure appeared highest during the last leg of the race from Unalakleet to Nome, also likely due to fatiguing dogs. However, the observed difference in TEE across the segments of the race was not statistically significant (p=0.10). This is likely a reflection of our small sample size with only three of four females completing the race.

Dietary records suggested an adequate intake of protein based on recommendations for endurance athletes by the American Dietetic Association, the American College of Sports Medicine and the Dietitians of Canada (2). The reported amount of daily carbohydrate intake (3.7±0.3g·kg\(^{-1}\)·day\(^{-1}\)) fell short of the recommendation of 7-13 grams per kg body weight per day (15, 27, 33). There is evidence that carbohydrates (CHO) may be the optimal macronutrient to enhance performance in severe cold (35-37). The recommended amount of fat (g·kg\(^{-1}\)·day\(^{-1}\)) for athletes has not yet been determined to the best of our knowledge. It is difficult to determine the actual intake of macronutrients due to possibility of underreporting.

It has been clearly demonstrated that sled dogs have exceptionally high energy requirements during racing in the cold (14). When energy expenditure data are scaled to body weight, the sled dogs demonstrated 4.4±0.4 MJ·kg\(^{-75}\)·d\(^{-1}\) compared to mushers in the present study 0.4±0.1 MJ·kg\(^{-75}\)·d\(^{-1}\). Our research demonstrates that mushers during the Iditarod have an increased energy expenditure above that estimated for the free living population (31) (male subject 22.6 MJ·d\(^{-1}\) vs. 13.5 MJ·d\(^{-1}\), respectively) and comparable to
wildland firefighters (23.0±1.5 MJ·d⁻¹)(28), Marines during 11 day cold weather field exercise (20.6±0.8 MJ·day⁻¹)(16), and soldiers during arctic exercise (20.1±3.9 MJ·d⁻¹)(20). This elevated level of TEE demonstrates the integral role of the musher in the total energy requirements of the team.

The relatively high values for estimated VO₂peak (3), suggest that the demands of dog handling alone provides some aerobic conditioning, since only 40% of the mushers enrolled in the study indicated regular participation in organized exercise outside of general dog care and training. This would agree with the previous case study done in our laboratory, which demonstrated a 20.6% improvement in treadmill VO₂peak during on snow training prior to the Iditarod race (8).

The average percent body fat of our subjects were well within the average recommendations for men and women for almost all sports (27). These data are also in agreement with our previous case study, which demonstrated a percent body fat of 18.6% in a female musher (8).

There are a number of factors to consider in optimal fuel selection during endurance events in the cold that may need further study, such as the duration and severity of the cold, as well as the acclimation of the individual. Continued study in this area may help to clarify the appropriate quantity of fat necessary to maintain adequate energy during the event, without compromising the ability to ingest adequate quantities of carbohydrate. A more accurate method of documenting ingested macronutrients would be to document the amount of food sent out to the checkpoints in the food drop bags, and to collect the uneaten foods for analysis after the musher has left the checkpoint. It would also be of some interest in this population of athletes to explore the
connection between adequate carbohydrate intake and levels of fatigue and cognitive performance during the Iditarod.
Table 1. Descriptive characteristics of Iditarod subjects

<table>
<thead>
<tr>
<th>Subject #</th>
<th>Gender</th>
<th>Rookie</th>
<th>Veteran</th>
<th>hgt (cm)</th>
<th>wgt (kg)</th>
<th>BF (%)</th>
<th>LBM (kg)</th>
<th>VO₂ Est. ml·kg⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M</td>
<td>V</td>
<td></td>
<td>179.0</td>
<td>88.5</td>
<td>16.5</td>
<td>73.9</td>
<td>66.2</td>
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<tr>
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<td>F</td>
<td>V</td>
<td></td>
<td>164.0</td>
<td>56.8</td>
<td>16.6</td>
<td>47.4</td>
<td>48.2</td>
</tr>
<tr>
<td>3</td>
<td>F</td>
<td>R</td>
<td></td>
<td>159.0</td>
<td>51.5</td>
<td>17.4</td>
<td>42.5</td>
<td>46.9</td>
</tr>
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<td>F</td>
<td>V</td>
<td></td>
<td>161.0</td>
<td>59.8</td>
<td>15.4</td>
<td>50.6</td>
<td>42.7</td>
</tr>
<tr>
<td>5</td>
<td>F</td>
<td>R</td>
<td></td>
<td>164.0</td>
<td>63.5</td>
<td>28.4</td>
<td>45.5</td>
<td>62.1</td>
</tr>
</tbody>
</table>

Mean±sd

| (f)       | 19.4±5.4 | 50.0±8.4 |

M (male), F (females). R (rookie), V (veteran), Hgt (height), (cm) centimeters, wgt (weight), kg (kilograms) BF (body fat), LBM (lean body mass), VO₂ Est. (estimated VO₂max), ml·kg⁻¹ (ml per kg body weight). Measurements were taken in Anchorage, prior to the start of the race.
Table 2. Individual variations in measured rates of total energy expenditure during various segments on the Iditarod Trail sled dog race. TEE data are expressed as MJ/day±sd, (kcal/day±sd), multiples of basal metabolic rate [x BMR], and the energy of expenditure of exercise [EAA, MJ·day⁻¹].

<table>
<thead>
<tr>
<th>Race Segment</th>
<th>Start-Ruby</th>
<th>Ruby-Trail2</th>
<th>Trail2-Unalakleet</th>
<th>Unalakleet-Nome*</th>
<th>Ruby-Nome*</th>
<th>Start-Nome</th>
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<tbody>
<tr>
<td>Miles</td>
<td>0-328</td>
<td>328-6+96 hrs</td>
<td>+96 hrs-860</td>
<td>860-1121</td>
<td>328-1121</td>
<td>0-1121</td>
</tr>
<tr>
<td>Subject</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>1 (M)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MJ-day⁻¹</td>
<td>17.6</td>
<td>19.7</td>
<td>23.8</td>
<td>26.0</td>
<td>22.6</td>
<td>20.8</td>
</tr>
<tr>
<td>kcal-day⁻¹</td>
<td>(4198)</td>
<td>(4713)</td>
<td>(5692)</td>
<td>(6213)</td>
<td>(5406)</td>
<td>(4972)</td>
</tr>
<tr>
<td>x BMR</td>
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<td>2.7</td>
<td>3.2</td>
<td>3.5</td>
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<td>2.8</td>
</tr>
<tr>
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<td>10.3</td>
<td>14.0</td>
<td>16.0</td>
<td>12.9</td>
<td>11.3</td>
</tr>
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<td>2 (F)</td>
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<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>MJ-day⁻¹</td>
<td>10.9</td>
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<td>9.3</td>
<td>13.1</td>
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<td>(2224)</td>
<td>(3130)</td>
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<td>(2766)</td>
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<td>3.1</td>
<td>6.5</td>
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</tr>
<tr>
<td>3 (F)</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>MJ-day⁻¹</td>
<td>9.3</td>
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<tr>
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<td>(2516)</td>
<td>(2051)</td>
<td>(3123)</td>
<td>(2570)</td>
<td>(2434)</td>
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<tr>
<td>x BMR</td>
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<td>2.6</td>
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<td>2.0</td>
</tr>
<tr>
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<td>4.2</td>
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<tr>
<td>MJ-day⁻¹</td>
<td>12.6</td>
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<td>13.7</td>
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</tr>
<tr>
<td>kcal-day⁻¹</td>
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<td>(3513)</td>
<td>(3282)</td>
<td>(3271)</td>
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<td>(3224)</td>
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<tr>
<td>x BMR</td>
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<td>MJ-day⁻¹</td>
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<td>(3117)</td>
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<td>EEA</td>
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<td>6.3</td>
<td>6.5</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

Mean±sd (F)

| MJ-day⁻¹     | 11.8±2.3   | 12.5±1.8    | 11.2±2.7          | 13.3±4           | 12.3±1.7    | 11.8±1.7   |
| kcal-day⁻¹   | (2829±551) | (2993±425)  | (2685±639)        | (3175±83)        | (2925±399)  | (2808±397)  |
| x BMR        |            |             |                   |                  |             |            |
| EEA          |            |             |                   |                  |             |            |

(M) male, (F) females. Race segments identify key checkpoints along the trail where urine samples were collected. Miles indicate distance for segments throughout the race. The +96 hrs sample point was collected by each subject on the trail approximately 96 hours following the collection at the Ruby checkpoint. DNF = did not finish. *The portion of the race that included driving from Anchorage to Fairbanks was not included.

EAA = (TEE-DIT-BMR), where EAA = energy expenditure of physical activity, TEE = total energy expenditure, DIT = diet induced thermogenesis, BMR = basal metabolic rate (calculated)
Table 3. Individual variations in rates of total energy intake and macronutrient contribution based on food records during the Iditarod trail sled dog race. Data are express in MJ·d$^{-1}$±sd (kcal·d$^{-1}$±sd) for energy intake; grams and % total MJ(kcal) average per day for macronutrients.

<table>
<thead>
<tr>
<th>Subject</th>
<th>MJ (Kcals)</th>
<th>CHO (g·kg$^{-1}$·d$^{-1}$)</th>
<th>CHO (%)</th>
<th>Fat (g·kg$^{-1}$·d$^{-1}$)</th>
<th>Fat (%)</th>
<th>Pro (g·kg$^{-1}$·d$^{-1}$)</th>
<th>Pro (%)</th>
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<tbody>
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<td>31</td>
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<td>54</td>
<td>1.9</td>
<td>16</td>
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<tr>
<td>3 (F)</td>
<td>5.4 (1281)</td>
<td>3.4</td>
<td>55</td>
<td>0.8</td>
<td>29</td>
<td>1.1</td>
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<tr>
<td>4 (F)</td>
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<td>44</td>
<td>1.7</td>
<td>40</td>
<td>1.6</td>
<td>17</td>
</tr>
<tr>
<td>Mean (F)</td>
<td>10.3 (2078)</td>
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<td>43</td>
<td>1.8</td>
<td>41</td>
<td>1.5</td>
<td>17</td>
</tr>
<tr>
<td>±sd (F)</td>
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<td>10</td>
<td>1.1</td>
<td>11</td>
<td>0.4</td>
<td>01</td>
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(F) females.
References


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<tr>
<th>Subject</th>
<th>Wgt (g)</th>
<th>Anc (g)</th>
<th>Calories</th>
<th>Calories</th>
<th>Calories</th>
<th>Mjoules</th>
<th>Mjoules</th>
<th>CHO (g)</th>
<th>CHO (%)</th>
<th>Fat (g)</th>
<th>Fat (%)</th>
<th>Pro (g)</th>
<th>Pro (%)</th>
<th>Kcal/kg bw</th>
<th>CHO/kg</th>
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<td>11.42</td>
<td>209.13</td>
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<td>165</td>
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M (male) F (female), R (rookie) V (veteran), Ex (exercise program, N (no) Y (yes)
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Heart rate and Fatigue rating scale (self perceived) raw data

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Checkpoints 1 (Anchorage) 2 (Ruby) 3 (Unalakleet) 4 (White Mountain) 5 (Nome)  
Urine Osmolality (mOsmol·L⁻¹), Fatigue rating scale 1-5 (least to most fatigued)

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Table 4. continued

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CONCLUSIONS

The Iditarod Trail sled dog race presents an excellent opportunity to study the physical and psychological effects of prolonged cold exposure, sleeplessness, and physical activity on the dog sled driver. In addition, assessment of the physical fitness associated with the sport of endurance mushing can be studied.

Prior to the start of the race, a standard step test was utilized to predict VO$_2$peak in the dog sled drivers. In addition, mushers were monitored at seven checkpoints along the trail from Anchorage to Nome to determine total energy expenditure, distribution and quantity of macronutrients consumed, hydration status, self-assessment of fatigue and cognitive function (state of attentiveness).

The results demonstrated a greater than average VO$_2$peak in the mushers. Total energy expenditure during the event averaged 20.8 MJ·day$^{-1}$ (4972 kcal·day$^{-1}$) and 11.8± MJ·day$^{-1}$ (2808±397) kcal·day$^{-1}$ from Anchorage to Nome for our male and female subjects, respectively. Food records demonstrated an average intake below recommended levels for carbohydrates and adequate in protein for endurance athletes. The majority of mushers showed signs of dehydration during the event based on common urinary markers. Mushers demonstrated an increased level of fatigue (self rated) during the event. Measurements of cognitive performance did not change significantly during the race.