HYDRATION STATUS AND WATER TURNOVER OF DOGSLED DRivers DURING AN ENDURANCE SLED DOG EVENT IN THE ARCTIC

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ABSTRACT

Objectives. To determine changes in common urinary markers of hydration maintained by the drivers (mushers) during a wilderness endurance event in the arctic and to determine water turnover in this select group of individuals.

Study Design. During this descriptive study, data was systematically collected on hydration, water turnover, changes in resting and exercise heart rate, fatigue and rating of perceived exertion during an arduous dogsled race in the arctic.

Methods. Sixteen mushers were recruited for the study, 13 of whom completed the entire race. At five different checkpoints along the 1049-mile trail (symbolic distance), urine was collected. Urine osmolality (U$_{osm}$) was determined using freezing point depression. Urine specific gravity (U$_{sg}$) was determined using a hand-held refractometer. Water turnover was measured in 5 mushers from rates of deuterium ($^2$H$_2$O) elimination (rH$_2$O). Prior to the start of the race, and at five checkpoints along the trail, a resting heart rate, fatigue rating scale and a rating of perceived exertion (RPE), were collected.

Results. Out of the 13 subjects that completed the event, four of the mushers had a U$_{sg}$ $\geq$ 1.030 (mean 1.023 ± 0.007) at some point during the event. Ten had a urine osmolality $\geq$ 900 mOsm L$^{-1}$ at some point during the event, with an average U$_{osm}$ of 868 ± 277 mOsm L$^{-1}$ over the duration of the event. Water turnover demonstrated that rH$_2$O averaged 2.85 ± 1.18 ml kg$^{-1}$ day$^{-1}$ (range 2.03 – 4.60) over the duration of the event. Resting heart rate increased significantly over the course of the race. The RPE was related to the overall fatigue rating scale.

Conclusions. These data demonstrate that the majority of mushers studied showed signs of dehydration based on common urinary markers during the long-distance dogsled race. The dehydration appears to have had an influence on the resting heart rate, overall fatigue and the rating of perceived exertion during the race.

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Keywords: dehydration, musher, urine osmolality, urine specific gravity, water turnover
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 (1). Dehydration can result in elevated heart rate and decreased stroke volume (2), fatigue (3) and decreased performance (4). Dehydration also shortens the time to the onset of fatigue (5).

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 (4). The cold environment may also diminish the sensation of thirst (6).

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 (7) 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 (1) 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. Prior research has shown that dog sled drivers in the Iditarod have an increase in their hematocrit over the duration of the race, suggestive signs of dehydration (7, 8). 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 there is no ready access to a laboratory.

The purpose of our study was to determine changes in common urinary markers of hydration and to assess rates of water turnover (rH₂O) 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.
MATERIAL AND 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. Nine men and seven women were recruited. The mean age was 35.5 years and the mean body mass index was 24 (Table I).

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, including Ruby (mile 328), Unalakleet (mile 860) and White Mountain (mile 1044), and at the finish in Nome. In addition, body weight was obtained using a calibrated digital scale (accuracy of ± 100 gram) 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, a bench-step test, exercise and recovery heart rate, rating of perceived exertion (RPE) using a 15-point scale, a fatigue rating scale and a cognitive test, were administered. In addition, a urine sample was collected from the musher as soon as logistically possible 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% atom percent excess (APE) Cambridge Isotope

| Table I. Individual musher demographics and anthropometrics. |
|---------------------------------------------------------------|
| **Musher** | **Gender** | **Age** | **Height (cm)** | **Weight (kg)** | **BMI** | **% body fat** |
|-----------|------------|---------|-----------------|----------------|--------|----------------|
| 1         | 1          | 47      | 175.3           | 70.9           | 23     | 16.5           |
| 2         | 1          | 45      | 179             | 88.5           | 28     | 19             |
| 3         | 1          | 30      | 182             | 89.4           | 27     | 12.8           |
| 4         | 1          | 27      | 175.3           | 65.9           | 21     | 9.3            |
| 5         | 2          | 25      | 171.3           | 64.2           | 22     | 19.2           |
| 6         | 1          | 26      | 165.1           | 65.9           | 26     | 5.8            |
| 7         | 1          | 35      | 177             | 71.3           | 21     | n/a            |
| 8         | 2          | 53      | 164             | 56.8           | 21     | 16.6           |
| 9         | 2          | 18      | 159             | 51.5           | 20     | 17.4           |
| 10        | 2          | 51      | 161             | 59.8           | 23     | 15.4           |
| 11        | 2          | 47      | 167             | 60.1           | 22     | 21.6           |
| 12        | 1          | 22      | 186             | 99.8           | 29     | 17             |
| 13        | 1          | 37      | 168.5           | 68.8           | 24     | 14.7           |
| 14        | 2          | 42      | 164             | 63.5           | 24     | 28.4           |
| 15        | 1          | 32      | 170.5           | 82.9           | 29     | n/a            |
| 16        | 2          | 31      | 181             | 69.2           | 22     | n/a            |
| **Mean**  | n/a        | 35.5    | 171.6           | 70.5           | 24     | 16.4           |
Laboratories, Andover, MA] based on 1.43g (range 1.35-1.52) kg\(^{-1}\) after the collection of a background urine sample (between 22.00 and 23.00 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 and drinking until the first void urine samples were collected. All overnight urine was collected. First and second morning voids were collected between 04.30 and 07.05. The five subjects were weighed immediately after the first morning void, wearing 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 and 500 mOsm 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 the isotopic analysis of all urine samples. Briefly, deuterium analysis was performed by chromium reduction according to Schoeller (9), 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 were used to calculate the “per mil” 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 (10).

**Physical fatigue**

The heart rate response was measured at each checkpoint, using a standardized bench-step exercise test (11). 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 his/her perceived level of effort, using a 15-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 by 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 (12). FAS and CFL were repeated at Unalakleet (FAS) and Nome (CFL).

Statistical analyses
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), followed by planned comparison using a non-paired t-test. Pearson correlation coefficients were used to determine correlations between and the 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 the subject’s dog team, another with a broken ankle.

Dehydration was determined using the criteria of $U_{osm} \geq 900$ mOsm L$^{-1}$ recommended by (13) and $U_{sg} \geq 1.030$ (14). 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 $U_{sg}$, four (31%) were dehydrated at some point during the race. The National Collegiate Athletic Association recommends the use of $U_{sg} \geq 1.020$ to determine the upper level of euhydration (15); according to this criteria, all but one musher (92%) were mildly dehydrated at some point during the event.

When finish place is considered, the top two finishers in our subject population had average urine osmolality values of 504 mOsm L$^{-1}$ and 619 mOsm L$^{-1}$, respectively, compared to the two mushers in the back of the subject pool, who had average $U_{osm}$ values of 1415 mOsm L$^{-1}$ and 971 mOsm L$^{-1}$. One of the latter 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, 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$^{-1}$, while those in the back 1/3 of the pack had an average $U_{osm}$ of 971 mOsm L$^{-1}$.

Five of the subjects were female drivers. Females had an average $U_{osm}$ of $802 \pm 276$ mOsm L$^{-1}$, while the male (eight subjects) average was $909 \pm 287$ mOsm L$^{-1}$ (Table II). Eight of the mushers were veterans of the Iditarod, having completed the race at least once prior to 2003; the remaining five were novices, or “rookies”. When comparing veterans to rookies (who had never completed an Iditarod race), veterans averaged $830 \pm 204$ mOsm L$^{-1}$ compared to $952 \pm 426$ mOsm L$^{-1}$ for the rookies (Table II).
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 (Figure 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 2). 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 (p < 0.05) relationship between the rating of perceived exertion during the step test at the various checkpoints of the race (Figure 3), and the overall fatigue rating scale (Figure 4).

The Pearson correlation coefficient (r = 0.97) demonstrated a positive relationship between the average resting heart rate and the 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.

### Table II. Urine osmolality (mOsm L\(^{-1}\)) and specific gravity for population subsets over the entire course.

|                  | Females (r and v) | Males (r and v) | Rookies (m and f) | Veterans (m and f) |
|------------------|-------------------|-----------------|-------------------|--------------------|
| Osmolality (mOsm L\(^{-1}\)) | 802 ± 276         | 909 ± 287       | 952 ± 426         | 830 ± 204          |
| Specific gravity | 1.022 ± 0.007     | 1.023 ± 0.006   | 1.026 ± 0.010     | 1.022 ± 0.005      |

r = rookies; v = veterans; m = males; f = females.

p > 0.05, see text.
There was no 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 ± 1.63 kg (range 3.1 kg loss to 1.7 kg gain) during the entire race.

The mean water turnover (rH₂O) was 2.9 ± 1.2 ml kg⁻¹ day⁻¹ from Ruby to Nome, and 2.7 ± 0.9 ml kg⁻¹ day⁻¹ over the entire race. This corresponded to 43.5 ± 7.1 ml kg⁻¹ day⁻¹ and 42.3 ± 5.4 ml kg⁻¹ day⁻¹ from Ruby to Nome and over the entire race, respectively (Table III).

Table III. Water turnover (ml kg⁻¹ day⁻¹) during the different checkpoints of the race. Data are expressed as individual data and mean ± SD.

| Subject | Start – Ruby | Ruby – Trail (48 hours outside of Ruby) | Ruby – Unalakleet | Ruby – Nome | Ruby – Nome |
|---------|--------------|----------------------------------------|-------------------|-------------|-------------|
| 1       | 4.11         | 4.31                                   | 4.37              | 4.60        | 51.92       |
| 2       | 2.11         | 1.99                                   | 1.93              | 2.03        | 34.40       |
| 3       | 2.10         | 2.37                                   | 2.39              | 2.38        | 45.86       |
| 4       | 2.42         | 2.51                                   | 2.35              | 2.39        | 40.44       |
| 5       | 2.73         | 2.56                                   | 2.18              | na          | 34.11       |
| mean    | 2.69         | 2.80                                   | 2.64              | 2.85        | 43.16       |
| ± SD    | 0.83         | 0.90                                   | 0.98              | 1.18        | 7.12        |

a data for the Ruby – Unalakleet portion of the trail (532 miles).
b does not include subject #5.
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, according to the criteria of $U_{\text{osm}} \geq 900 \text{ mOsm L}^{-1}$. 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 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 changed in hydration during this early segment of the race. Between Unalakleet and White Mountain, hydration markers declined (Figure 1). During the Unalakleet to White Mountain portion of the race, there were multiple checkpoints where mushers could obtain fluids, and the longest distance between checkpoints was 58 miles.

In general, dogsled drivers who finished in the front third of the pack were better hydrated than those who were in the back third of the pack. 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 had it not been for two of the mushers. Indeed, one musher in the top five finishers was dehydrated during the entire race (average $U_{\text{osm}} = 1049 \pm 48 \text{ mOsm L}^{-1}$, range 1001-1101 mOsm L$^{-1}$). Complaints of severe fatigue were noted at each checkpoint, and the average rating of fatigue was $4.5 \pm 0.6$ (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 $U_{\text{osm}} = 360 \pm 199 \text{ mOsm L}^{-1}$ (range 165-656 mOsm L$^{-1}$) and an average on the fatigue rating scale of $2.4 \pm 0.5$ (range 2-3).

Dehydration can lead to decreased plasma volume, increased heart rate and decreased stroke volume (16). This was also demonstrated in our study, with a significant positive relationship between dehydration and increased heart rate at rest.

Mushers may benefit by maintaining adequate hydration during the Iditarod Trail Sled Dog Race, in terms of both finish place and the reduced rating of perceived exertion. Our data demonstrated an increased rating of perceived exertion during the entire duration of the race. Rintamaki et al. (17) 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, maybe due to 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 (5), may all be advantageous for the musher.

Increased cognitive processing time has been linked to dehydration (18, 19). 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 cyclists (47 ml kg⁻¹ d⁻¹)(20), but was lower in comparison to trekking (78.7 ± 17.5 ml kg⁻¹ d⁻¹) (21), climbing at high altitude (73 ± 20 ml kg⁻¹ d⁻¹ ascent; 83 ± 17 ml kg⁻¹ d⁻¹ descent) (22) and wildland fire suppression (94.8 ± 20.1 ml kg⁻¹ d⁻¹) (23). This is probably 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.

Although this research was targeted at an endurance race, it may also imply that peoples of the far north may be at risk of dehydration during endurance activities with dog teams.

Future research should focus on methods to decrease the rate of dehydration in dog sled drivers such as preparing meals with foods containing a higher water content, like stews and cooked cereals, and filling several thermos flasks with hot water at rest stops.

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